Thermal-structural Coupling Analysis of Automobile Ventilated Disk Brake

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Abstract

Taking the ventilated disc brake used by a car as the object of study, the three-dimensional model is established and properly simplified. The finite element simulation model of direct thermal structural coupling is established to determine the boundary conditions needed for analysis. Analysis of the results of its temperature field and stress field. The results show that: During the braking process, the distribution of the temperature field of the brake disc is not axisymmetrical. There are obvious temperature differences in the radial direction, circumferential direction and axial direction in the three directions. The stress field of brake disc is mainly thermal stress, and the trend of change is basically the same as that of temperature field during braking.

Keywords

Thermal-structure coupling,Temperature field,Stress field.

1. Introduction

With the rapid development of social economy, automobiles have gradually become the main means of transportation, and their output has increased year by year. The failure of the brake system accounts for 45% of the traffic accidents caused by automobiles. When a vehicle brakes, a lot of heat is produced by friction between the friction pairs of the brake, which makes the temperature of the brake disc rise rapidly. Excessive temperature will make the brake disc appear thermal fading phenomenon. At the same time, it will also lead to thermal fatigue cracks on the surface of the brake disc, thus affecting the braking performance of the vehicle. Therefore, it is necessary to study and analyze the brake in order to improve the braking performance and service life of the vehicle. Aiming at a car disc brake, a three-dimensional model with the same size as the real one is established. The influence of centrifugal force, friction disc pressure and friction shear stress on the brake disc during braking is analyzed.

2. Finite Element Method for Coupled Thermal Structure Analysis of Ventilated Disc Brake

When a car brakes, the brake disc of the disc brake and the friction disc produce a lot of friction heat, because most of the friction heat will not be emitted in a short time, so that the temperature of the brake disc and the friction disc rises sharply. The contact between the friction disc and the brake disc is periodically variable, so the contact pressure between the friction disc and the brake disc is periodically variable, making the temperature distribution of the brake disc uneven, so the temperature distribution of the brake disc uneven will cause its uneven thermal deformation, uneven thermal deformation will lead to both. The contact pressure distribution is not uniform, and the uneven contact pressure will further cause the uneven distribution of temperature field. Therefore, when the vehicle is braking, the temperature field and the stress field of the disc brake are interacted.

2.1 Heat Conduction Equation for Three Dimensional Transient Temperature Field of Ventilated Disc Brake

As shown in Fig. 1, the three-dimensional contact model diagram of the ventilated disc brake is simplified.

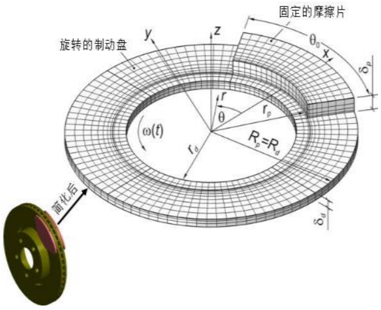


Fig. 1 Three-dimensional contact model of disc brake

Because the angular velocity of the brake disc is constantly changing during the braking process of the vehicle, in order to establish the heat conduction equation of the three-dimensional transient temperature field of the ventilated disc brake conveniently, the cylindrical coordinate system is adopted, the geometric center of the brake disc is taken as the origin of the cylindrical coordinate system, and the z axis is taken as the cylindrical coordinate system perpendicular to the friction surface of the brake disc If the radial direction is r and the circumferential direction is θ, then the three-dimensional transient temperature field of the brake disc and the friction disc can be expressed and solved by solving the following heat transfer equations and related boundary conditions:

$$K_P\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}\right)=\rho_P c_P\frac{\partial T}{\partial t} \tag{1}$$

$r_P < r < R_P, -0.5\theta_0 < \theta < 0.5\theta_0, 0 < z < \delta_P, 0 < t < t_s$

$$K_d\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}\right)=\rho_d c_d\left[\frac{\partial T}{\partial t}+\omega(t)\frac{\partial T}{\partial \theta}\right] \tag{2}$$

$r_d < r < R_d, 0 < \theta < 2\pi, -\delta_d < z < 0, 0 < t < t_s$

$$K_d\frac{\partial T}{\partial z}\Big|_{z=0^-}-K_P\frac{\partial T}{\partial z}\Big|_{z=0^+}=q(r,\theta,0,t);(r,\theta)\in\Omega, 0\le t\le t_s \tag{3}$$

