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Static Analysis and Topological Optimization of Steering Block for Mining Shuttle

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Abstract. Taking the steering block of mine shuttle car as the research object, a three-dimensional solid model of the steering block of mine shuttle car is established by SolidWorks. Based on ANSYS Workbench, the total deformation and stress of the steering block of Mine shuttle car under tension are obtained. According to the boundary conditions, the steering block is optimized by topology optimization, and the steering block is optimized by the results of topology optimization, and finally verified by static analysis. The results show that the mass of the optimized steering block is reduced by 11.7%. This study provides a reference for comprehensive performance analysis and optimization of Mine shuttle car steering block.

1 Introduction

Mine shuttle car, as a trackless rubber-wheel vehicle for short-wall mechanized mining, is a coal mine auxiliary transportation system towed by wire ropes. Its main function is to transfer coal from continuous coal miner to feed crusher. It is suitable for rail transportation with long distance, large inclination, variable slope and large tonnage, featuring flexibility, simple structure and large volume.

Steering block is a key part in mine shuttle car, which keeps the whole mine shuttle car running smoothly. However, the road under the working condition of mine shuttle car is relatively narrow and restricted by space, so the steering mechanism of mine shuttle car should be controlled sensitively. Therefore, the steering block is subjected to a great force, if a large deformation occurs, it will have a great impact on work efficiency and economic benefits. There is little research on the performance of steering block of mine shuttle car at this stage, so it is particularly important to carry out static research on steering block.

Therefore, this paper takes the mine shuttle steering block as the research object. Through the three-dimensional modeling of steering block structure, the stress variation of steering block is analyzed and the ideal state is obtained by combining the topology optimization module. According to the simulation results, the steering block structure is further optimized.

2 Modeling and finite element analysis

Firstly, three-dimensional model of steering block is established by Solidworks software, and the three-dimensional model of steering block is obtained as shown in Figure 1.

The forces acting on the steering block under actual conditions are complex, but it is mainly affected by the pulling force of the steering cylinder on the steering block, the resistance of the longitudinal pull rod and the soft shaft on the steering block, and the force on the spline joint. The model forces diagram are shown in Figure 2 below.

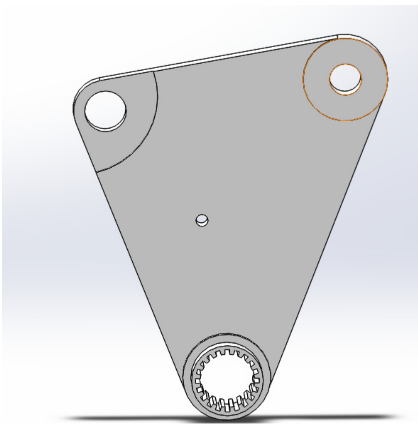

Fig. 1. Three-dimensional model of steering block.

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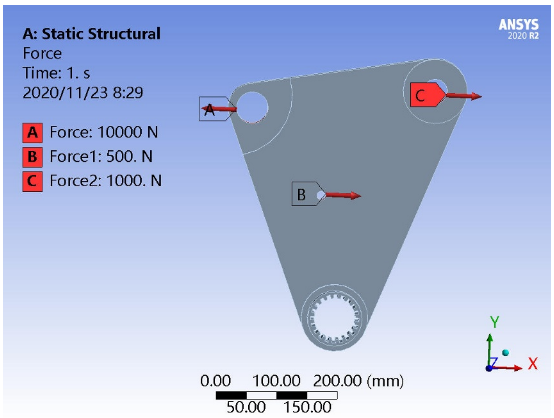

Fig. 2. Force analysis diagram of steering block.

Force is the pull of steering cylinder to steering block; Force 1 is the resistance of longitudinal tie rod to steering block; Force 2 is the resistance of soft shaft to steering block.

2.1 Static analysis

Static Structural module is used for static analysis of steering block. In classical mechanics, the dynamic equation of an object is:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F(t)\} \tag{1}$$

[M] Representation of Quality Matrix; [K] Representation of Damping Matrix; [x] Representation of displacement vector; [F] Representation force vector.

In static analysis, time has no effect on the results, so the time-dependent unknown number can be ignored and a simplified formula is obtained:

$$[K]\{x\}=\{F(t)\} \tag{2}$$

The model is imported into ANSYS workbench and given material properties. The material of steering block is Q550, with elastic modulus of 206000MPa, density of 7800kg/m3 and Poisson ratio of 0.3. Workbench is used to divide the grid of the model. This time, the tetrahedral grid method is used to divide the model. Body sizing is introduced and the minimum grid unit is set to 5 mm. The number of divided units is 273806 and the number of nodes is 397885. The result of grid division is shown in Figure 3.

