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COMPUTER SIMULATION RESEARCH AND ANALYSIS OF HEAT IN BRAKING PROCESS

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Abstract: Aiming at the problem of heat dissipation performance of disc brake, a computer simulation method is used to analyze the braking process. Taking ventilated brake disc as the research object, four geometric models of ventilated brake disc with different arrays and shapes were established. Considering typical braking conditions, the heat dissipation characteristics of ventilated brake discs were simulated by computational fluid dynamics (CFD). The influence of array mode and shape of rib heat dissipation structure on heat dissipation characteristics of ventilated brake disc is analyzed. The results show that the array mode of the rib plate heat dissipation structure in the radial ventilation duct has a great influence on the heat dissipation characteristics of the brake disc. In the ventilation duct of the triangular array ribbed heat dissipation structure, there is less air resistance, stronger turbulence, less flow separation, higher convective heat transfer coefficient and heat flux.

Keywords: computer simulation, finite element, CAE, heat transfer, brake

I. INTRODUCTION

Simply put, computer numerical simulation is to abstract a mathematical model from a real engineering problem. The finite element method is used to discretize the model and make it under proper working conditions. Then the model is handed over to the computer for simulation analysis [1, 2]. There are many advantages. One is that the cost will be greatly reduced, the speed of the second test will be greatly increased, and the modification and optimization of the test will be greatly simplified.

In the braking process, the brake disc is affected by friction heat, resulting in uneven local high temperature, namely hot spot. Hot spots usually occur in high-speed rotating conditions with low braking pressure [3]. The brake is affected by hot spots, which leads to the deterioration of braking performance, thermal jitter and local wear and tear, and seriously affects the normal operation of vehicles. The main feature of hot spot is the local high temperature on the surface of brake disc, sometimes accompanied by thermal deformation. Therefore, the process is analyzed and studied by means of computer simulation.

II. ANALYSIS OF HEAT TRANSFER PRINCIPLE

A. Analysis Methods and Types

A lot of heat will be generated during braking. Therefore, brake discs need to be effectively diffused into the atmosphere in order to meet the normal operation of vehicles. There are many factors affecting the heat dissipation characteristics of the brake disc, among which the rib heat dissipation structure of the brake disc is the main factor [4]. At present, most researchers have applied computational fluid dynamics (CFD) to solve the problem of heat dissipation characteristics of brake discs. In this paper, based on a stiffened plate heat dissipation structure, CFD method is used to compare and analyze the heat dissipation characteristics of various types of brake discs with improved structures. Based on the diversity and particularity of rib heat dissipation structure, the improved brake disc has certain advantages in heat dissipation with traditional structure. The problem of heat dissipation of ventilated brake disc involves the heat transfer principle and the basic theory of fluid mechanics.

B. Heat Transfer Form

The phenomenon of heat transfer from one part of the system to another or from one system to another is called heat transfer. Heat transfer is a complex physical phenomenon in nature. According to its physical nature, heat transfer can be divided into three basic forms: heat conduction, heat convection and heat radiation. In practice, the heat transfer modes are different for different fluid motion states. Heat transfer in stationary liquid is dominated by heat conduction, while heat transfer in flowing liquid or gas is dominated by heat convection or radiation. The brake works in the open air environment. During the braking process, the heat of the brake disc transfers its surface heat to the interior in the form of heat conduction. Heat convection is formed between the brake disc and the air, which diffuses most of the heat into the air. When the temperature of the brake disc is higher, thermal radiation will occur on the surface of the brake disc and form radiative heat transfer with the air around the object. Therefore, heat conduction and convection are often interrelated and interrelated in moving fluids.

C. Principle of Computer Simulation

In this paper, the computational fluid dynamics (CFD) method is used to solve the problem of fluid heat dissipation, and the finite element method of computational fluid dynamics (CFD) is needed. There are three methods to solve the problem of fluid heat dissipation: finite difference method, finite element method and finite volume method [5].

The finite difference method (FDM) is an earlier numerical method. The basic idea of this method is to divide the solution domain into difference grids, and then replace the continuous solution domain with a finite number of grid nodes. By using this method, the differential problem can be directly transformed into an algebraic problem. Finite difference method (FDM) is a numerical analysis method developed earlier, so its theory is relatively mature. This method is often used to solve hyperbolic and parabolic research problems, but it is difficult to solve research problems with complex boundary conditions.

Finite element method (FEM) is an efficient and commonly used numerical method. The continuous solution domain is discretized into a group of elements, and the approximation function assumed in each element is used to represent the unknown field function in the solution domain piecewise. The approximation function is usually expressed by the numerical interpolation function of the unknown field function and its derivatives at each node of the element. In the field of scientific computation, it is often necessary to solve all kinds of differential equations, and the analytical solutions of most differential equations are generally difficult to obtain. After the differential equations are discretized by finite element method, they can be solved by programming and other methods, using computer-aided method.

