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Experimental study on temperature field of civil airplane wheel and brake

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Abstract: *In this paper, a set of the temperature field experimental method of civil aircraft wheel and carbon-carbon composite heat sink material is established. The heat absorption performance of the carbon-carbon composite heat sink and the heat dissipation performance of the wheel structure were characterized by this method. Using this method, the temperature field experiment of the wheel and brake device of a civil aircraft is carried out, and the test working conditions of the temperature field of the civil aircraft are established, the curves of temperature change with time during normal braking, taxiing braking and cooling are obtained, and the maximum temperature and heat dissipation characteristics are obtained.*

Keywords: *temperature field experiment, civil airplane, wheel and brake, inertia test-bed.*

1. Introduction

During landing and taxi on the ground, the airplane realizes the braking function through the wheel braking assembly, which reduces the airplane speed even to zero, and the friction and wear of the brake disc transforms the airplane kinetic energy into the heat energy of the airplane wheel braking assembly. In order to accurately simulate the kinetic energy and the landing taxiing state of the airplane when it lands, and to reproduce the braking thermal environment of the airplane when it lands, it is necessary to use the large-scale airborne inertia test-bed to carry out the temperature field experiment. The airborne inertia test-bed is an important equipment for testing the performance and reliability of airplane tires, wheels and brake assembly [1]. It consists of loading equipment, drum assembly system, power distribution system, auxiliary equipment and other components.

Some achievements have been made in the field of wheel braking in China. Yao Pingping et al have analyzed the operating conditions of the powder metallurgy brake pair in different states of the airplane. According to the existing experimental conditions and the specific conditions of the airplane brake, the formation and distribution of temperature field of brake pair in different braking processes were investigated [2]. Zhou Ping et al made a finite element numerical analysis of the temperature field of the brake pair of the Powder metallurgy airplane, and studied the influence of the friction material physical parameters on the temperature field [3]. Jian zhenzhu et al calculated the temperature field of airplane brake pair through finite element method, and obtained the temperature distribution of brake pair during braking [4]. Tan Juan et al studied the temperature distribution of brake discs under different working conditions, and obtained the numerical distribution of temperature field and the distribution of maximum temperature point [5]. Lei baoling et al studied the temperature field during braking of C/C composite brake pair of B757 airplane through finite element method and inertia platform experiment [6]. The above scholars have made more achievements in the research of Powder metallurgy brake pair, and in carbon carbon composite materials, they mainly concentrated on simulating and calculating the temperature field and thermal stress of brake pair, and carrying out experiments, the experiment conditions were not set according to Ac-25, and the thermal field experiment was not carried out by civil airplane experiment program. For civil airplane wheels, airworthiness certification of civil airplane should be carried out according to airworthiness regulations in the process of design and experiment. In the study of the temperature field of the wheel and brake, these scholars can not give the actual operating conditions of the civil airplane wheel, there is no reliable experimental data of the temperature field of the civil airplane wheel, and the initial temperature boundary of the temperature field model is not given clearly.

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Figure 1: Physical drawing of airborne inertia test-bed

In order to solve the above problems, this paper developed the experiment method of temperature field of civil airplane wheel based on airworthiness criterion, and tested the temperature field of the civil airplane wheel brake, the capability of heat absorption and heat dissipation of the airplane wheel and brake was studied by experiments. According to the specifications of the civil aviation system and the actual use of the pilot, the experiment conditions of the temperature field of the civil airplane are established, including the take-off taxi braking, the landing taxi braking and the taxiing taxi braking. The temperature curve of the airplane wheel under the whole temperature field experiment condition is obtained, and the heat dissipation characteristics of the wheel can be characterized.

