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Finite Element Analysis and Optimization Design of Automobile Exhaust Pipe Lifting Lugs

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Abstract: Taking the lifting lug of the automobile exhaust pipe as the research object, the geometric modeling of the lifting lug of the automobile exhaust pipe was established. The lifting lug was analyzed by finite element method using Ansys software, and the lifting lug structure was optimized according to the topology optimization method. The 20% area of the lifting lug model was taken as the optimization area, and the new lifting lug model was established for verification. The verification results showed that the maximum stress and maximum deformation of the optimized lifting lug were increased to some extent. However, it still meets the requirements for lifting lug materials.

1. Introduction

With the rapid development of the automotive industry, the related structure of automobiles has become a research focus[1,2]. Automotive component optimization refers to the improvement and optimization of various components of a car to improve its performance, safety, reliability, and economy. The automobile exhaust pipe lifting eye is a structural component used to support and fix the exhaust pipe, and is one of the important components that affect the performance of the car[3]. Its main function is to support and fix the exhaust pipe during vehicle operation to prevent vibration or collision with other vehicle components. Therefore, the lifting eye needs to have sufficient strength and stiffness to maintain the position and function of the exhaust pipe. Therefore, research and optimization of automotive related components are essential[4,5].

By optimizing the design of automotive components, the use of materials can be reduced, and the performance and reliability of the parts can be improved. With the rapid maturity of topology optimization method, topology optimization design has been widely promoted and applied in the automotive field[6]. It can lightweight design the body and auto parts, improve vehicle performance, reduce weight, improve safety and enhance the sense of riding experience. Topology optimization method provides a new design idea, which can optimize the vehicle to the maximum extent on the premise of ensuring the strength and functional requirements of the vehicle[7,8].

In this study, the lifting lug of the automobile exhaust pipe is taken as the research object, and the lifting lug of the automobile exhaust pipe is optimized according to the topology optimization method. On the premise of ensuring the strength and stiffness of the material, the lifting lug mass is optimized by 20%.

2. Car exhaust pipe lifting lug model

2.1 Finite Element Analysis Theory

Finite Element Analysis (FEA) is an engineering numerical analysis method used to solve mechanical problems in continuous media. It divides a complex structure into many small discrete elements, and then uses mathematical modeling to solve the mechanical response and behavior of the entire structure using numerical calculation methods.

The basic principle of finite element analysis is to use differential equations and variational principles to transform the continuity problem of actual structures into a discrete algebraic problem. By dividing the structure into a finite number of elements and approximately describing the distribution of displacement and stress in each element, discrete algebraic equation can be established. This system of equations can be solved numerically to obtain relevant information such as stress, displacement, and deformation of the structure.

The steps of finite element analysis include: establishing a finite element model, which discretizes the structure into a finite number of elements; Establish the constitutive relationship of the element, that is, define the stiffness matrix and load vector of the element; Assembling units, that is, combining the stiffness matrix and load vector of all units into the stiffness matrix and load vector of the entire structure; Apply boundary conditions, which define the boundary conditions of the structure, such as support and loading conditions; The algebraic equation are solved, that is, the response of the structure is obtained through numerical calculation.

Finite element analysis is widely used in the engineering field and can be used to solve problems such as structural strength, stiffness, vibration, and heat conduction. It can accurately predict the behavior of structures, optimize design, and improve engineering efficiency and safety.

2.2 Lifting Lug Grid Model

In finite element models, mesh partitioning is the process of dividing continuous objects or structures into discrete finite element elements. These finite element elements constitute the discretization representation of the whole model, which makes it possible to carry out numerical calculation and analysis.

The goal of grid partitioning is to divide the model into units that are small enough and simple in shape to accurately approximate the original geometric shape and physical behavior.

Establish a geometric model of the automotive exhaust pipe lifting lug using 3D modeling software, and then import the lifting lug model into Ansys. The material is made of Q235 steel, with an elastic modulus of 210 GPa, shear modulus of 80 GPa, Poisson's ratio of 0.3, density of 7850 kg/m3, tensile strength of 375 MPa, and yield strength of 235 MPa. Select an automated partitioning method for grid partitioning, set the grid size to 2mm, and the partitioned grid model is shown in Figure 1.

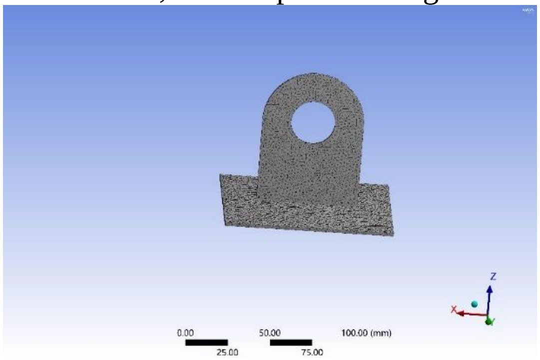

Figure 1: Lifting Lug Grid Model

3. Finite Element Analysis of Lifting Lugs

Strength and stiffness analysis is of great necessity in the field of engineering, for the following reasons:

(1) Safety assurance: Strength and stiffness analysis is used to evaluate the ability of a structure to withstand external loads. By analyzing the strength of the structure, it can be determined whether it is strong enough to safely withstand the design load without damage or failure. This helps to ensure the safety of engineering design and prevent accidents and damage.