The finite volume method is also called the control volume method. It is a numerical analysis method that directly discretizes the integral conservation law on each cell of the selected grid in physical space, and then solves the original differential conservation law. Therefore, it is a relatively neutral method between the two methods. The finite element volume method (FEM) is a commonly used finite element method in computational fluid dynamics (CFD), and it is also a widely used discretization method. The research of ventilated brake disc is also carried out on the basis of finite element volume method.

III. ANALYSIS MODELS OF HEAT DISSIPATION CHARACTERISTICS OF BRAKE DISC

A. *Heat Dissipation Process*

Most of the heat generated during braking is absorbed by the brake disc and transferred with the surrounding air by heat convection. The rest of the heat is diffused by heat conduction or radiation. In the braking process, the ventilated brake disc rotates at high speed, and the rib heat dissipation structure plays a similar role as the centrifugal fan. It converses the absorbed large amount of cold air with the heat in the disc, increases the heat exchange rate and improves the heat dissipation characteristics of the brake disc.

B. *Establishment of Finite Element Model*

The geometric model of ventilated brake disc with rib heat dissipation is established by using three-dimensional modeling software Pro/E, as shown in Fig.1. The inner diameter of the brake disc is 330 mm, the outer diameter is 750 mm, and the number of ribs in the ventilation duct is 120. Considering the axisymmetric center of the brake disc model, 1/4 of them are taken for analysis.

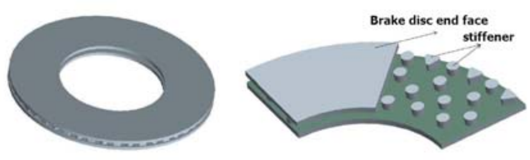


Fig.1 Three-dimensional model of brake

Good meshing results are one of the key factors to improve the credibility of simulation when using finite element method for structural simulation. In this paper, the convergence of the model is analyzed by combining the partial mesh refinement method and the stress concentration point refinement method, in order to obtain a more reasonable mesh structure. In order to reduce the influence of fluid and heat transfer boundary layer near the brake disc, a fluid calculation domain with the size of 750 mm *750 mm *1000 mm is established. The brake disc is regarded as a solid domain. The area near the wall of the inner diameter of the brake disc is set as the entrance boundary, and the area near the wall of the outer diameter is set as the exit boundary [6].

The specific settings of the fluid-solid coupling calculation domain are shown in Fig.2. ANSYS-CFX finite element analysis software is used to mesh the brake disc model. The inlet and outlet areas of air are important areas in the fluid calculation area. In order to improve its calculation accuracy, the grid of air outlet and entrance area is set as an encryption layer, the encryption layer is 8 layers, the growth rate is 1.5, and the other areas are tetrahedral meshes. The meshing result of solid and fluid models is shown in Fig.3. The braking process belongs to the transient process, and the air is set as incompressible fluid. Under this braking condition, the rotating speed of the ventilated brake disc is higher in a short time, and the velocity of the surrounding flow field is also increased. It is assumed that the internal flow of the ventilated brake disc is a fully developed turbulent flow, and the effect of high Reynolds number near the wall is significant.

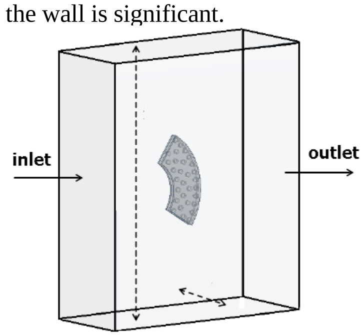


Fig.2 Fluid-solid coupling analysis model

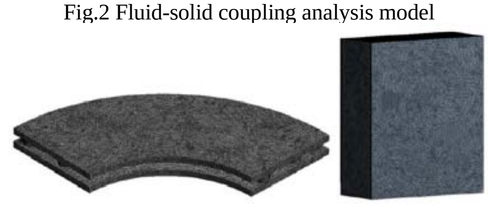
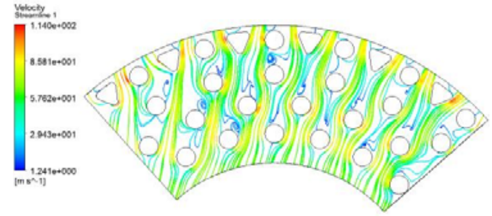


