Research on Hub Lightweight Based on Lightweight Materials

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Abstract. Taking the hub of a certain vehicle as the research object, according to the actual operation conditions of the hub, the stress analysis of the hub is carried out to obtain the stress of the hub, which provides a reference for the lightweight design of the hub. The wheel hubs of structural steel, magnesium alloy and aluminium alloy are loaded and restrained respectively, and the displacement nephogram, stress nephogram and modal analysis diagram of the three materials are obtained. The results show that the three materials meet the requirements of stiffness and strength. Aluminum alloy is the best choice in terms of weight reduction effect and price.

Keywords: Hub, Lightweight, Materials.

1. Introduction

In recent years, environmental problems such as energy security, energy saving and emission reduction have gradually attracted public attention. Environmental protection in the automobile industry has become a hot project for every country to actively invest in production and research. The overall weight loss of automobiles can not only save energy and reduce consumption, but also improve the safety performance of automobiles. According to some data, every 1% weight loss, 2% fuel saving and less burning of 1L fuel will reduce the emission of 215g CO\(_2\)[1].

Table 1. Hub parameters.

| Tire Specification | Diameter(mm) | Width(mm) | Hub spacing(mm) | Central hole spacing(mm) |
|--------------------|--------------|-----------|-----------------|--------------------------|
| 245/35ZR18         | 641          | 283       | 112             | 66.5                     |

There are generally two ways to lighten steel, one is to replace steel with various lightweight materials, such as carbon fiber composites, magnesium alloys, aluminum alloys, and the other is to optimize and improve structures such as miniaturization and hollowing[2].

Wheels in operation need to bear various dynamic pressures, torques and irregular alternating stresses. Therefore, the quality and reliability of wheels are related to the maneuverability, smooth operation and safety of vehicles [3]. Common steel hub has single structure, low cost and is not easy to cause fatigue damage. With the improvement of manufacturing technology and the decrease of material price, in recent years, a large number of light materials, such as magnesium alloy, aluminum alloy, composite
materials, have been used in automobile hub. These light materials have improved the drawbacks of high resistance and high fuel consumption of steel hub to a certain extent.

2. Mechanical Analysis of Hubs
A wheel hub is taken as the research object. The material is structural steel. The hub parameters are shown in Table 1.

According to the wheel hub load requirement of Passenger Car Wheel Performance Requirements and Test Method (GB/T5334-2005), the formula for calculating wheel radial load is as follows:

\[ F_r = F_c \cdot K \]  

\[ F_c = \frac{M \cdot g}{n} \]

where \( F_r \) is the maximum rated load of the hub, \( K \) is the coefficient of intensification experiment, and the value is 2.25.

\( n \) is the number of automobile wheels, this car has four; \( M \) is the quality of automobile, 1655 kg is taken. Through calculation, the maximum rated load of hub is 4054.8N, and the radial load of hub is 9123.2N.

In practice, the formula for calculating the bending load on the hub is as follows:

\[ M = (R \cdot \mu + d) \cdot F_c \cdot S \]

\( \mu \) is friction coefficient, taking 0.7; \( R \) is the radius of the wheel. The radius of the hub in this paper is 18 inches, that is 0.4572 m; \( F_c \) is the maximum rated load of the hub, taking 4054.8N; \( d \) is the offset distance of the hub, taking 0.02m; \( S \) is the strengthening factor of bending load, taking 1.6.

From the above formula, the bending moment is \( M = 2206N \).

2.1. Traditional Hood Structure
Under actual working conditions, hub bearings are fixed by threaded holes and bolts, so the six degrees of freedom of bolt holes on hub are restricted. Combining with the actual operation condition of the hub, the load is applied.

