Parameterized Structure Design of Giant-magnetostrictive Disc Brake

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Abstract. Brake is one of the important components of automobile braking system. The speed, safety and stability of its performance are the important evaluation indexes of automobile braking system. The existing brakes have some shortcomings in these aspects. The paper designed a new type of disc brake, which has the advantages of faster response speed, stronger reliability and simpler structure compared with traditional brake. At the same time, it provides a new idea for the design of disc brake.

1. Introduction

With the development of science and technology and people's increasing demand for quality of life, the active safety performance of automobiles is related to the life safety of passengers. As an important part of automobile braking system, the performance of automobile brakes has a great influence on the active safety of automobiles. At present, the brakes on the market are mainly disc brakes. Although it has been widely used in manufacturing, there are still some shortcomings such as complex mechanism, large size and mass, which show that there is still much room for improvement in the design and manufacture of automobile disc brakes. In the field of automobile research, it is one of the important topics in the field of automobile research to improve the design and manufacturing level of brakes through parametric design [1].

Giant-magnetostrictive material (GMM) is widely used in engineering field because of its high displacement resolution, large strain, fast response speed, large output force, high energy density, etc[2]. The paper designs a new type of magnetostrictive disc brake by adopting parametric structure design and three-dimensional solid modeling, which provides a new idea for the design and selection of brake.

2. Design and Calculation of GMM Disc Brake

2.1. Structure and working principle of GMM disc brake

Compared with the traditional hydraulic or pneumatic drive, the disc brake designed in this paper uses GMM rod as the drive source instead. Compared with the traditional drive mode, this drive mode has obvious advantages in response speed, lighter weight and simplified structure, and its structure is shown in Figure 1.
As shown in the figure, the brake comprises a giant magnetostrictive actuator 3, which is composed of an outer shell 7, a reel and coils 8, a GMM rod 9 and an end cover 10. When receiving a braking signal, the coil 8 on the reel will pass current and generate a corresponding magnetic field, and the GMM rod 9 will undergo corresponding deformation and displacement based on the magnetostrictive effect under the action of the magnetic field. The force generated by the giant-magnetostrictive rod 9 is transmitted to the transmission mechanism 6, and finally the force generated by the giant-magnetostrictive rod 9 is transmitted to the friction lining 2 and the brake disc 1 by the transmission mechanism 6, so that the brake disc and the friction lining are clamped, thereby achieving the effect of slowing down or stopping the automobile.

2.2. Design and calculation of main parameters
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2.2.1. Selection of GMM rod. NJ-X10004ZC is selected, and the vehicle parameters are shown in table 1.

| Project            | Automoble mass \(m_a\)(kg) | Front axle load \(m_1\)(kg) | The rear axle load \(m_2\)(kg) | Height of centroid \(h_g\)(mm) | wheelbase (of a vehicle) \(L\)(mm) | Tyre size       |
|--------------------|-----------------------------|-----------------------------|--------------------------------|-------------------------------|-----------------------------------|-----------------|
| be fully loaded    | 800                         | 440                         | 360                            | 560                           | 2100                              | 175/65R14       |

According to the axial load, \(a=1155\text{mm}, b=945\text{mm}\).
The full text assumes that the common road adhesion coefficient of the car is $\mu = 0.8$. The normal reaction force of the ground acting on the front and rear wheels during automobile braking is:

$$
\begin{align*}
F_{Z1} &= \frac{G(b + \varphi_s)}{L} \\
F_{Z2} &= \frac{G(a - \varphi_s)}{L}
\end{align*}
$$

(1)

It can be concluded that the normal reaction force of the ground acting on the front and rear wheels during automobile braking is:

$$
F_{z1} \approx 2600 \cdot 27 \, N \\
F_{z2} \approx 1319 \cdot 73 \, N
$$

As the ground adhesion is:

$$
\begin{align*}
F_{\varphi1} &= F_{Z1}\mu \\
F_{\varphi2} &= F_{Z2}\mu
\end{align*}
$$

