International Journal of Modern Research in Engineering and Technology (IJMRET)
www.ijmret.org Volume 4 Issue 6 ǁ June 2019.

Finite Element Analysis of Brake Heat Transfer Based on Comsol

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ABSTRACT : *Based on the heat conduction calculation of temperature field and thermo-mechanical coupling method, the transient temperature field of disc brake is simulated by COMSOL. The maximum temperature of disc brake is located at the contact surface of friction pair because the rate of heat generation by friction is obviously higher than that of material. Friction heat generation and heat dissipation rate have a direct impact on the maximum temperature. When the speed of the two approaches gradually, the brake has a transient maximum temperature. On the premise of ensuring the structural stiffness and strength of the brake disc, the axial size of the brake disc is reduced, and the maximum temperature on the surface of the brake disc is reduced by 35%.*

KEYWORDS -*heat, simulation, temperature, optimization*

I. INTRODUCTION

Locomotive is one of the most important transportation equipment in production. With the increase of the locomotive's carrying capacity and running speed, the huge heat generated during the braking process greatly reduces the braking effect and even causes braking failure [1]. In practical engineering, the analysis of brake temperature field is very critical, and it is one of the important methods to ensure locomotive working stability. Because braking is a thermo-mechanical coupling process, there are a lot of non-linear factors, so the transient analysis is more in line with the requirements of working conditions [2].

At present, domestic and foreign scholars mainly study the coupling of temperature field and stress field based on finite element method [3], including direct coupling and indirect coupling. Direct coupling is more in line with the actual situation, but due to the large amount of calculation, there are few studies involving long-term braking or multiple cycle braking. In this paper, based on COMSOL software, the transient temperature field of locomotive during long time braking is studied.

II. CALCULATION OF HEAT CONDUCTION IN TEMPERATURE FIELD

2.1 Model simplification

The friction pair of locomotive disc brake is composed of brake disc and friction disc. In the analysis of transient temperature field, there are many non-linear factors. In order to facilitate the finite element calculation, it is necessary to simplify the model and boundary conditions.

(1) It is assumed that the brake disc and friction disc are homogeneous and isotropic materials, ignoring the anisotropic properties; in the braking process, the contact plane between the brake disc and friction disc is the ideal plane, that is, the braking pressure load is uniformly distributed.

(2) The inherent properties of the friction pair material will not be changed by the friction and wear factors in the braking process [4].

(3) In the braking process, the locomotive is considered to be a uniform deceleration motion.

2.2 Heat transfer calculation

According to the conservation of energy law and Fourier's law, the heat flux vector of any point in the space can be decomposed in *Oxyz* coordinates. In infinitesimal parallelepiped, 3-D unsteady heat conduction differential equation can be expressed as Eq. (1).

$$\rho c\frac{\partial t}{\partial \tau}=\frac{\partial}{\partial x}(\lambda\frac{\partial t}{\partial x})+\frac{\partial}{\partial y}(\lambda\frac{\partial t}{\partial y})+\frac{\partial}{\partial z}(\lambda\frac{\partial t}{\partial z})+\dot{\Phi} \quad (1)$$

Where ρ, c, τ, $\dot{\Phi}$ are respectively density, specific heat, time, and heat that generated in unit time and volume. The ventilated disc has a great number of fins, which can increase the heat radiation area of the convection and radiation, improve heat transfer capability, and ensure the strength.

III. NUMERICAL SIMULATION OF TRANSIENT TEMPERATURE FIELD

3.1. Establishment of Finite Element Model

In this paper, the three-dimensional model of disc brake is established by Pro/E. The assembly drawings are saved as intermediate data format and imported into COMSOL, and the material properties are defined. The material of brake disc is HT200, and the material of friction disc is semi-metallic composite material [5]. The elastic modulus and thermal expansion coefficient of friction disc are related to temperature, and the friction coefficient of friction pair is related to pressure and temperature simultaneously.

In thermomechanical coupling calculation, mesh generation is the key. If the mesh is too rough, the error of calculation results will be large. If the mesh is too dense, the calculation time will be too long or the results will not converge. In this paper, 7640 tetrahedral elements are obtained by using the method of free meshing and local optimization for brake grids, as shown in Fig. 1.

