Shape Optimization of Hook for Marine Crane

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Abstract. The hooks are prone to fatigue fracture due to the frequent impact loads on the hooks at sea. In order to further strengthen the structural strength of the hooks, the influence of the three parameters on the hooks is studied, such as the deflection angle of the hooks with large openings, the opening diameter of the hooks and the position of the maximum thickness of the hook walls. The main points are as follows: parameterized modeling of crane hooks, data simulation and analysis with ANSYS, and optimization analysis of hooks' strength, which provide basis for further enhancing reliability of hooks.

1. Introduction
Hook is one of the important components of crane. When the crane is carrying out transportation operations, the hook will be subjected to frequent impact loads. Once there is a failure such as fatigue fracture of the hook, it will cause significant loss of personnel and property. As for the hook of the ship crane, it is mainly used for important tasks such as cargo transportation and transfer, sea supply, launching of underwater operation equipment and recycling. Ships on the sea will be affected by external environment such as wind, waves, currents and self-control, so that the crane hook will be subjected to more severe repeated loading than land operations, which puts forward higher requirements on the strength and fatigue strength of the crane hook and poses great challenges to the safe operation of the crane hook [1].

Under different loads, the crane hook has been optimized and studied. It has been found that the strength of the hook can be enhanced by increasing the thickness of the cross section of the hook and the width of hook [2]. In order to meet the use of crane hooks under more severe working conditions, the influence of changes in the three places on the strength and deformation of hooks was studied under the condition of keeping the maximum thickness of hooks unchanged, including the angle of deflection of hooks, the diameter of hooks and the position of the thickest hooks. Through the optimization numerical analysis of these three parameters, the further optimization of the hook is realized, so that the shape optimization of the hook has more choices and basis.

In this paper, ANSYS software is used to carry out parametric modeling and force analysis on the hook, and structural optimization analysis is carried out on the hook according to the response surface and sensitivity [3], which provides a reasonable basis for further shape optimization of the hook.

2. Hook parametric model and force analysis
The hook is a lifting device on the crane and is also the main bearing component of the crane. The strength of the hook and the rationality of its design are crucial to the safety of the crane's work. Taking the hook bearing 0.5t produced by a factory as an example, the strength analysis of the hook is carried out, the deformation and stress distribution laws of the hook are explored, and its dangerous
section is analyzed, which provides a theoretical basis for the study of hook structure optimization and has important engineering significance.

![Simplified structure of the hook](image)

**Figure 1. Simplified structure of the hook (Unit: mm)**

When modeling the hook, some unimportant details and details that have little influence on the strength of the hook are ignored, thus simplifying the hook model and eliminating interference on the optimization parameters. The structure diagram of crane hook is shown in figure 1. Low alloy steel is selected, with a density of 7800kg/m³, an elastic modulus of 2e11, poisson’s ratio of 0.27, and a tensile strength of 450MPa. The hook model is divided into 48911 units and 73168 nodes using tetrahedral grids.

### 3. Strength analysis of automatic unloading hook

When the hook is working on a crane, the bottom of the hook is subjected to the gravity exerted by the rope. In this paper, the load acting area of the suspension cargo cable to the hook is simulated by projection marks, where in the load applied by the cable to the hook is 5000N. After the hanger lug of the hook is subjected to displacement constraint, the strength of the automatic unloading hook is analyzed. The constraint conditions and loads are shown in figure 2.

![Constraint and loads](image)

**Figure 2. Constraints and loads**

Where in the A load is the load caused by the gravity of 500 kg of goods. As for the determination of the action area of the A load, the projection area of the steel cable on the hook in the vertical direction when the crane hook is working is simulated, that is, the contact area between the hook and the rope. At the same time, the projected positioning is associated with the sketch of the hook, so as to ensure that when the hook is optimized later, the load action area will not be affected due to changes in parameters, thus eliminating the interference of the load action area on the result.
The equivalent stress distribution of the hook is shown in figure 3, the maximum equivalent stress value is 115.17 MPa, the distribution of hook shape variables is shown in figure 4, and the maximum shape variable is 0.21289 mm. The maximum equivalent stress occurs at the center of the hook body bend of the hook, which is caused by the tensile force and bending moment of the load at the hook bend, resulting in tensile deformation. The maximum deformation of the hook occurs at the top of the hook opening. Since the maximum deformation is only 0.17362 mm, it can ensure the safety of hanging goods during operation. Under the load, the maximum equivalent stress of the hanger is only 115.17 MPa, and its minimum safety factor is 3.91, which meets the safety requirements of the hanger. Therefore, on the premise of ensuring that the strength and shape variables of the automatic unloading hook meet, the shape of the hook is optimized.