Therefore, the ground adhesion is:

$$
\begin{align*}
F_{\varphi1} &= 2080.20 \, N \\
F_{\varphi2} &= 1055.78 \, N
\end{align*}
$$

Maximum ground braking force $F_{xb_{\text{max}}} = F_{\varphi} = F_{z}\varphi$. Therefore, it can be known that the maximum ground braking force of braking is:

$$
\begin{align*}
F_{xb1} &= F_{\varphi1} = 2080 \cdot 20 \, N \\
F_{xb2} &= F_{\varphi2} = 1055 \cdot 78 \, N
\end{align*}
$$

In this way, before and after braking, the required braking torque on the axle is:

$$
\begin{align*}
T_1 &= F_{xb1} \cdot r_r = 605 \cdot 3 \, N \\
T_2 &= F_{xb2} \cdot r_r = 307 \cdot 2 \, N
\end{align*}
$$

According to the above theory, the braking torque is:

$$
T' = 2 \cdot f_1 \cdot P \cdot R
$$

(2)

In the above formula, $P$ is the pressing force of the unilateral brake pad to the disc. In this paper, the friction coefficient of friction plate is preliminarily selected as $f_1 = 0.5$. $R$ is the effective radius, and its average value is $R_m = \frac{R_1 + R_2}{2}$, you can also use the effective radius value: $R_e = \frac{4}{3} \left(1 - \frac{m}{(1 + m)^2}\right) \cdot R_m$.

In this formula $m = \frac{R_1}{R_2}$. Average radius $R_m = 110 mm$, effective radius $R_e = 111.21 mm$.

Therefore, when the brake is locked, the one-side pressing force required by the lining block is:

$$
P = \frac{T_1}{2 \cdot 2 \cdot f_1 \cdot R_e \times 10^{-3}} = 2722 \, N
$$

(3)

The unilateral pressing force of the brake disc is 2722N. In order to make the force transmitted by the mechanism have a larger component force in the clamping direction, the preset included angle between the chamfering direction and the pressing force direction is 30, and the force in the chamfering direction of the reverse thrust mechanism is:

$$
F_1 = 2722 \div \cos 30^\circ = 3144 \, N
$$

By setting the hinge point of the side link at the midpoint, the force at the guide bar above the side link can be known $F_2$ and $F_1$ equal in size and symmetrical in direction with respect to the center of the hinge point of the side link. From the angle between clamping force and chamfering, we can know...
that the included angle with GMM rod push rod is 30 degrees, from which the minimum force to be output by GMM rod can be calculated:

\[ F_{\text{min}} = F_2 \div \cos 30^\circ = 3631 \text{ N} \]

The gap between brake disc and brake pad is usually selected in the range of 0.05mm to 0.15mm[3]. Here, 0.05mm is selected as the gap between them, that is, GMM pushes the displacement of linkage mechanism in the direction of clamping force, \( S_1 = 0.05 \text{ mm} \). the displacement of the linkage mechanism in the chamfering direction is:

\[ S_2 = S_1 \div \cos 30^\circ = \frac{\sqrt{3}}{30} \text{ mm} \]

It can be seen that the output displacement of GMM rod, that is, the minimum elongation length of GMM rod, is as follows:

\[ X_{\text{max}} = S_2 \div \cos 30^\circ = 0.067 \text{ mm} \]

The minimum output force of GMM rod is known now \( F_{\text{min}} = 3631 \text{ N} \), the minimum elongation \( X_{\text{max}} = 0.067 \text{ mm} \), the maximum elongation of GMM rod is related to its own length, which is determined by the formula:

\[ l_{\text{GMM}} = \frac{\Delta l_{\text{max}}}{\lambda_S} = \frac{x_{\text{max}}}{\delta \lambda_S} \quad (4) \]

In which, \( l_{\text{GMM}} \) is the GMM rod length, \( \Delta l_{\text{max}} \) is the maximum elongation (saturation elongation) of GMM rod, \( \lambda_s \) is the saturation magnetostriction rate, \( X_{\text{max}} \) is the maximum working displacement of the driver design. For mathematical factors \( \delta \), generally set in linear workspace. The larger the value, the more difficult it is to linearize.

