Lightweight design of hub under three working conditions based on Topological optimization

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Abstract: SpaceClaim was used to parameterize the main dimensions of 6.50R16 trailer hub model. The sensitivity diagram of hub parameters was obtained based on Central Composite Design (CCD) algorithm, and the stress area of hub was screened out. Using transient mechanical fatigue analysis was carried out on the wheel under the condition of impact load on the S-N fatigue curve obtained hub fatigue failure area, through Admass STEP function wheel movement geometry curve under impact load is determined, according to the result of wheel hub parameter sensitive figure, fatigue analysis and topology wheel movement curve area under impact load, The shape of the hub model was optimized based on topology optimization, and the new hub model was constructed by SpaceClaim geometric post-processing. After topology optimization, the hub quality is reduced to 16%

1. Introduction
As the bearing part of the automobile, the automobile hub is an important part of the automobile driving process. Minimizing the weight of the automobile hub on the premise of ensuring its strength can not only reduce fuel consumption, but also improve the driving speed of the automobile [1].

In this paper, CCD algorithm is used to perform dominant calculation on hub under static, impact load and uniform transient condition. The Kringing model is constructed with the main size of the wheel hub as the basic quantity, the load as the independent variable, the stress force and deformation as the dependent variables, and the sensitivity diagram of wheel hub parameters is obtained. The effect of load on the hub can be intuitively obtained, and the result can be obtained by one calculation, reducing the solving steps and reducing the error.

The hub fatigue under impact load was analyzed by transient mechanics, and the fatigue failure zone of the hub was determined according to the S-N curve. Based on Adams STEP function, the hub under impact load was simulated and the velocity curves of each point of the hub were obtained. Based on the sensitivity diagram of wheel parameters, fatigue safety factor diagram and Adams simulation motion diagram, the shape optimization of wheel hub was carried out based on topology optimization. Finally, SpaceClaim geometric post-processing was used to build the optimized hub model, which was verified again in three cases and met the requirements of strength and stiffness. The optimized hub mass is reduced to 16%.
2. Hub dominance analysis

QT450 material 6.50R16 trailer hub is selected. The main dimensions of the hub model are parameterized. The hub parameterization diagram is shown in Figure 1.

![Figure 1 Parameterization diagram of wheel hub size](image)

2.1 Hub constraint loads under three working conditions

For the rear three-axle trailer, the mass of the empty vehicle under static load is 40T, and the weight of the rear three-axle trailer accounts for 60% of the whole vehicle. Each tyre was calculated to be supported by 45KN. The pressure on the hub is 0.65mpa. In addition to the support, it is also affected by tire pressure. [2]

According to GB/9744-2007 standard 6.50R16 tire pressure is 0.45mpa bolt hole to fix the brake disc, the application of section method to obtain bolt pretightening force is 25000N, under the static load at the bolt hub is shown in Figure 2.

![Figure 2 Hub constraint load diagram under static load condition](image)

Dacai CA6DK1-28E5 engine is used in this paper. When the semi-trailer is running at a uniform speed on the flat road, according to the engine parameters and specifications, it can be known that the speed \( N = 2300 \text{RPM} \) and the power \( P = 170 \text{KW} \). According to the formula \( P = M \times N \), it can be concluded that the torque \( M = 1100 \text{N/M} \) under uniform motion. Constraints of hub at uniform speed are shown in Figure 3.

![Figure 3 Constraints of hub at uniform speed](image)

The vehicle driving on the highway will produce more or less turbulence, the vehicle virtually increased a inertia force, to fully consider the inertia force, often use a dynamic load coefficient to multiply the static load to express the inertia force. [3]

Road conditions in China are divided into eight grades. Under standard loads, dynamic load coefficients of each grade have their respective ranges. [4] According to the speed of 80km/m of class C road surface, the dynamic load coefficient is 2.5. The impact load on the hub on grade C road surface is about 1200KN. Hub constraints under impact load are shown in Figure 4.

![Figure 4 Hub constraints under impact load](image)
2.2 DOMINANT solution of CCD

From the wheel hub constraint load diagram under the three conditions, it can be concluded that the wheel hub under the same constraints under the three conditions, but the load is different. According to this conclusion, the Kringing mathematical model is constructed with the load on the hub as independent variable and the maximum stress and deformation as dependent variables. The Kringing model is shown in Figure 5.

