Topology optimization of aircraft flip spreader for lightweight

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Abstract. In recent years, structural optimization design and computer-aided design methods have achieved long-term development. In order to achieve design innovation, improve product performance, and reduce production costs, enterprise pay more and more attention to the new design methods. Optimization design has become the key process of product development. Especially in the fields of aerospace, automobile that focus on lightweight and fuel saving, the scope and depth of topology optimization design is rapidly developing. In this paper, topology optimization has been applied on design of aircraft flip spreader, using ANSYS Workbench software to reduce the weight of the spreader. First, using static structural tool for static analysis, set loads and supports, solve the stress distribution of spreader under various working conditions. Then, using topology optimization tool for optimization design, set the optimization variables, constraints and objective, solve the optimal material distribution. At last, compared with traditional experience-based design methods, topology optimization design methods have obvious advantages, the weight of spreader has been reduced 25.5%, without affecting the component strength.

1. Introduction

1.1. About topology optimization

In recent years, aerospace, automobile and other field pay more and more attention to structural optimization design methods, enterprise wants to improve product performance and enhance market competitiveness through optimization design methods, optimization design methods has become a key process of the product development. [1-7]

Structural optimization methods is to comprehensively consider the design input conditions such as loads, material properties, manufacturing process, and boundary constraints, by changing the optimization variables, finally achieve the design goals which can reduce stress, weight, production cost, and improve the overall structural performance.

According to the design variables, structural optimization methods can be divided into three levels, size optimization, shape optimization and topology optimization.

Size optimization design is a primary optimization method, and optimization variables are a limited number of structural dimensions, such as the cross-sectional size of the beam and the thickness distribution of the plate or shell. [7-8]

Shape optimization design is a more in-depth optimization method. For discrete structure optimization variables are node coordinates, for continuous structure optimization variables are structure shapes. [9-12]
Topology optimization design is the most advanced optimization technology. For discrete structures, the optimization variables are the node layout and the connection relationship between nodes. For the continuum structure, the optimization variables is the number and location of holes in the structure. [13]

Topology optimization can build a brand-new topology form, set the node layout at any position in the design area, or open a hole at any position, therefore, topology optimization can produce a new topological configuration that is more in line with the actual force transmission path and material economy during the optimization process, optimization effect is the best.

1.2. About aircraft flip spreader
The aircraft flip spreader is an important tool in the production process of the aircraft assembly. It is mainly used for lifting the aircraft in the horizontal or vertical states, and flipping between the horizontal and vertical states.

The aircraft flip spreader is composed of hanging beam, beam plates, front lifting arms, rear lifting arms, wire ropes, bolts, nuts, etc.

Fig.1 shows the structure of aircraft flip spreader. Front and rear lifting arms connected with the aircraft by bolts, in the horizontal state, the flight axis is parallel with ground, in the vertical state, the flight axis is vertical with ground, when flipping between the horizontal and vertical states, the aircraft rotate around the flip axis.

Before use, workers install these parts on the aircraft one by one, the process of assembling and disassembling heavy parts will threaten the safety of workers and aircraft. So, the weight of each parts should be reduced as much as possible.

Lifting operation is one of the hidden dangers of enterprise production process, sufficient design margin should be reserved when designing spreader parts. In order to avoid spreader crushed from over load, maximum stress should not exceeds material yield strength. Therefore, lightweight design without affecting the component strength is key of spreader optimization design.
2. Design approach

In this paper, we introduce in detail the optimization design of aircraft flip spreader used topology optimization methods, the design process is shown in Fig.2.

![Design process](image)

**Figure 2.** Design process.

2.1. Optimization pre-processing

2.1.1. *Initial design.* Carry out preliminary design based on the design input indicators of the aircraft product dimensions, interface, weight, etc., build spreader 3D model in Creo2.0 software.

2.1.2. *Force analysis.* Analyse the force of spreader parts under horizontal and vertical states.

2.1.3. *Static strength calculation.* Mesh the finite element, apply loads and constraints, and solve the stress and strain distribution of the structure.

2.2. Topology optimization

2.2.1. *Define the optimization area.* Divide the structure into optimized and non-optimized areas. Topology optimization only designs the optimized area and keeps the non-optimized area. We can
choose the optimize area according to the functional needs of the structure, in order to obtain the best effect, the optimization area should be expanded as much as possible. Structures such as bolt holes and mating surfaces on the force transmission path and structure that affects the assembly relationship of parts should be divided into non-optimized areas. In addition, we can divide some key structures into non-optimized areas according to our design experience, thereby reducing the amount of calculation and save solve time.

2.2. Define the objective and constraint. Set the minimum mass or minimum volume as the optimization objective, set the mass, volume, global von-mises stress, local von-mises stress, reaction force, displacement, natural frequency as constraints.

2.2.3. Topology optimization solution. Topology optimization is an iterative algorithm, usually needs more than 20 iterations, during the solution, we should pay attention to software error and warning information, check solution information, look at the convergence chart and shape evolution process, determine whether the results are converging, and select the final optimization plan.

2.3. Optimization post-processing

2.3.1. Re-modelling. Remove material according to the optimization results, and establish the optimized structural model.

2.3.2. Static strength calculation. Apply the same loads and constraints to the structure, static analysis again, determine whether the structural strength meets the requirements.