(2) Optimization design: Stiffness analysis is used to evaluate the stiffness and deformation of a structure under external loads. By analyzing the stiffness of the structure, the degree of deformation under working conditions and whether it meets design requirements can be understood. Stiffness analysis can help engineers optimize design, making structures more stable, rigid, and cost-effective.

(3) Material selection and design verification: Strength and stiffness analysis can be used to select suitable materials and verify their performance. By simulating and analyzing the combinations of different materials and sizes, the optimal design scheme can be determined to meet the expected strength and stiffness requirements. This helps to ensure the adaptability of materials and the effectiveness of design.

(4) Fault analysis and prediction: Strength and stiffness analysis can be used for fault analysis and prediction. By analyzing the strength and stiffness characteristics of the structure, potential problem areas and fatigue life can be identified, and corresponding measures can be taken, such as increasing support, strengthening materials, or adjusting design to prevent failures and extend service life.

(5) Cost and resource savings: By conducting strength and stiffness analysis, potential problems can be identified early and failures and damages can be avoided in practical applications. This helps to reduce the cost of maintenance and replacement, and saves resources and time.

Based on the actual working situation of the lifting lug of the automobile exhaust pipe, load and boundary conditions are applied to the lifting lug to analyze its maximum stress and maximum deformation. The analysis results are shown in Figure 2 and Figure 3.

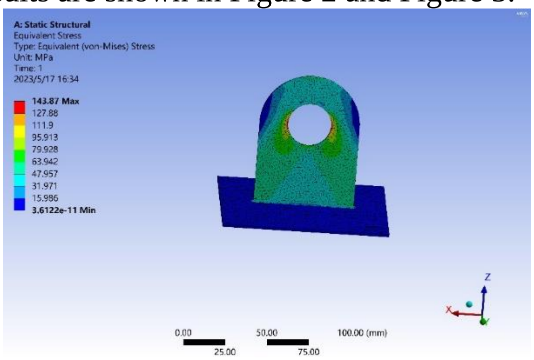

Figure 2: Maximum stress of lifting lug

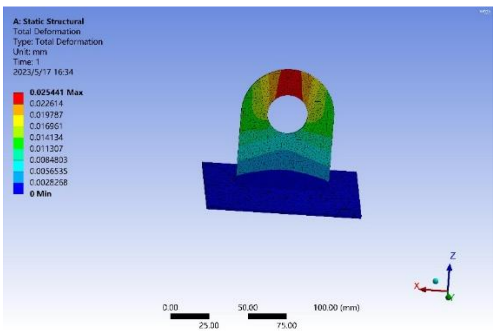

Figure 3: Maximum deformation of lifting lug

According to the analysis results, it can be seen that the lifting lug of the automobile exhaust pipe is subjected to a maximum stress of 143.87MPa and a maximum deformation of 0.025mm in the actual process, which meets the strength and stiffness requirements of the material and also has some optimization space.

4. Topology optimization design

4.1 Common optimization methods for automotive components

The structural optimization methods for automotive components include the following aspects:

(1) Structural analysis and simulation: Designers can use computer-aided engineering (CAE) technology for structural analysis and simulation of components, including finite element analysis, fatigue analysis, modal analysis. And the potential weaknesses are identified by simulating and evaluating the component's force distribution, stress distribution, and deformation.

(2) Material selection and optimization: The designers need to consider the performance requirements of the materials while selecting appropriate materials, such as strength, stiffness, toughness, wear resistance, and corrosion resistance. Then, based on different application scenarios, the combination and proportion of materials are optimized to meet the performance requirements of the components.

(3) Structural topology optimization: Structure optimization algorithm is used to optimize the shape and structure of the parts. Topology optimization can change the internal structure layout of components to minimize stress concentration, reduce weight and improve stiffness. Common methods include topology optimization, density optimization and shape optimization.

(4) Material distribution optimization: By changing the distribution of materials in components, the optimization of load paths is achieved. For example, using methods such as material reinforcement ribs or local material thickening to improve the strength and stiffness of components and reduce the use of materials in other parts.

(5) Optimization of vibration reduction and noise resistance: In components involving vibration and noise control, the damping and anti-noise properties of the structure need to be considered. The vibration and noise levels of components and vehicles can be reduced by using appropriate structural shock absorbing materials, sound insulating materials and structural shock absorbing measures.

(6) Multi physical field coupling optimization: Conduct multi physical field coupling analysis and optimization for components involving multiple physical fields, such as heat conduction, electromagnetic field, fluid flow, etc. By comprehensively considering the interaction of multiple physical fields, comprehensive optimization of component performance is achieved.

