Lightweight design of brake callipers based on OSF response surface algorithm

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Abstract: In this paper, ANSYS Workbench software is used to establish the brake caliper finite element model, finite element analysis of the model. Under the premise of satisfying the strength, stiffness and stability of the caliper model, Workbench DesignXplorer module was used to optimize the caliper parts' dimensions, and a two-level response surface model was constructed based on OSF algorithm. The caliper mass was taken as the main output parameter, and the lightweight design was carried out through MOGA multi-objective optimization. In terms of material lightweight, new vermicular cast iron was selected to replace QT450, QT600 and Q235 materials. After lightweight design, the yield strength and tension and compression strength of calipers were satisfied, and the mass was reduced by 15.4%

1. Introduction
Brake caliper is an important part of automotive active safety system. Lightweight brake calipers can reduce the weight of the suspension system improve the power of the car improve the fuel economy of the car.[1]

Brake caliper is mainly composed of three parts: main caliper body, vice caliper body and bracket. [2] The main material of the traditional pliers body and vice pliers body is ductile cast iron, and the bracket is 235 steel. Replacing lightweight materials is a common approach to lightweight design. Vermicular cast iron not only has the strength, rigidity and toughness of nodular cast iron, but also has good wear resistance.[3]

In this paper, ductile iron brake calipers as the research object. Mechanical analysis was carried out by replacing vermicular cast iron. The response surface model was built based on OSF algorithm for optimization and according to the optimal solution the size was optimized.

2. Caliper model establishment
This paper studies the floating caliper, which is characterized by only the main caliper body has a brake piston. When the piston pushes the friction plate to contact the brake disc, the vice caliper body moves under its reaction force, and the friction plate and vice caliper body form a clamping state of the brake disc to complete the braking. [4] Its overall structure is shown in figure 1, and its explosion diagram is shown in figure 2.
3. Force analysis of brake calipers

Brake caliper braking is driven by the force of tangential motion of brake pad generated by compressed gas of brake sub-pump, thus driving tangential motion of main and deputy caliper body to complete braking. The brake air chamber parameters are shown in figure 3.

\[ M = F \times R_e \times K_t \times i \times \eta \]

**M**: braking moment  
**F**: strong spring thrust  
**R_e**: push rod effective stroke  
**K_t**: braking efficiency factor  
**i**: transmission ratio  
**\eta**: efficiency

Being put into the formula, the maximum braking moment \( M \) was 2608.32 (N\*m). According to the pressure formula \( P = F/S \), the effective acting area of the push rod is about 0.094 (m²) put in the braking force and the acting area, and the pressure is about 504510.6Pa.

4. Finite element analysis of brake caliper

The material of the traditional main forceps body, auxiliary forceps body and bracket is QT450、QT600 and Q235. Its physical and mechanical properties at room temperature are shown in Table 1.

| The name of the material | Density (kg/m³) | Young's modulus (MPa) | Poisson's ratio |
|--------------------------|----------------|----------------------|----------------|
| QT450                    | 7100           | 1.69x10^5            | 0.275          |
| QT600                    | 7200           | 1.74x10^5            | 0.275          |
| Q235                     | 7830           | 2.1x10^5             | 0.274          |

4.1 The clamp body

According to table 1 to provide data to define QT450 material parameters. QT450 main forceps body weight is 9.4kg.

According to the working principle of caliper, the four bolt holes play a fixed role. The bolt pretightening force is 25000N, the maximum thrust of the push rod is 47424, acting force and reaction force, and the main clamp body cavity is also subjected to 47424N thrust. The boundary constraint figure of the main clamp body is shown in figure 4. The stress and deformation clouds are shown in figure 5 and figure 6.
As shown in the figure above, the maximum deformation in the inner cavity is 0.06mm and the maximum stress is 140.67MPa.

4.2 bracket
The steel bracket of Q235 weighs 15kg. The three-dimensional picture of the bracket is shown in figure 7.

Bolt hole 3 was subjected to a pretightening force of 25KN, The effective area of bracket guide1 and 2 is circular, according to the annular area formula $S_1=\pi(R_1^2-R_2^2)$, $R_1=19$mm, $R_2=13.5$mm $S_1=951.3$mm$^2$, $F=47424$N $P=F/S$, calculated $P_1=49.86$MPa. $S_2=1457.16$mm$^2$, $P_2=32.54$MPa. Bracket constraint diagram is shown in figure 8.