Table 2. Frequency comparison of hub with external excitation.

| Frequency value(Hz) | Hub restraint mode | Tire excitation | Drive excitation | Pavement Motivation |
|--------------------|--------------------|----------------|------------------|---------------------|
| 123.8-602.39       | 283                | 69.687         | 94.333           |

From the displacement nephogram of Figure 1, it can be seen that the displacement of structural steel hub is 0.096466 mm under the loading condition, and within the required range, it meets the requirement of structural stability. From the stress nephogram of Figure 2, it can be seen that the stress distribution of rim and spoke of structural steel hub under the loading and restraint conditions. In addition, the maximum stress of the hub appears near the hub center of the wheel spoke. The maximum stress value is 39.889 MPa, which is the most dangerous position on the hub. The stress of the hub is far less than the yield strength of the material. The structural steel hub meets the strength requirements. The following lightweight design should focus on the maximum stress location.

2.2. Modal Analysis
In the course of driving, automobiles are mainly stimulated by unbalanced wheels, transmission shafts and road surface, etc.

The tire excitation frequency is 11.614 Hz, the transmission shaft excitation frequency is 69.687 Hz and the external excitation frequency is 94.333 Hz with the vehicle speed of 120 km/h and the main deceleration ratio of 6. The constrained modes are smaller than those of the hub, as shown in Table 2.
3. Mechanical Analysis and Modal Analysis of Light Material Hubs

3.1. Magnesium Alloy Hub

Magnesium alloys have the characteristics of low density, high strength, large elastic modulus, good heat dissipation, good shock absorption, good technological performance, high impact load bearing capacity, and good corrosion resistance to organic matter and alkali. AM60B magnesium alloy is used in this paper. The material properties are shown in Table 3.

| Material | Density (g/cm³) | Modulus of elasticity (N/m²) | Tensile strength (MPa) | Poisson ratio |
|----------|----------------|-----------------------------|-----------------------|--------------|
| AM60B    | 1.76           | 11,614                      | 69.687                | 94.333       |

From the displacement nephogram of Figure 3, it can be seen that the displacement of magnesium alloy hub is 0.44148 mm under the loading and restraint conditions, and within the required range, it meets the requirements of structural stability. From the stress nephogram of Figure 4, it can be seen that the stress distribution of magnesium alloy hub under the same loading and restraint conditions as that of structural steel hub. According to the layout, the maximum stress of the hub appears near the bolt hole on the spoke of the wheel. The maximum stress value is 39.738 MPa, which is the most dangerous position on the hub. The stress is far less than the yield strength of the material and the maximum stress value of the structural steel hub, which meets the rigidity and strength requirements of the vehicle type to the hub.
The first ten restraint modes of magnesium alloys are between 123.8 and 602.39 Hz, which are larger than unbalanced excitation of wheels, driving shaft excitation and road excitation, so they meet the application requirements.

According to Figure 5, the maximum displacement of aluminium alloy is 0.28802 mm, which is less than 1 mm and meets the requirements. From Figure 6, it can be seen that the maximum stress position of the aluminum alloy hub is near the bolt hole in the hub center, and the maximum stress value is 39.8 MPa. This position is the most vulnerable position of the hub after loading, which is prone to fracture. The stress value is less than the yield strength of the material and meets the stiffness requirement of the hub.

The first ten restraint modes of Aluminum alloy are between 121.73 and 592.26 Hz, which are larger than unbalanced excitation of wheels, driving shaft excitation and road excitation, so they meet the application requirements.

### Table 4. Material properties of 6061 aluminum alloy.

| Material  | Density (g/cm³) | Modulus of elasticity (N/m²) | Tensile strength (MPa) | Poisson ratio |
|-----------|----------------|-----------------------------|-----------------------|--------------|
| AM60B     | 1.76           | 11.614                      | 69.687                | 94.333       |
4. Lightweight comparison of lightweight materials