(7) 3D printing and additive manufacturing: 3D printing and additive manufacturing technologies are being applied to enable personalized design and optimized manufacturing of parts. By optimizing design and manufacturing processes, more complex structures can be achieved and assembly connections of components can be reduced, improving overall performance and production efficiency.

These methods can improve the strength, stiffness, durability, and weight of automotive components through structural analysis and optimization.

4.2 Topology optimization theory

Topology optimization theory is a method used to optimize structural design. Its goal is to minimize the weight or cost of the structure by adjusting the shape, position, or connection of materials, while meeting given constraints.

In topology optimization, the structure is represented as a topology graph composed of nodes and edges. Nodes represent the position of materials, while edges represent the connections between materials. By adding or removing nodes and edges on the topology map, the shape and connection of the structure can be changed.

The basic principle of topology optimization is to constantly update the nodes and edges in the topology graph through iteration to find the optimal structure. Common optimization algorithms include topology optimization algorithm, genetic algorithm, simulated annealing algorithm, etc.

Topology optimization theory is widely used in engineering field, which can be used to design lightweight mechanical structure, optimize material distribution, improve the channel shape of fluid flow, etc. Through topology optimization, structural optimization design can be realized, material utilization and performance can be improved, and cost and energy consumption can be reduced.

4.3 Topology optimization results

In the process of topology optimization, the lifting lug base is selected as the reserved area, and the upper part of the base is the optimized area. 80% of the lifting lug mass is reserved, and 20% of it is set as the optimized space. The results after topology optimization are shown in Figure 4.

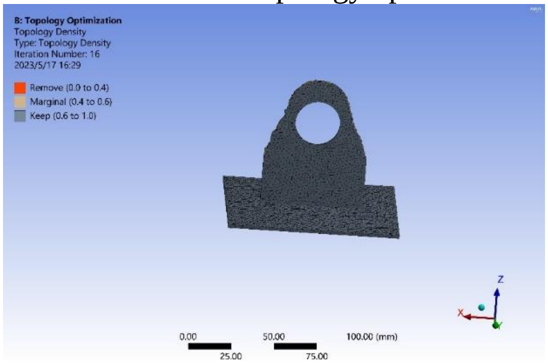

Figure 4: Topology optimization Results

5. Validation of optimization results

Reestablish the model after topology optimization, and import the reestablished model into Ansys for analysis. The analysis results are shown in Figures 5 and 6. Although the maximum stress and maximum deformation of the optimized lifting lug have increased to a certain extent, they are far less than the minimum requirements of the material and can still meet the normal working requirements.

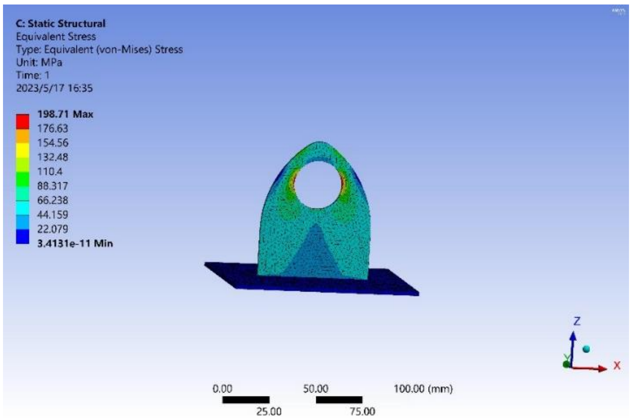

Figure 5: Maximum stress of optimized lifting lug

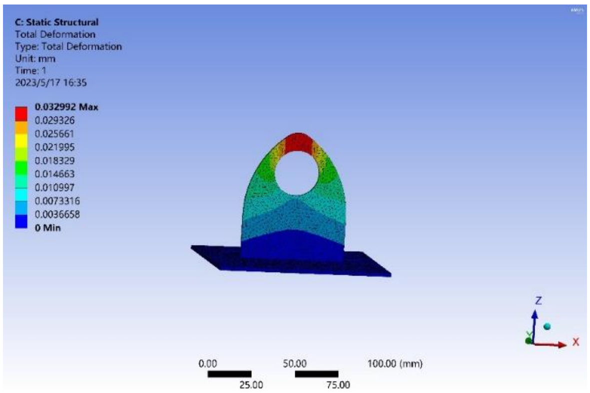

Figure 6: Maximum deformation of the optimized lifting lug

6. Conclusion

In this paper, the lifting lug of automobile exhaust pipe is taken as the research object, and the modeling is carried out according to the actual lifting lug model. The maximum stress and deformation of the lifting lug in the working process are analyzed by Ansys. The results show that the lifting lug has a large optimization space. The topology optimization method is used to optimize the lifting lug, and the optimized lifting lug is re modeled, and then analyzed. The analysis results show that the strength and stiffness requirements of the lifting lug are met.

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