Optimization analysis of parallel reed damper for optical sight

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Abstract: The parallel reed damper is very important for the optical sight to bear high-intensity impact, and its damping effect directly affects the firing accuracy of the weapon system. In this paper, based on the response surface methodology, the parametric modeling and finite element analysis of the parallel reed damper of the optical sight are carried out in the ANSYS Workbench. The response surface curve of the maximum displacement response to the structural parameters is obtained, and the influence rule of the structural parameters on the maximum displacement response is analyzed. The results show that the sensitive parameters of the parallel reed damper are the width of the reed, the height of the reed hollow layer, the thickness of the reed and the symmetrical distance of the reed. The results of the optimization analysis can be used to guide the structural design of the parallel reed damper of the optical sight and provide a favorable guarantee for improving the shooting accuracy of light weapons.

1. Introduction
Optical sight is an important subsystem of light weapons. Through the precise integration of optical system and mechanical system, the optical sight makes the warhead effectively coincide with the combat target in the flight trajectory. Among the light weapons in China, the optical sight and gun adopt dovetail groove guide rail structure[1]. The huge recoil impact produced by light weapons in shooting will affect the optical sight and its connection device, such as the wear of the connection device leading to looseness, the displacement of the optical sight makes it necessary to recalibrate the gun after several shots, etc. In order to improve the reliability of the optical sight, it is necessary to study the vibration reduction technology of the optical sight according to the characteristics of the impact load of light weapons.

At present, the most effective way to improve the stability of the optical sight in the military field is to integrate the sight connecting device with the active and passive vibration isolation device to build various types of stable sight system. Cheng Gang[2] compared the working principle and performance of rubber shock absorber and metal three-way shock absorber, and concluded that the latter can more effectively isolate the vibration in the working environment of the photoelectric stabilized aiming platform of aviation equipment. Yang Yanni[3] based on the theory of vibration reduction, carried out the analysis of the main technical indexes of the vibration reduction system, such as the rigidity and damping of the system, which provided the basis and reference for the vibration reduction design of the system. In addition to the structural damping design, the current research is to achieve the stability of the stabilized aiming system through active feedback control, such as using neural network and adaptive characteristics to achieve stable tracking control[4], using three loop control structure[5], auto disturbance
rejection device[6] and other methods to improve the anti-interference ability and dynamic response characteristics of the airborne optoelectronic stabilized aiming platform. Generally speaking, from the open literature, the research on stabilizing and aiming system is mainly focused on aerospace, heavy weapon system and other fields, and the research on light weapons is very few, but the single soldier light weapons are the most widely used, and the war out of sight is developing day by day, so it is very necessary to study the damping system of optical sight.

Based on the response surface methodology and the finite element method of parametric modeling, this paper analyzes the influence of the structural parameters of the parallel reed damper on the impact response of a light weapon optical sight. By studying the sensitivity of each parameter, the optimization route of the structural design of the parallel reed damper is proposed.

2. Response surface methodology

Response surface methodology (RSM) was first proposed by mathematicians box and Wilson. This is a method of optimizing experimental conditions, which is suitable for solving the related problems of nonlinear data processing. It includes many test and statistical techniques, such as test design, modeling, testing the suitability of the model, seeking the best combination conditions, etc.; by fitting the regression relationship between test indexes (dependent variables) and multiple test factors (independent variables), drawing the response surface and contour line, the response value corresponding to each factor level can be easily obtained[7]. Based on the response values of each factor level, we can find out the optimal response values and corresponding experimental conditions (including model parameters).

Suppose (1) is used to describe the relationship between the response structure \( Z \) and the random parameters of the system, \( n \) sample values are obtained by certain sampling method, the corresponding sample values are calculated to obtain the sample values of the system response, and the system response function can be obtained by the least square method. By using the response surface equation instead of the finite element model, the calculation time can be greatly reduced[8]. Generally speaking, response surface method is an effective method to reduce development cost, optimize processing conditions, improve product quality and solve practical optimization problems in the production process.

\[
Z = a_0 + \sum_{i=1}^{g} a_i Q_i + \sum_{i=1}^{g} a_{ij} Q_i^2 + \sum_{i<j} \sum a_{ij} Q_i Q_j + \varepsilon\tag{1}
\]

In the formula: \( a_0, a_i, a_{ij} (i = 1 \sim R; j = i \sim R) \) is the undetermined coefficient, \( \varepsilon \) is the error of \( Z_i \).

3. Multi parameter analysis of finite element response surface methodology

Through the optimization design module of the finite element analysis software ANSYS, the response spectrum of multi parameters is analyzed. The function of response surface is adopted for analysis and calculation, which can dynamically display the relationship between input and output parameters in the form of chart. In order to use this method, it is necessary to model the structure of the parallel reed damper of the optical sight.

3.1. Finite element modeling

![Fig.1 Solid model of sight system](image)
3.1.1. Optical sight. The optical sight for a certain type of light weapons is matched with the light weapons through the damping connection device. The physical model of the optical sight is shown in Figure 1. The recoil impact energy of about 200g (peak value) generated by the light weapon during shooting is transmitted to the high precision optical sight through the damping connection device composed of leaf spring. Therefore, the impact resistance, stability and reliability of the damping connection device after bearing the high-intensity and high-frequency sustained impact stress generated in shooting will be the key to the success of optical sight design.