2. Temperature field experiment platform for airplane wheel and brake

2.1 Experiment bench and related parameters

The temperature field experiment of airplane wheel and brake was carried out on the airplane wheel inertia test-bed of Changsha Xinhang aircraft wheel and Brake Co., Ltd. The airplane wheel inertia test-bed was showed in the Figure 1

The airplane wheel inertia test-bed is used to simulate the actual working state of the wheel in the process of taking off, landing, taxiing, braking and ground movement operation. The kinetic energy of the airplane is transformed into the heat energy of the airplane wheel brake through the friction and wear of the carbon brake disc. According to the standard of AVIC, the following expression is obtained [8]:

$$E_k = \frac{CWV^2}{N} \tag{1}$$

In the above formula, E_k is the Kinetic energy absorbed for a single wheel brake;C=0.0382 (Rear three point airplane, First three-point airplane is 0.0443) ;W-design landing weight;V-airplane speed;N-the number of wheel with brake;

In the process of the airplane wheel inertia test-bed, the inertia test-bed uses the moment of inertia to be equivalent to the kinetic energy of the airplane landing or the ground taxiing.

$$E_k = \frac{1}{2} J_f \omega_f^2 \tag{2}$$

In the above formula, J_f is the moment of inertia for the drum, ω_f is the angular velocity of the drum.The equivalent moment of inertia must take into account the moment of inertia of all the driving parts. The principle of equivalent moment of inertia is to keep kinetic energy consistent. The equivalent moment of inertia of airplane braking can be obtained by the above formula.

The Airplane wheel inertia test-bed is shown in Figure 2 below. The right side is the wheel fixed on the shaft. The lower side can simulate the forward wind. The wind direction is perpendicular to the shaft and at a 45 °angle to the ground. During the experiment, the left drum wheel rotates, the right wheel moves parallel to the left under the driving of the cantilever, contacts with the drum wheel, and then rotates with the drum wheel under the action of friction force.

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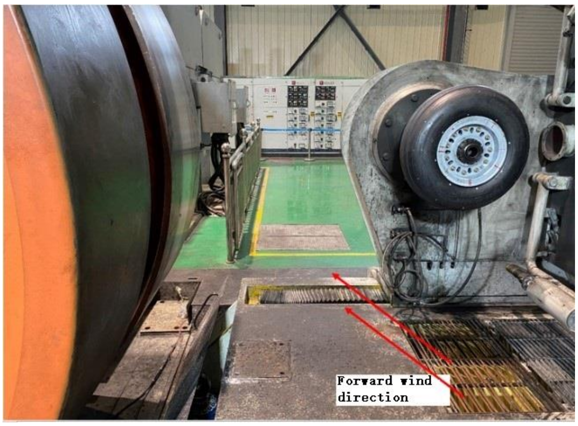

Figure 2: Physical picture of airplane wheel inertial test bed

2.2 Test-bed measurement and control system

The measurement and control system is an important system of the airplane wheel inertia test-bed, which includes the control part and the measurement part. During the experiment process of the wheel inertia test-bed, the braking state of the wheel brake experiment piece is controlled, and the experiment parameters are measured at the same time, such as speed, torque, temperature, etc.

The control part is responsible for the application of the experiment conditions, the application process and accuracy of the control variables such as brake speed, wheel load, brake pressure and energy supply meet the requirements of the experiment process, these process data related to experiment conditions are displayed in real time.

The measurement part is to measure and record the experiment object, that is, real-time display and record the process data related to the experiment object, play back the data, report of the experiment result and statistical inquiry of the experiment data, the physical parameters tested include brake pressure, brake torque, and temperature.

2.3 Experiment component sample and basic parameters of wheel and brake

Table 1: Experiment component sample

Component name	The number	Notes
Wheel Assembly	1 set	Inner/outer half hub, heat shield, guide rail, docking bolt, etc.
Brake Assembly	1 set	Torque tube, piston house, heat sink, etc.
Tire	1 strip	Tire size: H40*14.0-19
Tooling attachment	1 set	Tapered bearing, sleeve, shaft, etc
Thermocouple	3 kind	K type thermocouple, chip type thermocouple, temperature measuring sticker

The specific parameters and the corresponding adjustment are set as follows.