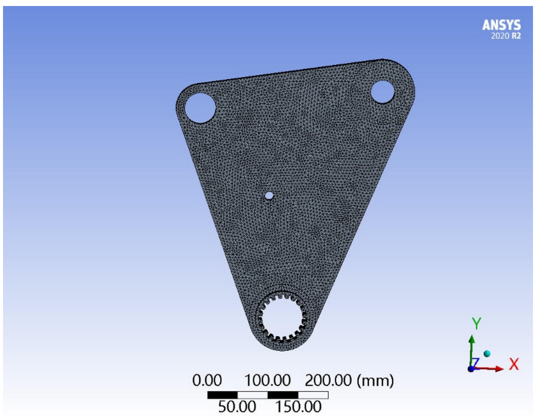

Fig. 3. Grid Dividing of Steering Blocks.

To add constraints and loads to the model, the force condition has been introduced above, and then the cylindrical restraint is set on the spline part of the steering block, whose axial restraint is Free. The total deformation diagram and stress cloud diagram of the steering block are obtained as shown in Figure 4.

2.2 Topological optimization

Topology optimization refers to shape optimization, sometimes referred to as shape optimization. The function of topology optimization is to give a model where material can be removed to reduce weight. A typical mathematical expression is:

$$g_1(\bar{x},\dot{\bar{x}},\bar{v})=0 \tag{3}$$

$$g_2(\bar{x},\dot{\bar{x}},\bar{v})\leq 0 \tag{4}$$

$$\min f(\bar{x},\bar{v}) \tag{5}$$

$\bar{X}$ -State variables representing the system; g1, g2-End equation of inequality; $\bar{V}$ -Represents design variables; $f(\bar{x},\bar{v})$ -Represents the objective function.

Topology optimization module is introduced based on static results. The maximum iteration step is 500, the minimum standardized density is 1.e-003 and the convergence accuracy is 0.1%. Exclusion area is set and the retention quality of response constraint setting is 50%. The positive and negative diagrams of the optimized steering block are obtained. Based on the results of the topology optimization, the redundant parts of the model are removed and the steering block is re-modeled in three dimensions as shown in the figure. The optimized total deformation and stress diagram of steering block is obtained by validating again with the static module.

3 Results

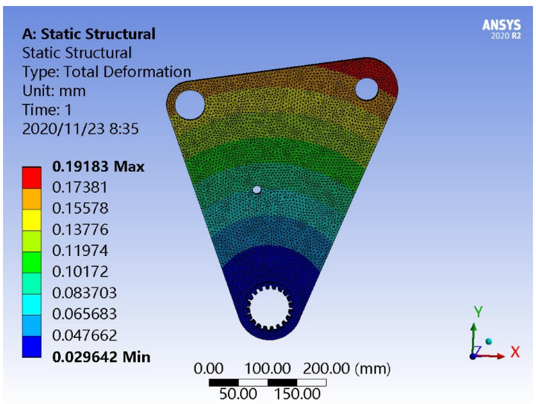

Fig. 4. Cloud View of Total Deformation of Steering Block under Force.

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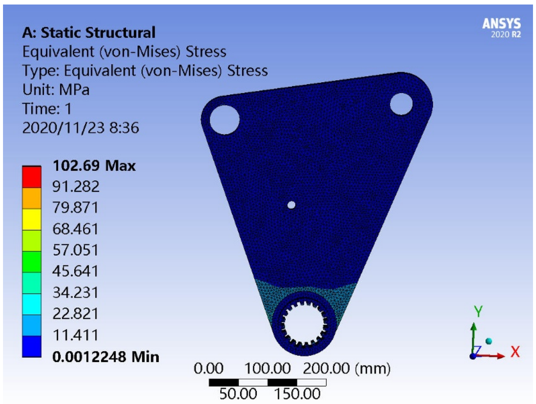

Fig. 5. Equivalent Force Cloud of Steering Block under Force.

It can be seen from the above diagram that the total deformation of steering block under stress is 0.19 mm and the stress is 102 MPa. The maximum deformation is at the joint of steering block with steering cylinder and longitudinal tie rod. The maximum stress occurs at the spline connection. Both data are relatively small and fully meet the strength requirements of steering block. Therefore, the steering block is topologically optimized and the redundant parts are obtained, as shown in Figures 6 and 7.

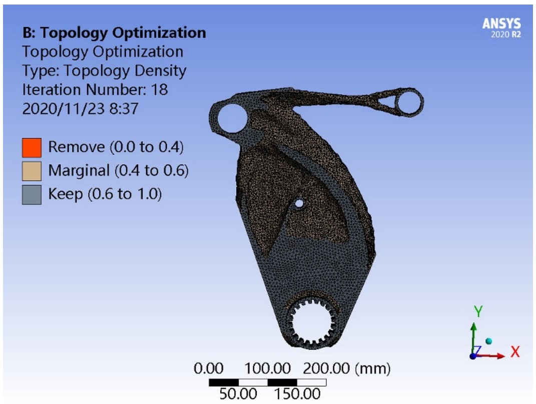

Fig. 6. Front view of steering block topology optimization.

