Dynamic Parameter Optimization of One Ramming Mechanism Based on Multi-island Genetic Algorithm

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Abstract. During the process of chambering, an excessive impact of the cartridge tray to the breech ring can damage mechanism while an insufficient one cannot meet the requirements of ammunition ramming because the speed of ammunition ramming can be slower than the speed of bayonet-chamber. In order to balance the impact and the time, a more efficient and stable process of the ammunition ramming is supposed to be designed. According to the operational principle of the ammunition ramming mechanism and the test, a dynamic model of the ammunition ramming mechanism is established in ADAMS considering the impact and the efficiency of ammunition ramming at the limit position. Taking the decreasing of the impact hit on the breech ring and the time of ammunition ramming as optimization goals and 3m/s as the minimum bayonet-chamber speed, this paper presents a method of optimization based on the multi-island genetic algorithm (MIGA). The validity of this algorithm is verified by the experimental results.

1. Introduction

On the digital battlefield with the developed information technology, it is emergency to improve the performance of modern weapons especially the manoeuvrability and firing rate of artillery. Therefore, a fully automatic loading system is an important direction for the development of artillery to improve the firing rate of artillery is in the future. The ramming mechanism is regarded as a key subsystem of the fully automatic loading system and a significant component in the automatic ramming process of the bullet. It directly affects the firing rate, the firing accuracy, and the reliability of the artillery. Accordingly, a more precise, effective and reliable ramming mechanism is supposed to designed and produced for needs of the overall deployment of artillery.

As for the study of the process of ammunition ramming, Ref. [1] reduces the attenuation of bullet velocity by optimizing initial position and attitude parameters of bullet. In order to improve the consistency of bayonet-chamber, an optimization model of ramming mechanism is established for consistency of ammunition ramming [2]. Ref. [3] proposed a optimization design of ramming mechanism based on fuzzy PID control algorithm to solve the problem of difficulty in loading and in ensuring the accuracy of firing at a large angle. In order to obtain the dynamic characteristics and the stress condition of key component in the process of automatic loading, a dynamic mechanical model of ammunition ramming is established, which provides a basis for the study of fault analysis and fatigue test of the ramming mechanism [4]. An active disturbance rejection controller (ADRC) based
on neural network was applied to improve the speed synchronization performance of automatic machine motor and feeding and ramming of chain automatic artillery [5]. The deterministic multi-objective optimization method is adopted to solve the problem of severe shock and vibration caused by excessive driving force of coordinating cylinder in the automatic loading system [6].

Based on the previous study, this paper focuses on the speed of ammunition ramming in ammunition ramming process. Considering the impact and ammunition ramming efficiency under the limit position, a dynamic model of the ammunition ramming process of a certain ramming mechanism is established. According to the working principle of ramming mechanism and combining bench test, the process of the ammunition ramming is analyzed in detail. Eventually, the model of multi-objective optimization is introduced to achieve the goals that decreasing the impact of the cartridge tray to the breech ring and the time of ammunition ramming.

2. Analysis Of Ammunition Ramming Process

2.1. Assumptions

According to the working principle of ramming mechanism and the analysis of the process of ammunition ramming, four assumptions are made as followed:

Ammunition 1: Every component is considered as a rigid body. Ignore the elastic deformation.
Ammunition 2: The breech ring, carriage and barrel are considered to be fixed directly on the ground taking no account of the effect of other factors.
Ammunition 3: The collision between the bullet, the cartridge tray, the breech ring and the barrel is elastic.
Ammunition 4: The motion of ammunition ramming can be simplified into a rigid motion of 6 degrees of freedom. Namely, three translations of the center of mass and three rotations around the center of mass.

Under conditions above, the virtual prototype model of ammunition ramming mechanisms is established in ADAMS. The barrel, breech ring and carriage are fixed on the ground. Contact between the bullet and the cartridge tray, the bounce plate and the coordination arm is defined.

2.2. Structure Description

As shown in Figure 1, the ramming mechanism which is powered through the pressure change of the cylinder in the hydraulic system is mainly composed of the cartridge tray, the gear, the gear rack, etc. The cylinder can convert the pressure energy of the hydraulic oil into mechanical energy. Receiving and transmitting hydraulic power through meshing transmission with the rack and pinion the loading oil cylinder in this paper is a single piston two-way oil cylinder.