![Figure 3. Hook equivalent stress distribution](image)

![Figure 4. Hook shape variable distribution map](image)

**4. Hook structure optimization**

**4.1 Design variables and output variables**

In order to optimize the shape of the hook, shape parameters need to be selected as design variables. The deflection angle DS _ C of the hook, the opening diameter DS _ R of the hook, and the position DS _ H at the thickest part of the hook section are selected as design parameters. The specific positions are shown in figure 1 below. Preview the shape change of the hook model within the specified range of the defined parameters. In order to avoid the shape distortion or fracture surface of the hook model within the range of parameter change[4].

At the same time, the maximum value of the equivalent stress of the hook and the maximum form variable are selected as the output parameters. The basis of the optimized design is that the spreader is within the safe range, and at the same time meets the requirements of normal operation, so that the
strength of the structure can be further enhanced. When carrying out the test design, the change range of each design variable must be set first. The specific parameter settings are shown in Table 1.

| Parameter                        | Symbol | Design parameter range |
|----------------------------------|--------|------------------------|
| Hook opening radius/mm           | DS_R   | 25~30                  |
| Deflection angle of hook/°       | DS_C   | 41~50                  |
| The thickest part of the hook section/mm | DS_H   | 6~9                    |

### 4.2 Sensitivity analysis and construction of response surfaces

The midpoint composite design method was used to design the design points, and 15 design points were selected for static analysis and response surface construction of the spread. The parameter sensitivity is shown in Figure 5.

![Parameter sensitivity map](image)

### 4.3 Multi-parameter and multi-objective optimization analysis

Carry out the same structural analysis on the optimized hook, and its analysis structure is shown in figure 6 and figure 7. As can be seen from figure 6, the maximum equivalent stress value of the hook after the sling is optimized is 102.03 MPa, which also occurs in the center of the hook body. Its value is far less than the allowable stress value of the material. The strength of the hook after optimization still meets the safety requirements. As can be seen from figure 7, the maximum shape variable of the hook after optimization is 0.655 mm, which is mainly located at the top of the hook opening. Since the shape variable of the hook is very small, the phenomenon of goods separation still does not occur. The comparison results before and after optimization are shown in Table 2.
Figure 6. Equivalent stress of spreader

Figure 7. Total deformation of spreader after optimization

Table 2. Comparison of results before and after optimization

| Parameter name                              | Symbol     | Design parameter range | Optimized value |
|---------------------------------------------|------------|------------------------|-----------------|
| Hook opening radius/mm                      | DS_R       | 25~30                  | 25              |
| Deflection angle of hook/°                  | DS_D       | 41~50                  | 46.2            |
| The thickest part of the hook section/mm    | DS_H       | 6~9                    | 6.1             |
| Maximum amount of total deformation/mm      | Total Deformation Maximum | 115.17                | 102.03          |
| Maximum value of the equivalent stress/Mpa  | Total Deformation Maximum | 0.21289               | 0.17419         |

5. Conclusion
The deflection degree of the hook has a slight influence on the strength and shape variables of the hook, while the opening diameter of the hook has a great influence on the strength and shape variables of the hook. When optimizing the hook, under the condition of maintaining the overall thickness, width and length, it can be considered to appropriately reduce the diameter of the opening of the hook. Among the three parameters, the location of the thickest hook section has the greatest influence on the
strength of the hook. In order to enhance the strength of the hook, the strength of the hook can be enhanced by changing the location of the thickest hook section under the condition that other shapes and structures are unchanged. By optimizing the design of the hook through the three parameters of the deflection angle of the hook, the opening diameter of the hook and the position of the thickest section of the hook, the analysis shows that the optimized hook meets the safety requirements in terms of structural strength and shape variables, achieves the expected purpose, and makes the shape of the hook more reasonable.

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