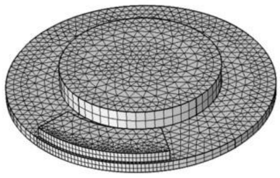

Fig.1 Meshing of brake

3.2. Load and boundary conditions

In the whole braking process, the speed variation characteristics of the electric locomotive are shown in Fig.2. The braking starts at 5S and ends at 17s. Therefore, the transient temperature analysis of the brake is set up as three analysis steps, and the total time of the analysis step is 30s. For load conditions, the speed of the locomotive is converted to the speed of the brake disc, and then applied to the brake disc as an angular speed load. The initial temperature of the brake is set at 20 ℃. The pressure of 2.5 MPa is applied to the upper surface of the friction disc at 5 s to 17 s.

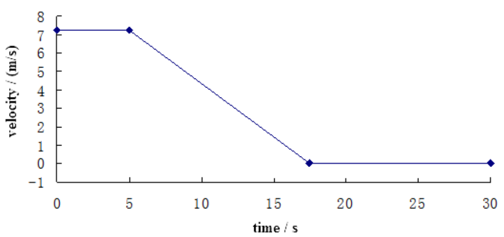

Fig.2 Velocity change curve

For the boundary condition [6], the displacement constraints on the upper surface of the friction disc only retain the axial translation, while the displacement constraints on the lower surface of the brake disc only retain the axial rotation.

3.3. Result analysis

Through the thermo-mechanical coupling calculation based on COMSOL, the transient temperature field distribution of disc brake can be obtained. The temperature distribution at 10.8s is shown in Fig.3. The highest temperature is located at the contact surface of friction pair. This is due to the fact that the heat generation rate of friction is obviously higher than the heat conduction rate of material during braking process, which makes the temperature of friction contact surface obviously higher than that of brake disc and friction disc.

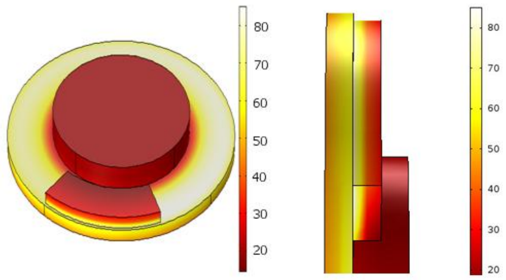

Fig.3 Transient temperature distribution at 10.8s

The results of the whole braking process show that: (1) in the 5s~7.6s stage, because the relative sliding speed between the brake disc and the friction disc is faster, the friction heat generation rate of the friction pair is far greater than the heat dissipation rate, therefore, the temperature of the friction pair rises rapidly, and the maximum temperature rises rapidly from 20 to 64 ℃, and the temperature varies approximately linearly with time. (2) During the period of 7.6s~10.8s, with the decrease of the relative velocity of the friction pair, the heat generation and heat dissipation rate of the friction pair approach gradually, reaching the maximum temperature value of 85 ℃ at 10.8s (lower than 150 ℃ stipulated in MT/T1064-2008 technical conditions). In this period, the variation trend of the maximum temperature with time approximates to a quadratic curve. (3) In the 10.8s~17s stage, the friction heat generation decreases greatly, and the instantaneous maximum temperature gradually shifts to the position near the outer diameter of the friction zone exit. The value drops to 69 ℃ at 17s, and the change of the maximum temperature with time also tends to quadratic curve. (4) After 17 seconds, the brake only dissipates heat, and the temperature decreases linearly with time.

In order to study the distribution and variation of the temperature field in the vector direction of the brake disc, according to the symmetry of the circumferential direction of the brake disc, the radial distribution of the transient temperature field of the brake disc is obtained through the post-processing module as shown in Fig. 4.

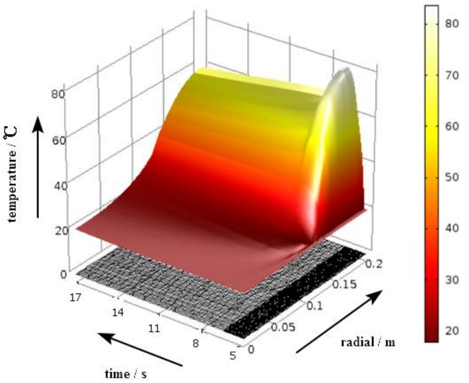

Fig.4 Distribution of radial temperature field of brake disc

In Fig.4, it can be seen that the surface temperature of the brake disc varies with the radius and braking time of the brake disc. There is no obvious temperature rise on the surface of the brake disc within 100 mm from the center of the circle. This is due to the distance between the inner diameter of the friction disc and the center of the circle. At the frictional radius, the temperature is obviously higher than that in other areas, showing a peak distribution.