![Figure 1. Schematic diagram of ammunition rammer structure](image)

2.3. Analysis of the Process of Ammunition Ramming

The ammunition ramming process consists of forced ram stage and inertia ram stage. In the process of ammunition ramming, the oil enters into the ammunition ramming cylinder, then it forces the piston rod to step forward. The piston rod drives the gear forward. The gear meshes with the gear rack on the
cartridge tray, then the cartridge tray drives bullet move forward. Firstly, the cartridge tray moves at the rate of acceleration. Then the time it reaches the maximum speed, it moves at the rate of deceleration, the bullet and the cartridge tray separate at the same time. Finally, the bullet moves into the barrel to finish the process of chambering. The cartridge tray is gradually decelerated by the pressure of oil but it will continue to move forward for a distance until it hits the breech. The impact of it may bring great damage to the ramming mechanism.

3. Dynamics Modeling And Experimental Verification

3.1. Dynamics simulation modeling

Firstly, the dynamic simulation model of the breech, the barrel and the ramming mechanism are all established. According to the actual structure of the artillery chamber based on the platform of ADAMS under the reference of the basic assumptions mentioned above. Then the physical contact among the cartridge tray, the bullet and the barrel is built. The carriage tray, the coordinator and the barrel are fixed to the earth. A slip pair is built between the coordinator and the cartridge tray and the rod. Other contacts are all built as shown in Figure 2. In order to achieve the static balance, at the first half second, the bullet slightly shakes on the cartridge tray, and then the simulation of the process of ammunition ramming begins. The load is applied on the piston rod of the cylinder to force the piston rod to move forward. Then the piston rod drives the gear forward. The gear meshes with the rack on the cartridge tray, thus the cartridge tray moves forward together. At last, the bullet leaves the cartridge tray and enters into the barrel for a certain distance, the simulation ends.

The coefficients of the contact in ADAMS are defined as the parameters of the steel contact in the state of lubrication, as shown in Table 1. Because the contact between the cartridge tray and the barrel is the contact between rubber and steel, the parameters are set separately, as shown in parentheses in Table I. After the analysis of the force of the rod and without considering the influence of other forces such as friction, the cylinder force can be expressed as

$$F = P_1A_1 - P_2A_2$$  \hspace{1cm} (1)

Here, $P_1$, $P_2$, $A_1$, $A_2$ is the cylinder-free cavity pressure, the rod cavity pressure, the rod area and the area without the rod cavity. In this paper, $P_1$ and $P_2$ are measured by experiment. $A_1=1590\text{mm}^2$, $A_2=883.67\text{mm}^2$. Figure.3 below shows the curve of $P_1$ and $P_2$ by experiment. Figure.4 is a graph of the cylinder force curve fitted according to Figure1.

| Parameter                  | Value     |
|----------------------------|-----------|
| Stiffness                  | 105(2855) |
| Force Exponent             | 1.5(1.1)  |
| Damping                    | 50(10)    |
| Penetration Depth          | 0.25(0.1) |
| Static Coefficient         | 0.2(0.3)  |
| Dynamic Coefficient        | 0.1(0.25) |
| Station Transition Velocity| 0.1(0.1)  |
| Friction Transition Velocity| 10(10)    |

When the cartridge tray, the bullet, and the barrel are in contact with each other, the contact stiffness is calculated according to Hertz's\[7\]. The contact collision impact is equivalent to the spring damping model. When the penetration amount to $\delta$, the normal contact force $F_n$ can be expressed as

$$F_n = k\delta^n + step(\delta,0,0,d_{\text{max}},c_{\text{max}})\frac{d\delta}{dt}$$  \hspace{1cm} (2)
Here, $k$ is the contact stiffness, $n$ is a nonlinear index, $d_{max}$ is the penetration depth when the damping reaches the maximum value for $c_{max}$, the value is determined by the material of the two collision parts. $step(\delta, 0, 0, d_{max}, c_{max})$ is the calculation function of damping, indicates that the corresponding damping $\delta$ changes from 0 to $d_{max}$ when $c$ changes from 0 to $c_{max}$. The friction required for contact collisions in the model is calculated by Coulomb's.

3.2. Test verification

Figure 5. show the bullet displacement and time curve of simulation and experiment at $0^\circ$ departure angle.

It can be concluded from Figure 5. that the variation of the displacement curve measured in the test is basically consistent with the simulation results, and the variation trend is similar, indicating that the simulation model can reflect the characteristics of the system more realistically.