3.1.2. Parametric modeling. In this paper, the parallel reed damper of optical sight is optimized. Therefore, the optical sight can be regarded as a whole, and the bottom plate assembled with the parallel reed damper is taken for simplified analysis. In the same way, the assembly part of the parallel reed damper and the light weapons can also be simplified as a flat plate. The damping elements are not simplified and modeled according to the actual state. In this way, the finite element parametric modeling in DM of workbench is shown in Figure 2.

3.2. Response spectrum analysis
The contact between the damping element and the optical sight and the light weapon plate is set as the bound contact, while the contact between the leaf spring group is set as the friction contact, and the friction coefficient is 0.1. The impact produced by light weapons shooting acts on the plate, so the lower surface of the plate is fixed support. The response spectrum analysis needs to be carried out on the basis of modal analysis. Because the design impact load is 10Hz, the horizontal (X-direction) amplitude is 200g acceleration, so it is enough to extract the low-order mode of the structure in X-direction. According to the results of modal analysis, extract the first 20 steps for expansion, select single point response spectrum analysis, apply the load on the bottom of the light weapons plate, and use the root mean square method (SRSS). The stress and displacement response nephogram of the structure under impact load can be obtained by modal synthesis response, as shown in Figure 3.
3.3. Response surface analysis

Based on the response spectrum analysis of the damper, carry out the optimization design of the structure based on the response surface method, and set L, H, L1, L2, L3, ZC2 as the input parameters. The value of L is set as [90, 102], the value of H is [27, 33], the value of L1 is [2.7, 3.3], the value of L2 is [1.8, 2.2], the value of L3 is [2.7, 3.3], the value of ZC2 is [18, 22], and the value of optical sight plate in response is [18, 22]. Under the spectrum analysis, the maximum displacement response in X direction is the output parameter. Under the de module, select the response surface, set the design variable type as continuous, the experimental design type as the central composite design method (CCD), the total number of design points is 46, and submit it to workbench for analysis.

3.3.1. Response surface. The response surface type is the standard response surface, that is, the response of the maximum displacement response to L, H, L1, L2, L3, ZC2 and other parameters is calculated by the complete quadratic polynomial fitting, as shown in Figure 4.

Through the response surface curve between the maximum displacement response of the optical sight plate and the input parameters, it can be seen that the displacement response follows the distance L between the two side leaf springs, the width H of the leaf spring group, and the thickness L2 of the middle short leaf spring of the single side leaf spring group, which is in the shape of a trough, and the valley bottom value can be taken; the displacement response monotonously increases with the height ZC2 of the middle short leaf spring, it means that the higher the actual height of the middle short leaf spring is, the lower the maximum displacement response is; the displacement response monotonically decreases with the thickness of the leaf springs, which means that the thickening of leaf spring can
reduce the maximum displacement response.

3.3.2. Sensitivity analysis. The sensitivity of structural parameters of parallel reed damper to maximum displacement response is defined as the change rate of maximum displacement response to structural parameters, so as to judge the sensitivity of maximum displacement response to structural parameters and guide the direction of optimization. Take the sensitivity diagram under the mean value (original design value) of each input parameter of response surface analysis, and the result is shown in Figure 5.

It can be seen from Figure 5 that the maximum displacement response is not sensitive to the distance L between the leaf springs on both sides, the thickness L2 of the middle leaf spring of the single leaf spring group, the height ZC2 of the middle leaf spring of the single leaf spring group and the thickness L3 of the inner leaf spring of the single leaf spring group, the thickness L1 of the outer leaf spring of the single leaf spring group and the thickness H of the leaf spring group. Therefore, on the single factor optimization route of the structure, the priority order of the six input parameters is: \( L > L2 > ZC2 > L3 > L1 > H \).

According to the comprehensive sensitivity chart and response surface curve, only the width H of leaf spring group in the response surface curve is the trough shape, which represents the optimal solution. Therefore, the width of leaf spring group should be selected preferentially when single factor optimization is carried out for the results, and the priority of other input parameters is \( ZC2 > L3 > L1 > L > L2 \).

3.4. Optimization

According to the results of response surface analysis, the objective driven optimization analysis under multi input parameters is carried out, and the optimization objective is set as min (minimum displacement response), which is solved in the optimization module of workbench. The results are as follows:
Table 1. Optimization analysis results

|                  | Design value | Optimization set 1 | Optimization set 3 | Optimization set 3 |
|------------------|--------------|--------------------|--------------------|--------------------|
| L (mm)           | 96           | 96.674             | 92.534             | 98.294             |
| Left_L1          | 3            | 3.3                | 3.2921             | 3.2024             |
| Left_L2          | 2            | 2.0742             | 2.018              | 2.0597             |
| Left_L3          | 3            | 3.3                | 3.2638             | 3.2753             |
| H                | 30           | 30.376             | 30.904             | 30.154             |
| ZC2              | 20           | 18                 | 18.239             | 19.141             |
| Maximum displacement response | 4.2556E-06 | 3.496E-06          | 3.5353E-06         | 3.6584E-06         |

As shown in the table, if the structural parameters given in the optimization set are selected, the maximum displacement response can be reduced by more than 20%.

4. Conclusion

(1) The width of the leaf spring group has the greatest influence on the shock resistance of the structure.

(2) In the optimization design process of optical sight damping elements, the adjustment priority of main structural elements is: width of leaf spring group > height of hollow layer of leaf spring group > thickness of leaf spring group > symmetrical distance of leaf spring group.

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