Fig.3 Meshing result of solid and fluid models

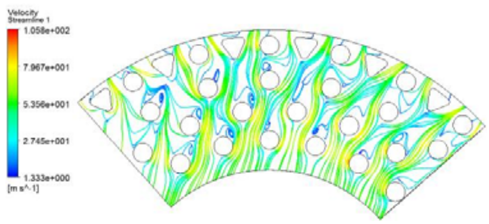
IV. ANALYSIS AND DISCUSSION OF RESULTS

A. *Velocity field analysis*

Fig. 4 is a cloud picture of airflow velocity change in the ventilation duct of brake disc under typical braking time. It can be seen from the figure that when the airflow flows radially through the triangular rib plate heat dissipation structure, the airflow velocity near the rib plate is lower and the turbulence intensity is smaller; when the airflow flows through the cylindrical rib plate heat dissipation structure, there is a smaller transition angle, which improves the airflow velocity near the rib plate, and the turbulence intensity is higher. When the braking time is 0.5s, a small turbulent area appears in the ventilation duct.



(a) 0.5s



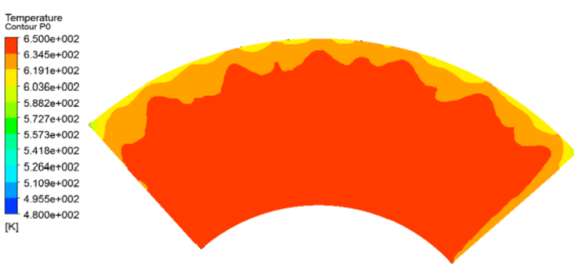
(b) 1s

Fig.4 Air flow velocity field at different time

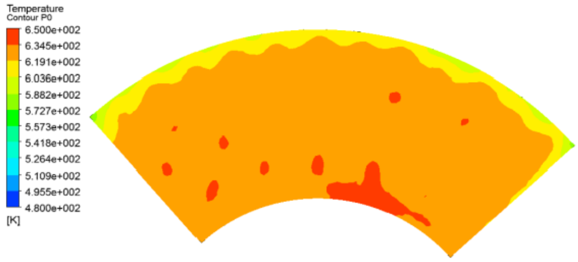
When the braking time is 11s~70.5s, the turbulent zone shows remarkable performance. The region with higher air velocity in the disk concentrates in the middle, and the velocity value of the two sides is low. Because the outer diameter area of the ventilation duct is composed of triangular and cylindrical ribs, the air flow state in the disk is influenced by the ribs' heat dissipation structure at the edge of the disk, which increases the air flow rate in the disk and speeds up to a certain extent. With the heat dissipation attached to the wall boundary, the uniformity of airflow velocity distribution in the disk is relatively good. When the braking time is 89s at the end of braking, the airflow in the disc mostly shows laminar flow, and the airflow speed is low, and the relatively high speed is still distributed near the triangle.

B. *Temperature field analysis*

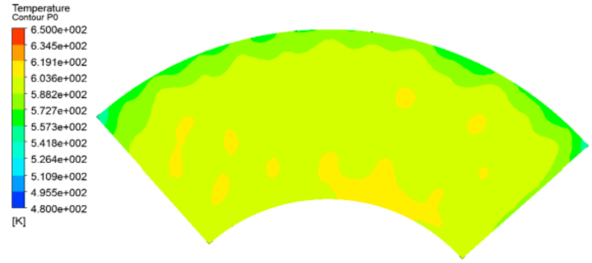
Fig.5 shows the temperature field of brake disc at different braking time. According to the figure, the average temperature of the brake disc surface is higher when the braking time is 6.5s and 11S respectively. In the early stage of braking, the heat accumulated on the surface of the brake disc could not diffuse into the ventilation duct in time, which resulted in higher disc surface temperature. When the braking time was 6.5s~11s, the disc surface temperature was relatively higher. When the braking time is 11s, the temperature band near the outlet of the brake disc is wavy. Because the rib heat dissipation structure near the outlet of ventilation duct is composed of triangular and cylindrical cross-array, the flow velocity at the outlet is influenced by the rib heat dissipation structure, which disturbs the flow velocity near the triangular and cylindrical ribs, and makes the temperature zone near the outlet fluctuate to a certain extent.