![Figure 5 Kringing model diagram](image)

The hub sensitive graph is obtained by CCD algorithm. FIG 6 shows the sensitivity of hub parameters

![Figure 6 Sensitivity diagram of wheel hub parameters](image)

According to the hub sensitive diagram solved by CCD algorithm, it can be found that no matter how the load changes, p6 and P8 in the sensitive diagram are not affected. The hub size diagram of P6 is shown in Figure 7, and that of P8 is shown in Figure 8.

![Figure 3 Hub constraint load diagram in motion](image)

![Figure 4 Hub constraint load diagram under impact load](image)
As can be seen from the figure, P6 corresponds to the radius of the hub circle, and P8 corresponds to the thickness of the hub flange.

3. Transient mechanical analysis, fatigue analysis and motion simulation of wheel hub under impact load

3.1 Transient mechanical analysis

According to the sensitivity diagram of the hub Kringing model, the region of the hub with no obvious stress can be directly obtained. In order to make the conclusion more convincing, according to the fatigue law, the component will yield under the mutation of external load. It is necessary to conduct transient dynamic analysis, fatigue analysis and Adams simulation for the hub under impact load to further observe the hub stress region.

According to the results of transient dynamic analysis in FIG. 9, the stress variation of the hub under impact load is normal.

3.2 Fatigue Analysis

For the impact load on the hub, it is not continuous and repeated and belongs to low-cycle fatigue. The strain fatigue theory analyzes the fatigue according to the action time of the impact load. The hub fatigue safety factor diagram is shown in Figure 10.
3.3 Adams motion simulation of wheel hub

Adams hub motion simulation model is constructed according to the constraints of Workbench transient dynamic impact load. STEP motion function equation is written according to the transient dynamic impact load and fatigue S-N curve. The hub motion simulation model is shown in Figure 11, and the STEP function of impact load is shown in Figure 12. STEP function of hub movement is shown in Figure 13.

According to sensitivity diagram, transient mechanics analysis results and fatigue safety factor diagram, Marker point 20 and Marker point 21 are respectively set at hub flange and hub brake disc bolt hole to start simulation. Figure 14 shows the point motion curve of Marker
Figure 14: Point movement curve of Marker

According to the simulation motion diagram, the motion displacement at the hub flange remains unchanged under impact load.

4. Hub topology optimization

According to the Kringing model diagram, hub sensitivity diagram, transient mechanical analysis, fatigue analysis and simulation motion curve, the hub can be determined and the hub topology can be optimized in the region. The hub topology optimization diagram is shown in Figure 15.

The topology hub needs to be post-processed by SpaceClaim to repair the hub model. The new 3d hub model is shown in Figure 16.

Figure 15: Hub topology optimization diagram
Figure 16: New hub model diagram

5. Static check

The new hub is checked statically to see if it meets its original strength and stiffness. The equivalent stress is shown in Figure 17 under static conditions, Figure 18 under motion conditions, and Figure 19 under impact load conditions.

Figure 17: Hub calibration under static state
Figure 18: Hub calibration under motion
The new wheel hub was checked under three conditions, and there was no large deformation or stress concentration. Shape optimization succeeded.

6. Summary

In this paper, the Kriging mathematical model is constructed with the main dimension parameters of the wheel as the basic quantity, the load under three conditions as the independent variable, and the maximum stress and deformation as the dependent variables. The sensitivity diagram of wheel hub size parameters is obtained based on CCD algorithm, and the optimized region of wheel hub can be obtained quickly according to the sensitivity diagram.

Compared with the traditional idea of static analysis in three cases and then one by one verification, the Construction of Kringing model in this paper can quickly and intuitively obtain the hub optimization region, reduce the solving times and reduce the error. Finally, topology optimization was carried out according to the hub optimizable region, and then SpaceClaim post-processing was carried out to repair the model. The static calibration of the new model shows no large deformation and stress concentration. Hub lightweight design is successful. Original wheel weight 30kg new wheel weight 25kg reduced by 16%.

References

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