2.2 Calculation of Thermal Stress of Ventilated Disc Brake

Ventilated disc brakes are subjected to tremendous friction heat flow loads when they are working, which makes the temperature of the friction pair components rise sharply. At the same time, they are subject to certain constraints, in which the friction discs have only the degree of freedom of translation along the axial direction, while the brake discs have only the degree of freedom of rotation around the rotating shaft. The thermal deformation caused by the temperature change is restricted by the two elements, resulting in the thermal stress inside them. In addition, the temperature variations of each part of the component are not the same, and this temperature difference also causes thermal stress in the component. For the brake disc, its thermal deformation can not affect the shear strain, so its initial strain caused by temperature change can be expressed as:

$$\varepsilon_0=\alpha(-T_0)[1\ \ 1\ \ 1\ \ 0\ \ 0\ \ 0] \tag{4}$$

$$\sigma=D(\varepsilon-\varepsilon_0) \tag{5}$$

3. Finite Element Model for Coupled Thermal Structure Analysis of Ventilated Disc Brake

3.1 Establishment of Finite Element Model for Ventilated Disc Brake

Before the thermal-structural coupling simulation analysis of disc brake, the following assumptions are made: the brake disc and the friction between the disc and the disc satisfy the Coulomb friction law; the pressure acting on the surface of the disc is constant and the distribution is uniform; the brake disc and the friction disc are composed of the disc and the disc. The material of friction disc is isotropic elastic material, the wear of friction disc and brake disc is not considered, the friction heat flow will be completely distributed to the brake disc and friction disc, but not absorbed by other aspects, and the influence of thermal radiation is not considered.

3.2 Finite Element Mesh Generation of Three Dimensional Model of Ventilated Disc Brake

In mesh generation, it is necessary to select the appropriate mesh size. Under the premise of guaranteeing the accuracy of solving the problem, the cost of calculation can be reduced as much as possible. Thermal-structural coupling problem is a highly nonlinear problem, which needs iteration repeatedly in the process of calculation. If the mesh is too dense, it will lead to accounting. The computation time is longer, but the accuracy of calculation results will not be greatly improved. Finally, the finite element mesh model of the ventilated disc brake is set up as shown in the figure.

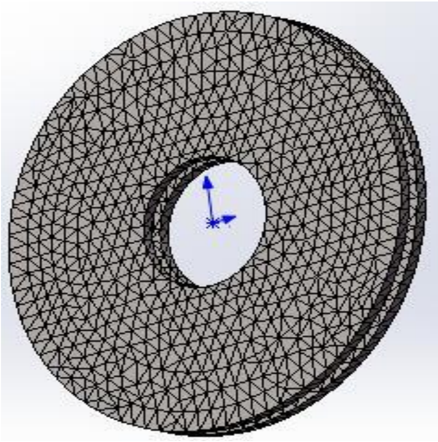
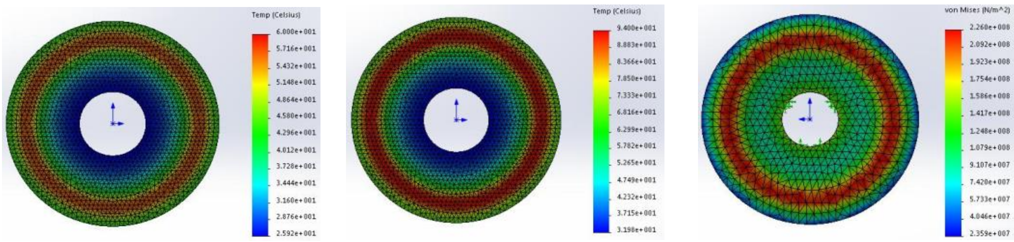


Fig. 2 Finite element mesh model of ventilated disc brake

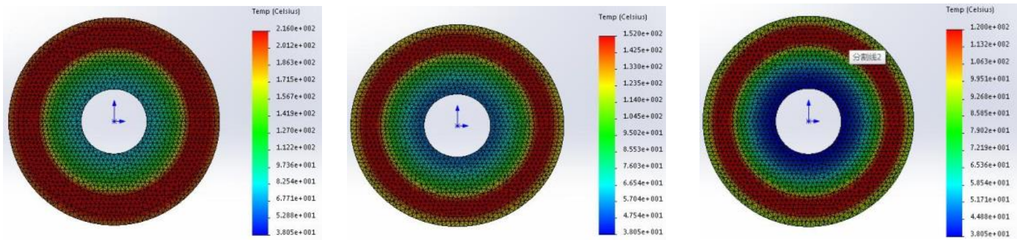
4. Thermal Structure Coupling Simulation Analysis of Ventilated Disc Brake

4.1 Distribution Characteristics of Temperature Field of Ventilated Disc Brake

According to the working principle of the ventilated disc brake, a lot of friction heat will be produced when it works, so that the temperature of the friction pair components will rise sharply, and the change of temperature will have a great impact on the braking efficiency of the brake. Therefore, it is very important to analyze the distribution and variation of temperature field when brake is used in thermal-structural coupling analysis of ventilated disc brake.