According to the design requirements of this paper, take \( \delta = 0.7 \), \( \lambda_s = 1.6 \times 10^{-3} \), \( \sigma_0 = 6.5 \text{ MPa} \), \( X_{\text{max}} = 0.067 \text{ mm} \), available \( l_{\text{GMM}} \approx 59.82 \text{ mm} \).

The cross-sectional area of GMM rod is \( A \), the material length is \( L \), and its elastic modulus[4] is \( E_y = 5 \times 10^{10} \text{ Pa} \), then

therefore

\[ F = \frac{E_y B A}{L} \cdot x = E_y B A \varepsilon \quad (5) \]

Set the pre-pressure of GMM rod as follows \( F_0 = \sigma_0 A \), \( \sigma_0 \) is the preloading stress. When the driver does not output displacement, the maximum output force is \( F_b \), it can be launched:

\[ A \geq \frac{F_b}{E_y B \lambda_S - \sigma_0} \quad (6) \]

When the output force of the driver at the maximum working displacement is required to be \( F_{\text{min}} \),

\[ \Rightarrow A = 2.074857143 \times 10^4 \text{ m}^2 \]

\[ \Rightarrow r = 8.127 \text{ mm} \]

You can get it
\[ \phi = 20\, \text{mm} \]

Then, according to the GMM bar specifications of Gansu Tianxing Rare Earth Functional Materials Co., Ltd., considering the reliability of braking performance and setting a certain margin, combined with the standard size of manufacturers, the selection of GMM bars is determined as follows: \( l = 70\, \text{mm}, \phi = 20\, \text{mm} \).

2.2.2. Diameter and thickness of brake disc. Considering that the selected vehicle is a mini car, the disk diameter adopted in this paper is \( D_1 = 260\, \text{mm} \). The initial thickness used here is 25mm.

2.2.3. Inner diameter and outer diameter of friction plate. As the diameter \( D_1 \) of the disc is 260mm, it can be generally known that the outer diameter \( R_1 \) of the friction pad is half of \( D_1 \), that is, 130mm. Because \( R_1/r_1 \leq 1.5 \), then \( r_1 \geq 86.7\, \text{mm} \). Therefore, in this paper, the inner radius \( r_1 = 90\, \text{mm} \) and the outer radius \( R_1 = 130\, \text{mm} \) are selected.

2.2.4. Friction coefficient of friction plate. In this paper, the friction coefficient of friction plate is preliminarily selected \( f = 0.5 \).

3. Three-dimensional solid modelling of GMM disc brake

After the parameters are determined, it is necessary to carry out 3D solid modelling. Three-dimensional solid modelling helps people to know products intuitively. Compared with traditional design, it saves design cost, improves design efficiency, and facilitates later simulation and modification of products[5]. CATIA software is used for 3D modeling in this paper. CATIA software is a large-scale high-end CAD/CAE/CAM integrated application software of French dassault systems Company, which is applied in many fields such as aerospace, automobile, machinery, shipbuilding, general machinery, numerical control machining, medical equipment and electronics.

The main components and finished products of giant magnetostrictive disc brake are shown in the following figures.

![Fig. 2 Structure diagram of brake disc](image1)

![Fig. 3 Structure diagram of giant magnetostrictive actuator](image2)


Fig. 4 Schematic diagram of giant magnetostrictive disc brake structure

4. Conclusion
The purpose of this paper is to design a new type of disc brake by combining the characteristics of giant magnetostrictive materials, selecting suitable GMM bars, simplifying and improving the brake structure, which makes the brake develop towards simplification, light weight and high efficiency. The giant magnetostrictive disc brake has the advantages of simpler structure, fast response of driving source, large output stress, strong stability and easier disassembly and maintenance, and can better meet the requirements of modern transportation for automobile braking performance. It is believed that it can provide a way for the design and improvement of automobile brakes.

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