(a) Wheel radial maximum static load: 160 KN, which can be adjusted according to the actual situation during experiment process;

(b) Tire inflation pressure: 1.35—1.56 mpa (no-load condition);If the tire load is adjusted, then adjust the tire no-load pressure according to the following formula (3) :

$$P_{test} = 1.56 * L_{test}/160000 \qquad (3)$$

In the above formula: P_{test} —tire experiment no-load inflation pressure, MPa; L_{test} —Tire experiment load, MPa;

(c) The starting speed tolerance of taxiing brake is ±1.85 km/h, and the other starting speed tolerance is ±1% .

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3. Experiment working condition and temperature measurement setting

3.1 Experiment condition

The experiment condition simulates the airplane actually taxiing-landing-taxiing at the airport, during which the pilot needs to apply the brakes according to the actual situation, the energy and times of normal braking, taxiing out and taxiing in braking are quantified under the experiment conditions, as shown in table 4 below.

Table 2: Taxi spectrum program

Experiment procedure	Experiment content	Number of times
Taxi spectrum	Accelerating to 22 knots (11.32 m/s), the belt rolls at 22 knots for 1 km and then decelerates to 3 knots (1.54 m/s) with a deceleration rate of 1.22 m/s 2	four
	Accelerating to 22 knots (11.32 m/s), the belt rolls at 22 knots for 1 km and then decelerates to 0 with a deceleration rate of 1.22 m/s 2	one

Table 3: Normal brake program

Experiment procedure	Experiment parameters			
	Brake energy (MJ)	Brake speed (km/h)	Braking deceleration(m/s^2)	Tire pressure(Mpa)
Normal braking	22.0	176	≥3.0	1.56

Table 4: Experiment condition

Experiment condition	Fuse plug melting point	Experiment procedure
Case 1	176℃	A) Perform the taxi spectrum of Table 2; B) perform normal braking in Table 3; C) perform the taxi spectrum of Table 2; D) apply shut-down pressure of 20.6 mpa until BTP reaches its peak value of 30 minutes;
Note: BTP- Brake temperture probe		

Table 5: Brake carbon disc break-in procedure

Experiment procedure	Experiment parameter	Number of times
Taxi procedure	Table 2	1
Low-energy braking	Braking Energy:10 MJ Braking Speed :65 kts Average deceleration: 2.1 m/s^2	8
Design the landing brake	Braking power is 37 MJ Braking speed is 132 kts Average deceleration 4.55 m/s2	2

3.2 Variation of forward wind in flight test

In the course of field test, the measured forward wind speed is 6.0 m/s. The whole wheel loading process (the first 5 times of taxi braking, the 22 MJ normal braking and the last 5 times of taxi braking) can be considered, forward wind speed reduced to 0 m/s. In the test, the wind direction is perpendicular to the axis and at an angle of 45 °with the horizontal plane.

3.3 Test temperature measuring point and installation position of thermocouple

In the course of the temperature field experiment of the airplane wheel, the selection method of the

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experiment temperature point can be seen in Figure 4. The specific selection method of the experiment point is as follows:

(1) Hub A and Hub B can take any point on the circumference of the circle;

(2) The fuse plug (3 places) is 120 °uniformly distributed in the circumferential direction of the hub, and a chip-type temperature sensor is installed at each position of the fuse plug;

(3) The temperature sensor for measuring the BTP is mounted on the widest rib of the torque tube and the measuring point is located on the top of the hole where the BTP is mounted;

(4) The stator 2 and the pressure plate are taken in the circumferential direction at the center.

4. Temperature field experiment process of airplane wheel

(1) The environmental temperature of the laboratory is 28 ~ 31 ℃, the initial temperature of the experiment is ≤40 °C.

(2) Before the new brake disc is used for the first time, run-in brake procedure is performed according to Table 6.

(3) After recording the value of the brake temperature, the brake is preheated and the starting temperature of the brake before the taxi is not less than 32 ℃;

(4) After the taxi stops, the waiting brake temperature will naturally drop to 100 ~ 105 ℃;

(5) Braking at the specified energy with a deceleration rate of no less than 3 m/s^2;

(6) The brake pressure is 20.6 mpa when the brake is applied after taxiing into the brake and waiting for stopping.