IV. HEAT ANALYSIS OF FRICTION PAIRS

In order to study the heat change, brake temperature rise and recovery characteristics of the friction pair under single braking, and predict the time for the friction pair to recover the ambient temperature, this paper simulates the locomotive braking for 100 seconds, and obtains the heat generation and heat dissipation characteristic curve and the maximum temperature change curve of the brake as shown in Fig. 5 and Fig. 6, respectively.

In the 100s thermo-mechanical coupling analysis of the brake, the ambient temperature is set at 60 ℃, the locomotive starts braking at 2s, ends braking at 17s, and is a single heat conduction process of the brake at 17s-100s. As can be seen in Fig. 5, the total heat generated by friction pairs rises sharply to a certain value and then remains unchanged. At 17s, the speed of the electric locomotive is 0, and there is no relative sliding between the friction pairs. Therefore, the heat generation is no longer increased and keeps stable. Because of the temperature difference between the friction pair and the surrounding environment, the heat dissipation keeps going, even when the braking process is over, the heat dissipation will not stop.

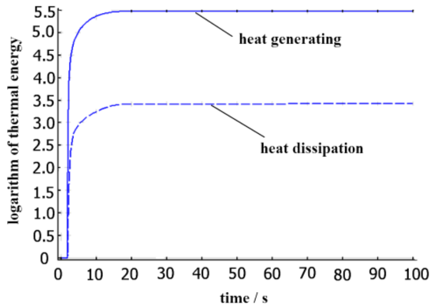

Fig.5Heat generation and heat dissipation curve

In Fig.6, it can be seen that the brake reaches the maximum temperature at 11S and the brake disc restores to the ambient temperature at 80s. According to the analysis results of Fig. 5 and Fig. 6, it takes a long time for the friction pair to recover the ambient temperature after each brake. Therefore, forced cooling devices should be added to locomotives with high heat production during braking or frequent braking.

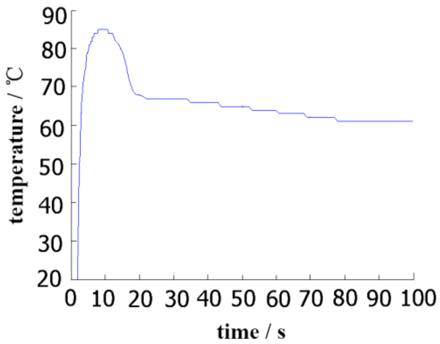

Fig.6 Maximum temperature change diagram of brake

V. STRUCTURAL OPTIMIZATION OF BRAKE DISC

Brake disc is the key component of disc brake. In the braking process, thermal fatigue and other factors lead to the reduction of braking effect [7]. Even if the friction disc is replaced, the braking effect cannot be restored. Due to the effect of temperature field, a large thermal stress occurs at the friction radius of the brake disc, which results in a large tensile stress on the bolt near the center of the circle, and a certain residual stress is maintained after braking. Thermal fatigue stress produced during braking makes the bolt connection position at the inner edge become a vulnerable part. Therefore, the structure of this position should ensure sufficient strength and toughness.

In order to reduce the maximum temperature on the surface of the brake disc and consider the structural stiffness of the brake disc comprehensively, the thickness of the brake disc is optimized, and the thickness is reduced from 15 mm to 10 mm. Under the same conditions, the numerical calculation is carried out. Finally, the maximum temperature of the brake disc surface is 55 ℃ at 12.8 s, which is 35% lower than that before optimization, as shown in Fig. 7.

To a certain extent, reducing the axial size of the brake disc can reduce the surface heat generation and temperature gradient of the friction pair on the premise of ensuring the structural stiffness and strength of the brake disc, and reduce the quality of the brake disc, making the structure of the disc brake more compact.

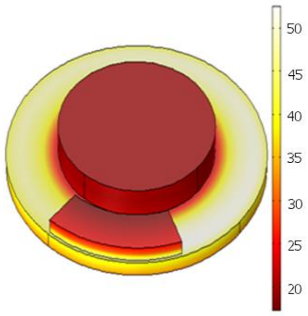

Fig.7 Transient temperature distribution at 12.8s

VI. CONCLUSION

The braking performance of locomotive disc brake will be degraded due to friction heat generation. Therefore, based on COMSOL, the thermo-mechanical coupling calculation of the brake is carried out, including the transient temperature field analysis.Then the maximum temperature and radial temperature distribution of the friction pair are obtained. Through 100s simulation of locomotive single braking process, the heat generation and heat dissipation characteristics of friction pairs can be obtained. By optimizing the axial dimension of the brake disc, the instantaneous maximum temperature of the brake can be reduced by 35%.

VII. Acknowledgements

The paper is supported by Doctoral Research Fund (2017Y22)

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