4.1. Stiffness and Strength Comparison

Through the static analysis of structural steel, aluminium alloy and magnesium alloy hub, it can be seen from the stress diagram that under the action of static load and bending moment, the overall structure of the hub (including rim and spoke) will undergo different degrees of deformation, and the hub of different materials will exert the same restraint and static load. Similar deformation will occur to a certain extent under load, but the magnitude of deformation will be different. The maximum stress value of wheels under load is closely related to the overall stiffness of rims and spokes in the hub. By comparing the maximum stress value and yield strength of each material, the hub of different materials is analyzed. Stiffness and strength, as shown in Table 5.

| Material   | Yield strength (MPa) | Tensile strength (MPa) | Maximum stress (MPa) | Maximum displacement (mm) |
|------------|----------------------|------------------------|----------------------|----------------------------|
| structural steel | 420                  | 715                    | 39.889               | 0.096466                   |
| AM60B      | 130                  | 240                    | 39.738               | 0.44148                    |
| 6061       | 240                  | 290                    | 39.8                 | 0.28802                    |

Table 6. Comparison of weight reduction effect of hubs.

| Material   | Density (g/cm³) | Hub single weight (Kg) | Hub total weight (Kg) | Weight loss effect (Kg) | Weight loss ratio |
|------------|-----------------|------------------------|-----------------------|-------------------------|------------------|
| structural steel | 7.8             | 13.43                  | 67.15                 | -                       | -                |
| AM60B      | 1.76            | 7.75                   | 38.75                 | 28.4                    | 42.29%           |
| 6061       | 2.7             | 10.06                  | 50.3                  | 16.85                   | 25.09%           |

Table 7. Material price comparison.

| Material   | Density (g/cm³) | Hub single weight (Kg) | Hub total weight (Kg) | Weight loss effect (Kg) |
|------------|-----------------|------------------------|-----------------------|-------------------------|
| structural steel | 7.8             | 19                     | 2                     | 21                      |
| AM60B      | 1.76            | 400                    | 23                    | 423                     |
| 6061       | 2.7             | 20                     | 1.56                  | 21.56                   |

4.2. Stiffness and Strength Comparison

Table 6 shows that the weight loss of single magnesium alloy hub is 5.68 kg, the weight loss ratio reaches 42.29%, the weight loss ratio of single aluminum alloy hub is 3.37 kg, and the weight loss ratio reaches 25.09%. Therefore, the quality of the whole vehicle will be reduced. The vehicle can achieve the requirements of lightweight and achieve the goal of weight reduction.

4.3. Economic comparison

Through the above experimental results, it can be shown that the use of lightweight materials can not only meet the stiffness and strength requirements of vehicle components, but also realize the lightweight of the vehicle and improve the safety factor. In addition to material properties, a kind of material has important reference value for its economic performance. According to the formula:

\[ P = p \cdot m + c \]  

Among them: p is the unit price of materials; m is material quality; c is Manual hours; P is the total cost [4].

The price comparison of the total cost of three materials per unit quality is shown in Table 7.

According to the price list, it is obvious that the price of magnesium alloys is far higher than that of the other two materials, whether in terms of material price or labor cost. Considering the economy, magnesium alloys have limited application in automobiles due to their high price and complex manufacturing process, while structural steels and aluminum alloys have limited application scope. The
price and cost of this kind of material is relatively moderate, and it is widely used in automobiles. When choosing materials, the excellent material performance is one aspect, but its economic performance is also a key consideration.

5. Conclusion
In terms of stiffness and strength of wheel hub, the three materials meet the requirements, and the materials do not give full play to the material properties and mechanical properties, so they have great development space. According to the weight reduction effect, the weight reduction ratio of magnesium alloy and aluminum alloy is as high as 42.29% and 25.09%. Especially magnesium alloy, in terms of vehicle lightweight, is comparable. Obvious results, but the current market of magnesium alloys is expensive, complex processing technology, low recycling value and other shortcomings limit the application of magnesium alloys in the automotive market, some of the more high-end cars will use this material. Aluminum alloy is the best choice for comprehensive weight reduction effect and price. It can not only lighten the hub structure of automobile, but also reduce the cost of the whole vehicle.

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