(7) After stopping and waiting, the slide-out experiment is started again after the waiting time or the temperature limit is finished;

(8) The brake temperature at the end of taxiing into the brake, the brake temperature at the stop, the waiting time for the stop, the brake temperature at the end of taxiing out of the brake are recorded on the table.

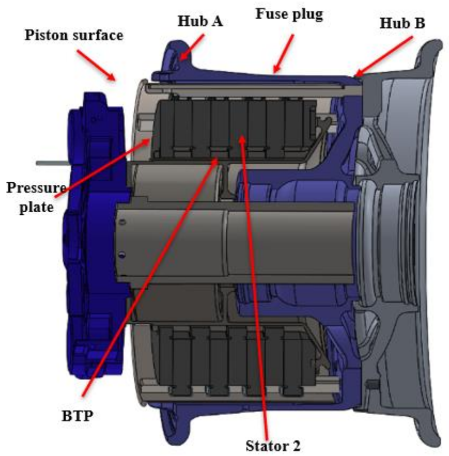

Figure 3: Position of temperature measuring point

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5. Experiment results and analysis

5.1 Results and analysis of the design landing brake

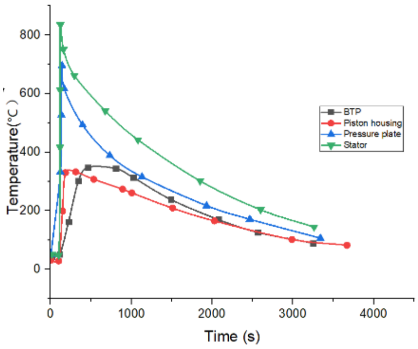

Figure 4: Design landing brake temperature curve

In the design, for this type of civil airplane wheel heat dissipation capacity mainly have the following requirements: The temperature of the brake probe (BTP) should be decreased from 450 ℃ to 100 ℃ within 25 min.

The curve shown in Figure 4 is the temperature curve of stator 2, pressure plate, BTP and piston house during the design of landing brake and cooling process. The analysis shows that the highest temperature of BTP is 361 ℃, corresponding time is 565s, when the cooling temperature is reduced to 100 ℃, the corresponding time is 3068s, and the cooling time is 2503s, about 46 min, which exceeds the 25min cooling requirement of the BTP. The temperature of the rear wheel and the brake device of the airplane brake meets the design requirements, and the heat dissipation capability needs to be further improved, to meet the operational requirements of this type of airplane.

5.2 Results and analysis of the first 5 taxi braking experiments

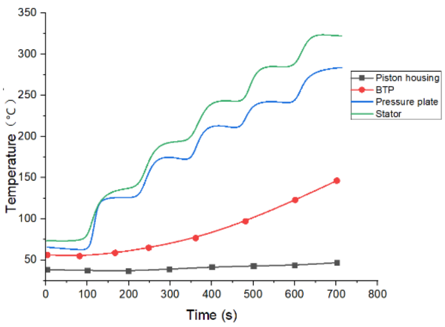

Figure 5: Experiment results of carbon disc assemblies for the first 5 times of taxi braking

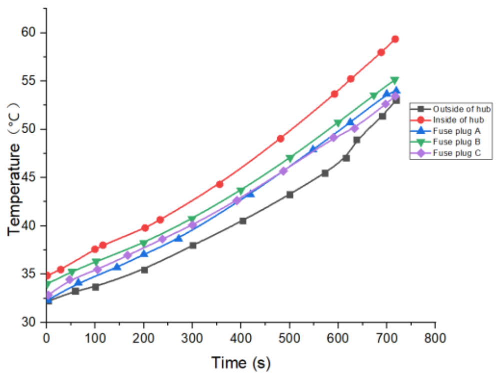

Figure 6: Experiment results of fuse plug and wheel hub for first 5 times of taxi braking