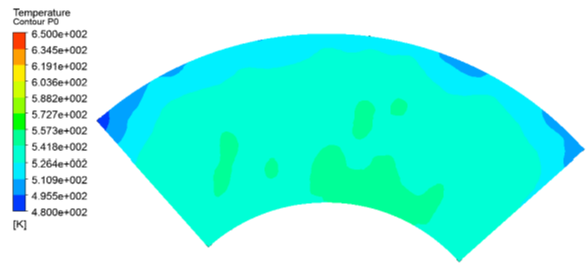
(a) 11s



(b) 14s



(c) 25s



(d) 59s

Fig.5 B. Temperature field at different time

With the braking time going on, the heat of the disc has spread to the ventilation duct greatly. The stiffened plate heat dissipation structure promotes the heat dissipation process, accelerates the heat dissipation attached to the wall boundary to a certain extent, and makes the temperature of the disc drop substantially. Because the disc is composed of the cylindrical stiffened plate heat dissipation structure, the temperature uniformity of the disc is improved. Fig.6 shows the temperature change curve of the disc near the outer edge of the brake disc. P0 represents the temperature of the whole disc and P´ represents the temperature near the outer edge of the ventilation duct of the brake disc. The disc surface temperature is affected by the cross array of triangular and cylindrical ribbed heat dissipation structures, which improves the change rate of outlet air flow, thus speeds up the change rate of outlet temperature, and is conducive to the heat dissipation process.

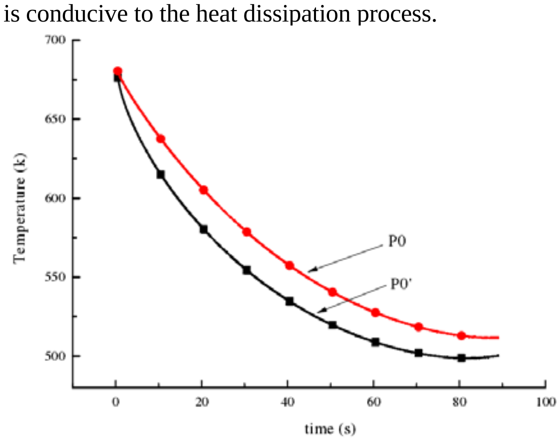


Fig.6 Temperature curve at disc outlet and disc temperature change

C. *Analysis of Heat Transfer Coefficient*

Fig.7 shows the distribution of the average convective heat transfer coefficient at the end of braking (t=89s). It can be seen from the graph that the average convective heat transfer coefficient of the disc corresponding to the ribbed area is uniform distribution. Because the flow field environment experienced by the ribs in the disc and ventilation duct is similar in the braking process, there is no other factor that will cause the uneven distribution of the surface. Therefore, it can be predicted that the convective heat transfer coefficient will also be uniformly distributed in the ventilation duct. The convective heat transfer coefficients around the ribs of the ventilation duct are almost uniformly distributed except for the outer edge of the brake disc. It can be seen that the flow field in this region has undergone drastic changes. In other areas of the ventilation duct, the flow field is relatively stable. Comprehensive analysis shows that the average convective heat transfer coefficient in the ventilation duct is consistent with the previous prediction.

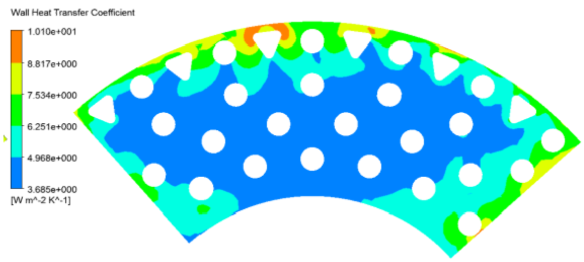


Fig.7 Nephogram of mean convective heat transfer coefficient variation in disk

V. Computer Aided Design of Brake Disc Structure

A. *Shape feature*

The shape of plate heat dissipation structure has a great influence on the heat dissipation characteristics of ventilated brake disc. The shape of plate heat dissipation structure has a certain influence on the braking performance of brake disc. The appropriate shape of rib heat dissipation structure can help to improve the distribution of temperature field on the disc surface or reduce the thermal decay of brake disc [7]. Therefore, it is of great significance to study the shape of heat dissipation structure of ventilated brake disc ribs.

B. *Model design*

At present, the stiffeners used in ventilated brake discs are straight stiffeners, cylindrical stiffeners and triangular stiffeners. The influence of stiffeners' heat dissipation structural parameters on the temperature field of brake discs is analyzed. Structural parameters of stiffened plate heat dissipation include stiffened plate heat dissipation structure shape, array mode or size parameters. Based on the previous research, this chapter designs brake discs with different shapes and arrays of stiffened plate heat dissipation structure. Considering the emergency braking conditions, computational fluid dynamics analysis method is adopted and compared with the original stiffened plate heat dissipation structure brake disc, in order to obtain a kind of stiffened plate heat dissipation structure brake disc with better heat dissipation characteristics.

VI. Conclusion

Computer simulation method has good application effect. The temperature field of brake disc, velocity field and convective heat transfer coefficient in ventilation duct can be obtained directly. The analysis shows that the array of heat dissipation structure can effectively reduce the airflow resistance near the rib plate, increase the heat exchange rate and turbulence between the airflow and heat, reduce the average surface temperature of the brake disc, reduce the separation of airflow and improve the convective heat transfer coefficient.

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