3. Design
This article mainly introduces the topological optimization design of several heavier spreader parts such as hanging beam, beam plates, front lifting arms and rear lifting arms. Lighter weight spreader parts such as wire ropes, nuts and bolts only need to be calculated for strength, which will not be described in detail in this article.

3.1. Optimization pre-processing

3.1.1. Initial design. Design the aircraft flip spreader, initial design is shown in Figure 1, material properties are shown in Table 1.

| Part                        | Hanging beam | Beam plate | Front lifting arm | Rear lifting arm |
|-----------------------------|--------------|------------|-------------------|------------------|
| Material                    | 45           | 30CrMnSiA  | 206Gpa            | 206Gpa           |
| Elastic Modulus(E)          | 206Gpa       | 206Gpa     | 0.3               | 0.3              |
| Poisson’s ratio(γ)          | 0.3          | 0.3        | 835Mpa            | 1080Mpa          |
| Yield strength(δs)          | 355Mpa       | 355Mpa     | 835Mpa            | 1080Mpa          |
| Breaking strength(δb)       | 600Mpa       | 600Mpa     | 835Mpa            | 1080Mpa          |

3.1.2. Force analysis. The weight of the aircraft is m=2000kg, in order to improve safety, it is necessary to increase the design margin, the maximum load of the spreader is

\[
F = i \cdot (1 + 20\%) \cdot mg
\]  

(1)

According to the design guidelines of the spreader, \( i = 4 \)


\[ F = 4 \times (1 + 20\%) \times 2000\text{kg} \times 9.80\text{N/kg} = 9.408 \times 10^4\text{N} \]  

(2)

3.1.3. **Static strength calculation.** Import the 3D model of spreader from Creo2.0 software to ANSYS Workbench, static analysis of spreader parts using the static structural analysis toolbox. Use the load step tool to simulate the horizontal lifting and vertical working conditions of the spreader, loads and constraint settings are shown in Fig.3.

\[ F = 4 \times (1 + 20\%) \times 2000\text{kg} \times 9.80\text{N/kg} = 9.408 \times 10^4\text{N} \]

3.2. **Topology optimization**

3.2.1. **Define the optimization area.** The three pin holes of the hanging beam are defined as non-optimized areas, and other areas are defined as optimization areas.
3.2.2. Define the objective and constraint. The topological optimization objective function of the hanging beam is defined as the minimum mass, and the constraint condition is set to the maximum stress below 355Mpa.

3.2.3. Topology optimization solution. Topology optimization solution of hanging beam is shown in Fig.6.

Optimization target convergence curve is shown in Fig.7, optimization target convergence when iterating about 20 times.

3.3. Optimization post-processing

3.3.1. Re-modelling. According to topology optimization, combine existing process conditions, finish secondary modelling of the spreader structure.

3.3.2. Static strength calculation. Perform static analysis to the hanging beam again, stress distribution and strain distribution of hanging beam are shown in Fig.8.
3.4.2. Front lifting arm

Figure 10. Optimization design of the front lifting arm.

Strength can meet requirements.

3.4. Optimization design of the other parts

Similarly, the other parts can also be optimized. Left figures are the spreader parts designed by traditional experience design method, right figures are the spreader parts designed by topology optimization design method.

3.4.1. Beam plate

Figure 9. Optimization design of the beam plate.

Figure 8. Stress and strain distribution of final design.

Maximum stress of hanging beam $\delta_{\text{max}} = 295.99\text{MPa}$, and material yield strength $\delta_s = 355\text{MPa}$, residual strength coefficient

$$\eta = \frac{\delta_s}{\delta_{\text{max}}} = \frac{355\text{MPa}}{295.99\text{MPa}} = 1.199 \tag{3}$$

where $\delta_s$ is the material yield strength, $\delta_{\text{max}}$ is the maximum stress of the beam, and $\eta$ is the residual strength coefficient.
3.4.3. Rear lifting arm

Figure 11. Optimization design of the rear lifting arm.

4. Lightweight analysis

The weight of spreader using topology optimization design method is obviously less than that using traditional experienced design method, the weight comparison analysis is shown in Table 2.

Table 2. Lightweight analysis.

| Part              | Topology optimization design | Experienced design | Lightweight | Rate  |
|-------------------|------------------------------|--------------------|-------------|-------|
| Hanging beam      | 16.79kg                      | 24.48kg            | 7.69kg      | 31.4% |
| Beam plate        | 11.57kg                      | 16.53kg            | 4.96kg      | 30.0% |
| Front lifting arm | 13.54kg                      | 19.02kg            | 5.48kg      | 28.8% |
| Rear lifting arm  | 15.85kg                      | 18.43kg            | 2.58kg      | 14.0% |
| Total             | 98.71kg                      | 132.44kg           | 33.73kg     | 25.5% |

5. Conclusions

In this paper, the weight of aircraft flip spreader is reduced without affecting the strength of the material. The aircraft flip spreader weight is reduced by 25.5% after topology optimization, due to which the safety of spreader operation process will be increased. Therefore, under the same load conditions, constraints and design goals, topology optimization effect is better. Even without much design experience, no need to modify and design the project repeatedly, topology optimization can achieve a more ideal design goal.

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