As shown in Figure 5, the first group of taxiing is the first 5 low-speed taxiing with small energy in

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table 3, which convert 2.5 MJ of energy each time. During the taxiing braking process, the temperature of the carbon disc increases obviously, the temperature of the BTP and the piston house rises slowly, which means that the heat energy is absorbed by the carbon disc and the temperature of the carbon disc rises sharply, and then the heat is transferred to the surrounding parts by heat conduction, heat convection and heat radiation. BTP measures the temperature of the air in the middle stator close to the small hole in the middle of the torque tube, which is in direct contact with the brake disc, the temperature is greatly affected by the high temperature of the carbon disc, the temperature rise is faster, the temperature rise speed is much higher than the piston house temperature; The temperature of the piston house rises most slowly. The temperature changes most slowly during the braking process, and its position is far from the carbon disc. Figure 6 shows the temperature changes at the inner and outer sides of the hub and the three fuse plug positions. After the first five times of taxi braking, the temperature of the stator increased from 74 ℃ to the highest temperature of 327 ℃, which increased 253 ℃.

5.3 Normal braking at 22 MJ power

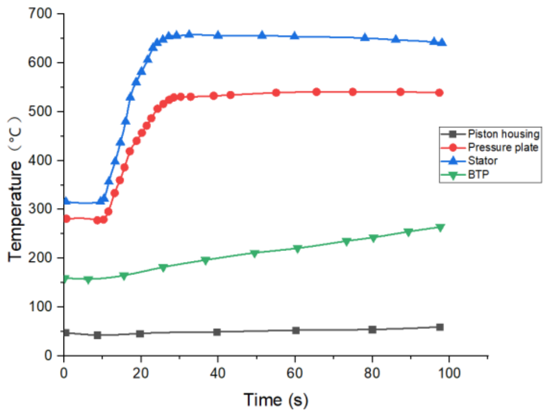

Figure 7: Temperature profile of carbon disc after normal braking

Figure 7 shows the temperature curve of the carbon disc under normal braking conditions. It describes the temperature of the brake assembly when the wheel brake and the tyre absorb 22 MJ energy. The temperature of the stator rises most rapidly, the pressure disc takes second place, and the temperature of the BTP and the piston house rises slowly. After absorbing the heat generated by friction and wear of brake pair, the stator temperature increased 341 ℃ from 316 ℃ to 657 ℃ . The pressure plate temperature increased 258 ℃ from 280 ℃ to 539 ℃ . The temperature of the stator is higher than that of the pressure plate during the brake experiment.

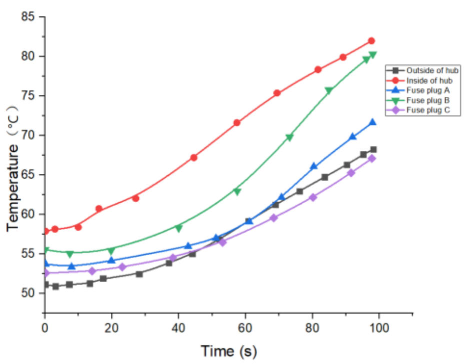

Figure 8: Temperature profile of wheel hub after normal braking

After the normal braking at 22MJ power, it is mainly the carbon brake pair that generates a large amount of braking heat, which causes the temperature of the stator and the pressure plate to rise sharply, and the wheel hub and fuse plug are not directly connected with the brake pair, the heat of the brake pair is transmitted to the wheel hub by heat conduction and heat convection. The temperature of the wheel hub and fuse plug rises slowly because of the heat shield, its temperature rose to 82 ℃. The temperature of the fuse plug and the inner and outer side of the wheel flange have little difference, and the trend of temperature change is the same.