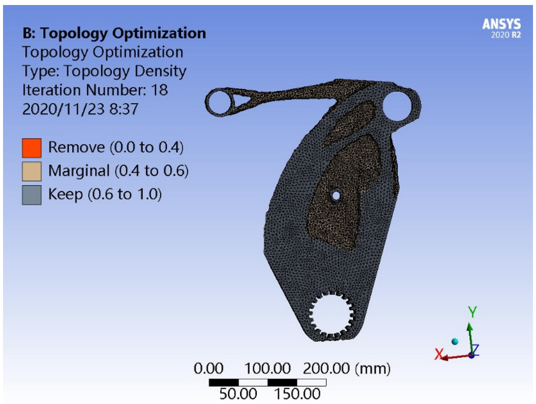

Fig. 7. Reverse schematic of steering block topology optimization.

From the results we can see that red is the removed part and gray is the retained part. Where the removed parts are concentrated in the middle of the steering block, corresponding to the equivalent stress map of the steering block above, in the area of little stress and deformation. In order to make the optimized steering block regular, according to this result, the steering block is re-modeled by Solidworks software, and the middle part of the original model of the steering block is excavated symmetrically. After reconstruction, the steering block is modeled symmetrically. The model is shown in Figure 8.

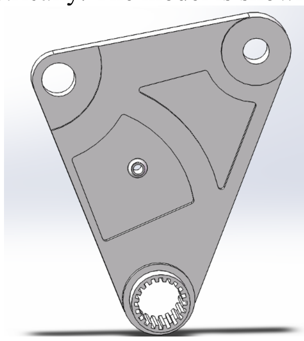
Fig. 8. Reconstructed steering block model

By using the reconstructed steering block model and verifying it by static analysis again, the total deformation and equivalent stress diagram of the reconstructed steering block are obtained as shown in Figures 9 and 10.

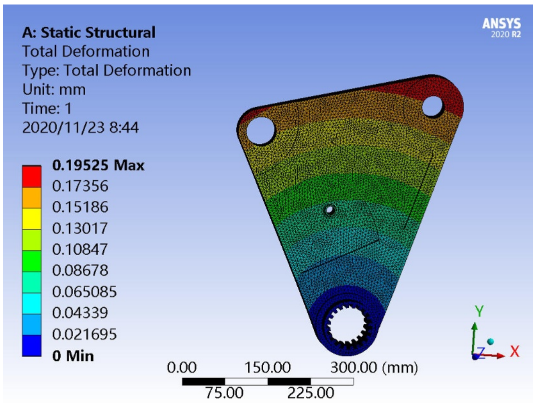

Fig. 9. Total Deformation Map of Reconstructed Steering Block

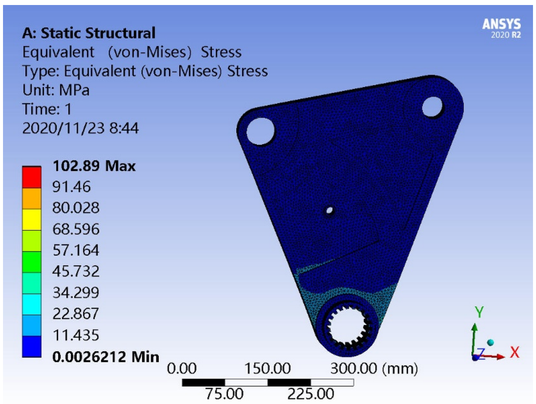

Fig. 10. Reconstructed stress cloud of the rear steering block

All the data above are combined to get the quality changes before and after optimization of steering block, as shown in Table 1.

Table 1. Stress and quality comparison of steering block before and after optimization

	Maximumstress	Quality
Before optimization	102.69MPa	34.863kg
After optimization	102.89MPa	30.753kg

It can be seen from the table that the maximum stress after optimization is 0.19% higher than that before optimization, but the quality of the optimized model is reduced by 11.7%, and the data change range is not large, which fully meets the material properties.

4 Conclusions

In this paper, the static analysis of the steering block of shuttle car is carried out by using ANSYS Workbench. The total deformation diagram and stress diagram of the steering block are obtained. The maximum deformation and stress position of the steering block are analyzed. The results are consistent with the material properties. Then topology optimization module is used to optimize the model, which reduces the mass of steering block by 11.7%. The static analysis results before and after optimization are compared, which has certain reference significance for the optimization method of shuttle car steering block in the future.

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