(a) t=0.2 s (b) t=0.8 s (c) t=1.2 s



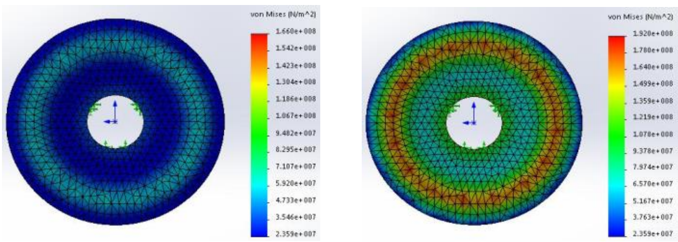
(d) t=1.8 s (e) t=2.6 s (f) t=3.4 s

Fig. 3 Distribution of temperature field of brake at different braking time

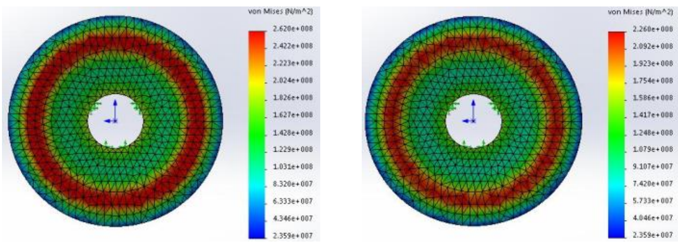
As can be seen from Figure. 3, the friction surface temperature of the brake disc increases rapidly during the initial braking period from 0 s to 0.2 s; the brake disc surface temperature increases continuously from 0.2 sto 1.2 s, but the brake disc speed increases slowly; at 1.8 s, the brake disc temperature reaches the maximum value, the maximum temperature is 216 C; at 1.8 s to 3.4 s, the brake disc temperature drops. . The temperature field of the whole brake disc is not uniform, the radial temperature difference is the largest, the maximum temperature difference can reach 128 C; with the braking process, the circumferential temperature tends to uniform distribution; because of the heat conduction and convection heat dissipation, the axial temperature of the brake disc also exists temperature difference, the maximum temperature difference can reach 96 C. The reason for the temperature difference in three directions of the brake disc is that when the ventilated disc brake is first braked, the heat generated by friction makes the temperature of the brake disc rise rapidly, while the heat transfer speed of heat conduction and the heat convection heat dissipation speed are far less than the friction heat generation speed, so the temperature distribution of the brake disc is not uniform. During braking, under the action of heat conduction and convection, the temperature field of the brake disc is gradually uniform, and the temperature difference in each direction gradually disappears; after braking, the ventilated disc brake only has the function of heat conduction and convection, so the temperature of the brake disc begins to drop, and finally the temperature is uniformly distributed, and there is no temperature difference in each direction.

4.2 Distribution Characteristics of Stress Field of Brake Disc

The change of temperature field and stress field of ventilated disc brake in braking process is a complicated process. The temperature field will be affected by many factors such as friction heat flow, convection heat transfer and heat conduction inside the brake parts. The stress field has a strong coupling characteristic with the temperature field, so it will affect the disc brake. The distribution law of stress field is studied.



(a) t=0.2 s (b) t=0.8 s



(c) t=2.6 s (d) t=3.8s

Fig. 4 Distribution of stress field of brake at different braking time

As can be seen from Fig. 4, the equivalent stress of the brake disc increases first and then decreases during the whole braking process. In the initial braking stage, the temperature of the whole brake disc is not high, and the equivalent stress is mainly caused by mechanical stress. With the braking process, the brake disc temperature rises sharply and produces huge thermal stress. At this time, the equivalent stress of the whole brake disc is mainly thermal stress, and its value is far greater than the mechanical stress. When t=2.6s, the maximum equivalent stress of the brake disc is 262MPa, while the material strength limit [σ]=400MPa of the brake disc studied in this paper, so the maximum equivalent stress is less than the material strength limit, which meets the strength requirements of the material. As the braking continues, the temperature of the brake disc begins to decrease, resulting in the equivalent stress of the brake disc also began to decrease gradually, but the internal residual thermal stress is still very high. In addition, according to the analysis of the temperature field of the brake disc, the brake disc reaches the highest temperature in the whole braking process at t=1.8s, which is mainly because the highest temperature of the brake disc usually occurs on its friction surface, and the maximum equivalent stress of the brake disc is due to the thermal deformation of the whole disc body temperature rising and being subjected to. Thermal stress due to some constraints requires more energy from the friction surface to the interior before it occurs, and heat transfer from the friction surface to the interior takes a certain time, so the maximum stress occurs slightly later than the maximum temperature occurs.

5. Conclusion

The finite element analysis software is used to simulate the thermal structure coupling of the ventilated disc brake, and the distribution characteristics of the temperature field and stress field of the brake disc under emergency braking condition are analyzed.

(1) During the whole braking process, the temperature field of the brake disc is not axisymmetrical, and there is a certain temperature gradient in the circumferential direction. Because the temperature field of the brake disc is affected by friction heat flow, convection heat transfer and heat conduction, the change trend of the overall temperature of the brake disc is that the brake disc rises rapidly in the early stage, rises slowly in the middle stage and drops slightly in the later stage.

(2) During braking, the stress of the whole brake disc is mainly thermal stress, the change of its equivalent stress is basically consistent with the change of temperature, but there is a certain lag in time, mainly because the thermal stress is due to the constraints of thermal deformation, and to produce large thermal deformation requires a lot of energy, these energies. It mainly comes from the heat transferred by the friction surface, and the heat conduction process takes a certain time, so the maximum equivalent stress of the brake disc has a time lag compared with the maximum temperature.

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