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5.4 The results and analysis of the last 5 taxi braking experiment

As shown in Figure 9, after brake temperature field experiment of 22MJ, the temperature changes of stator, pressure plate, BTP and piston house of taxiing brake were carried out for 5 times. After the last five times of braking, the temperature of the carbon disc did not increase too much. From the first time of braking to the fifth time of braking, the temperature of the stator increased by 50 ℃, the temperature of the pressure plate decreases by 3 ℃ to 4 ℃. In the cooling process, the heat dissipation environment of the torque tube is better than that of the carbon disc assembly, so the temperature of the BTP is lower than that of the carbon disc assembly.

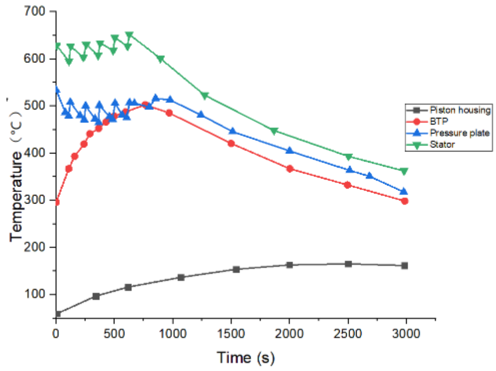

Figure 9: Carbon disc temperature results of the last 5 times taxi braking

As shown in Figure 10, the temperature changes of the fuse plug and the wheel hub during five times of taxiing braking and cooling after 22 MJ braking of the wheel are given, the temperature increases gradually, after the brake, the cooling stage, because of absorbing the heat transfer of the carbon disc module, its temperature continues to rise, after reaching the equilibrium point, slowly reduce. As can be seen from Figure 10, the maximum temperature of the wheel hub after the last 5 times of taxi braking is 168 ℃, and the working temperature of the fuse plug is 176 ℃.

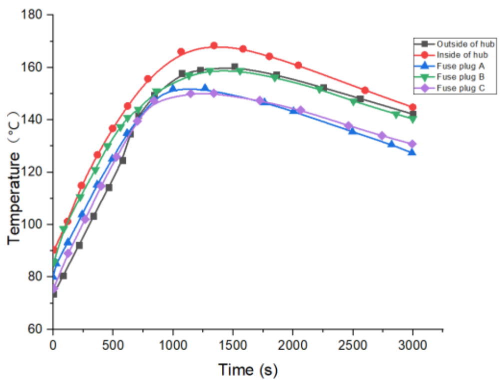

Figure 10: The temperature change curve after the last 5 times of taxi braking

6. Concultion

This paper introduces a set of temperature field experiment method for civil airplane wheel and carbon-carbon composite brake disc, the heat absorption performance and heat dissipation performance of carbon-carbon composite wheel structure can be characterized by the experiment. After the analysis of the experiment data of the temperature field of the civil airplane wheel, the following conclusions can be drawn:

(1) Under landing conditions, the maximum temperature of BTP is 361 ℃, the corresponding time is 565s, when the temperature is reduced to 150 ℃ ,the corresponding time is 3068s, the cooling time is 2503s, about 46min, which exceeds the 25min cooling requirement of BTP, the temperature of the rear wheel and the brake device of the airplane can meet the design requirements, and the heat dissipation capacity needs to be further improved to meet the operational requirements of the airplane.

(2) After the first five times of braking, the temperature of the brake disc increased from 60 ℃ to the

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highest temperature of 325 ℃, which increased by 265 ℃. The temperature measuring point of BTP is at the last braking and the temperature is below 150 ℃, which satisfies the requirement that the total braking energy is 10 MJ after the wheels of this type of civil airplane apply the braking spectrum, and the braking temperature of BTP is not more than 150 ℃ at the last braking time.

(3) After braking with 22MJ energy, the temperature of the stator increased rapidly, increased by 341 ℃ from the initial temperature of 315 ℃ to 656 ℃, and the temperature of the pressure plate and 260 ℃ from 278 ℃ to 536 ℃.

(4) The maximum temperature of the wheel hub after the last 5 times of taxi braking is 168 ℃, and the working temperature of the fuse plug is 176 ℃ , the wheel can work normally.

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