It can be seen from figure 9 that the maximum stress is 1067.6MPa, because the position of cross section mutation belongs to stress concentration, and the stress concentration factor $K=\frac{\text{Max}}{\sigma}$, when $1<K<3$ for plastic materials, it is necessary to reconsider the applied load size. After calculation of the bracket $K>3$. Belongs to stress singularity. As shown in figure 10, the maximum deformation is at the support, which is 1.406mm.
4.3 The Vice Clamp Body

The weight of the vice pliers made of QT600 material is 12.4kg. The three-dimensional vice pliers
body is shown in Figure 11, and the constraint boundary of the vice pliers body is shown in Figure 12.
The stress cloud diagram of the vice pliers body is shown in Figure 13, and the deformation cloud diagram
is shown in Figure 14.

5. Lightweight Design of Brake Caliper

5.1 Lightweight Design of the Main Clamp Body

The main clamp body of QT450 material is replaced by RuT420 material, and the main dimension
parameters of the main clamp body are parameterized by using Workbench Geometry for static
analysis. The constraint load conditions are unchanged, and the main parameters are taken as output
variables. According to Workbench Optimal Space-filling algorithm, a new experimental design table
was constructed as an optimization fitting point.

A response surface model was constructed, and the response surface model of the main forceps
body was shown in Figure 15. On this basis, the model of the master clamp body was optimized and
MOGA multi-objective optimization method was selected. Three objective quantities of minimum
mass, minimum deformation and maximum stress were taken as output parameters. The MOGA
optimization method screened the fitting points constructed by OSF algorithm to obtain the optimal
candidate points. The comparison between the candidate points of the master clamp body optimization
and the original points was shown in figure 16

Figure 15 Response surface model of the main forceps body
The response surface model is smooth, indicating that the experimental points fit well.
Compared with the original data, the data of candidate point 1 was selected as the optimized size of the master pliers. After optimization, the weight of the RuT420 main pliers was 8.3kg, which was 11% lower than that of the QT450 main pliers

Figure 16 Comparison of primary forceps candidate points and original points
Compared with the original data, the data of candidate point 1 was selected as the optimized size of the master pliers. After optimization, the weight of the RuT420 main pliers was 8.3kg, which was 11% lower than that of the QT450 main pliers

5.2 Lightweight design of vice clamp
The material of the vice pliers was replaced by the QT600 material with the RuT450 material. After the major dimension parameters of the vice pliers were parameterized, the OSF algorithm was used to construct a new experimental design table as the optimization fitting point, and a second-level response surface model was constructed. The response surface model was shown in Figure 17.

Figure 17 Response surface model of vice forceps body
The minimum deformation, maximum force and minimum mass were taken as the output variables and the multi-objective MOGA algorithm was used to optimize the design. The optimal candidate point diagram of the vice clamp body was shown in figure 18.
According to the optimization results, candidate point 1 data was selected as the optimization size of vice pliers. After optimization, the weight of RuT450 vice pliers was 10.38kg, which was 16% lower than that of QT600 vice pliers.

5.3 Lightweight design of bracket
The Q235 material bracket replaces the RuT450 material. Adaptive multiple-objective algorithm was used to optimize the design directly. Bracket candidate point diagram is shown in figure 19.

According to Figure 19, candidate point 3 is taken as the optimization parameter. After optimization, the weight of RuT450 bracket is 12.6kg, which is 16% lower than that of Q235 material bracket.

6. Summary
In this paper, the stress distribution and deformation distribution of the transmission brake caliper are obtained by statics analysis, and the size is optimized according to the analysis results. The lightweight design scheme of caliper adopts the combination of material lightweight and size optimization. A new type of vermicular graphite cast iron was used as light material for mechanical analysis.

AWE DesignXplorer module was used to iterate the input and output parameters of each part of the optimized caliper. When the objective function of this cycle reaches the optimum, the optimization cycle is completed. The optimum results were used as the new caliper size parameters to model the caliper lightweight design.

The final result satisfies the yield strength and tension and compression strength of each material, and the total weight of calipers is reduced by 15.4% after lightweight design.

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