4. Parameter Optimization and Result Analysis of Ramming Process

4.1. Optimization algorithm and process

Be widely used to solve multi-objective optimization problems, genetic algorithm is a highly parallel optimization algorithm that mimics the genetic propagation mechanism of biological evolution [8]. Through coding the optimization problem (binary or other hexadecimal) and such operations as selection, crossover, mutation, etc., of the encoded individual population the combination containing the optimal solution or the optimal solution can be found. Compared with traditional genetic algorithms, MIDA, a common algorithm for improving genetic algorithms, has higher computational
efficiency and superior global solution ability [9]. Isight is a design platform that integrates and automates the optimization process, in which MIGA is embedded. The basic flow of optimization is that design experiment, uniformly take sample in the design space, set the effective design area based on the initial value, and combine the actual selection optimal compromise solution in all the obtained Pareto optimal solutions[10].

4.2. Ammunition ramming process optimization model

![Optimization process design](image)

Figure 6. Optimization process design

![History table in the optimization process](image)

Figure 7. History table in the optimization process

Figure 6 illustrates a multi-objective optimization design flow chart based on Isight. In order to reduce the impact between the cartridge tray and the breech ring and improve the efficiency of the ammunition ramming, the parameters of the ammunition ramming process are optimized on the basis of the dynamic simulation model established above. According to the design requirements:

1) The design variable: The longitudinal displacement deviation of the axis of the cartridge tray, the opposite axis of the barrel is Htdb. The tray radius is Rtdb. And the ammunition ramming forces are $F_{c, \text{max}}$, $F_{c, \text{min}}$. The range of values for each design variable is shown in Table 2:

| Variable   | Lower limit | Upper limit |
|------------|-------------|-------------|
| Htdb(mm)   | -0.5        | 2           |
| Rtdb(mm)   | 80          | 82          |

2) The objective function: The impact of the tray against the breech is as small as possible while the time of the ammunition ramming is as short as possible.

3) The constraint: the minimum 3m/s bayonet-chamber velocity ($v \geq 3\text{m/s}$).
4.3. Optimization result analysis

The MIGA algorithm control parameters used in the optimization design. 5 for sub-population number, 5 for number of islands, 5 for migration interval, 0.8 for rate of Crossover, 0.01 for rate of mutation, 0.2 for rate of migration, 3 for interval of migration, and 125 for iteration number. Bring relevant data into Isight, you can obtain optimized results. As shown in Fig.7 through Isight, you can view the History table in the MIGA algorithm optimization process. In the table, the design variables and the corresponding optimization results after each optimization can be observed, that is, the Pareto solution set. The green bar in the table indicates the best design point recommended by Isight. Light blue indicates a viable design point and white indicates no significant advantage. Set the impact and time to the same weight of the objective function. Figure 7 shows that the optimal design point recommended by Isight is the 94th sample, and then the values of the design variables and the pairs before optimization are shown in Table 3. The results are shown in Table 4. The objective function is reduced by 17%, the impact of the cartridge tray is reduced by 31015N, and the time of the ramming time is shortened by 0.0369s. Figure 8 shows the change of impact and time before and after optimization.

Table 3. Optimization before and after design variables

| States            | Htdb (mm) | Rtdb (mm) | Fmax (N) | Fmin (N) |
|-------------------|-----------|-----------|----------|----------|
| Original Valve    | 0         | 80        | 15855    | -395     |
| Optimized Value   | 1.602     | 80.44     | 15980    | -3       |

Table 4. Results before and after optimization

| States            | Fcmax (N) | T (s)  | Objective Function |
|-------------------|-----------|--------|--------------------|
| Original Valve    | 109710    | 1.1923 | 2.7596             |
| Optimized Value   | 78695.0   | 1.1554 | 2.2796             |

Figure 8. Comparison of the impact before and after optimization
5. Conclusion

5.1. Optimization algorithm and process

This paper established the dynamic simulation model in ADAMS based on the basic principle of the process of ammunition ramming. Besides, on account of the multi-island genetic algorithm, the optimization model with the goal of decreasing the impact caused by the quick movement of the cartridge tray and the time of ammunition ramming is built. The conclusions of the optimization were briefly summarized as follow:

1) The bullet can inevitably impact on the barrel. If the longitudinal difference between the cartridge tray and the barrel axis can be declined, the speed loss caused by the collision between the bullet and the barrel could be effectively reduced.

2) Through changing the pressure of the rod, the impact of the cartridge tray and the breech is reduced meanwhile the speed of the ammunition ramming is increased on the premise of ensuring the speed of chambering (3 m/s).

3) The conclusions of the paper can be used in the optimization design of the process of ammunition ramming process providing a reference for the parameter determination and optimization design of the ramming mechanisms.

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