

A Study on the Bench Test of Friction-Induced Hot Spots in Disc Brake

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ABSTRACT

During light to moderate braking at high speed, the local high temperature phenomenon can be observed on the brake disc surfaces, known as hot spots. The occurrence of hot spots will lead to negative effects such as brake performance fade, thermal judder and local wear, which seriously affect the performance of vehicle NVH.

In this paper, based on the bench test of a ventilated disc brake, the basic characteristics of hot spots is obtained and the evolution process of temperature field and disc deformation is analyzed in detail. In temperature field, hot bands appear first and grow, migrate from inner and outer radius to the middle, with the growing temperature fluctuation and finally hot spots appear in the middle radius of the brake disc. The stable SRO waviness forms much earlier than the temperature fluctuation. In the stop brake studied in this paper, the SRO waviness stabilizes in main 7 order state which is lower than the final hot spot order. As the braking continuing, other high component grows and finally SRO stays in the main 9 order state which corresponds to the number of final hot spots.

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INTRODUCTION

The friction-induced hot spots is the phenomenon that local high temperature appears on the brake disc surface while braking. Hot spots usually occur at high speed with relatively low braking pressure. The occurrence of hot spots will lead to negative effects such as brake performance fade, thermal judder and local wear, which seriously affect the performance of vehicle NVH [1, 2, 3, 4]. With more demands from consumer on vehicle NVH performance, the hot spot problem draws more and more attention.

Due to the difficulties of observation and operating condition control in vehicle test, bench test becomes the main method to study the brake hot spots. The bench test is usually on a brake dynamometer, using stop brake or drag brake at a high speed over 1000 rpm and brake pressure lower than 50 bar. There is no general standard for the hot spots testing yet. In order to obtain the temperature and deformation information of brake disc in the high speed and high temperature hot spot test, infrared pyrometer and non-contact displacement sensor are applied [3, 5, 6]. Infrared thermal camera are often used to capture the temperature distribution of the disc.

Local high temperature distribution is the main characteristic of hot spots. Hot spot usually distributed uniform in circumferential direction on friction surface with the temperature difference higher than 200 °C[7]. The number of hot spots of different disc brake are not the same. But for the same disc brake under different operating condition, the same hot spots number is observed [8, 9, 10]. With the help of thermal couple and thermal camera, the circumferential hot

spots on each surface of the disc appear alternatively. The circumferential position of hot spots on one side corresponds to the place of temperature minima on opposite side. [11, 3].

Obvious circumferential waviness distortion could be observed when hot spots occurred. This waviness distortion has a high order harmonic characteristic which is quite different from the 1 or 2 order distortion of the disc initial surface run out (SRO). The high order waviness distortion is considered as the reason of hot spot. Sardá's experiment showed the stable high order distortion which corresponds to the final hot spots will form in short period after braking [3] but Dufrénoy believed the waviness distortion will stabilize in different orders as the processing of braking [4].

Several hypotheses have been suggested to explain the cause of hot spots, such as thermal elastic instability (TEI) [12], thermal buckling [13], progressive waviness distortion [14] and thermal-mechanic theory [15]. But there is still a lot of difficulties in hot spots critical condition prediction and transient simulation.

In this paper, a hot spots test of a ventilated disc brake is conducted in a LINK 3900 brake dynamometer. Based on the testing results, the critical speed, basic characteristics of disc surface temperature and displacement are concluded. Then the evaluation of temperature field and disc displacement is analyzed in detail. The data processing method and analysis of hot spot evaluation characteristics could provide useful information for further studies of hot spots.

HOT SPOT BENCH TEST

Test Equipment

The brake-induced hot spots bench test was proceeded on a LINK model 3900 brake dynamometer. Because the designed data sample rate of LINK model 3900 is not high enough for a hot spots test, an additional high rate data sample system was applied in this paper. In order to capture the temperature field of whole friction surface, a fixture of the brake system was designed based on the tailstock of LINK model 3900.

Test rig:

- Rotational inertia $78.6 \text{ kg} \cdot \text{m}^2$
- Brake pressure controlled
- Cooling air 20 km/h at 20°C

Measurement system:

- Data acquisition instrument with sample rate of 10kHz
- Pressure sensor
- Torque sensor
- Revolution speed sensor
- Revolution angle sensor
- 6 non-contact displacement sensors
- Rubbing thermal couples
- Infrared thermal camera
- Three dimensional acceleration sensor

Test object:

- Ventilated brake disc
- Disc diameter 312mm
- Disc thickness 25mm
- Pad arc length 20°

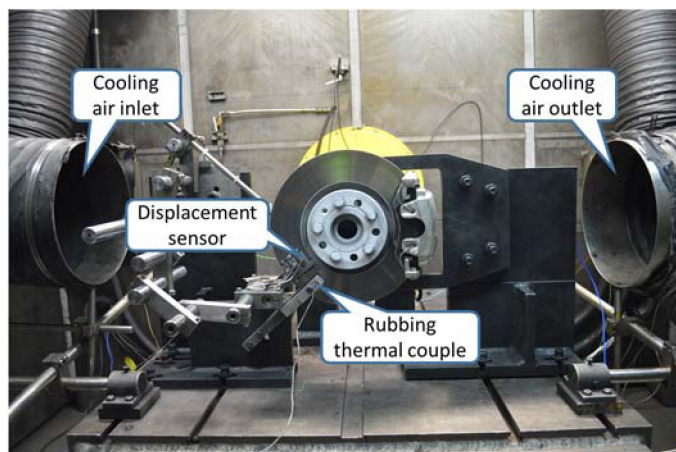


Figure 1. Brake system installation and sensors (forward)

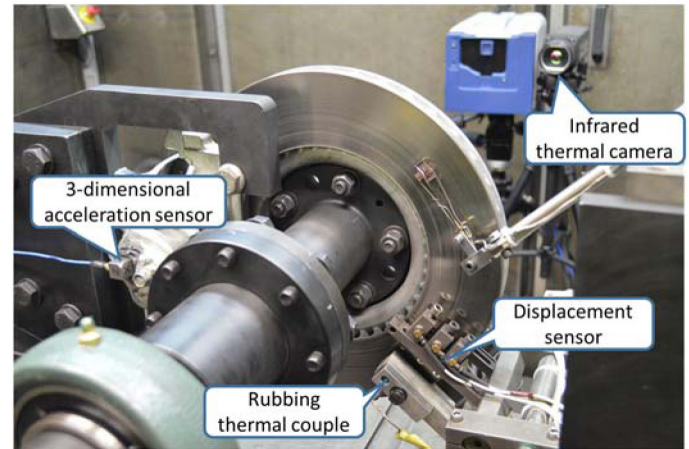


Figure 2. Brake system installation and sensors (backward)

Test Program

The stop brake operating condition was chosen in this study. The former studies showed hot spots tend to occur at high speeds and relatively low brake pressure. Thus higher initial speed and lower constant brake pressure relatively were applied. The initial speed were 1000 rpm , 1250 rpm , 1500 rpm , 1750 rpm and 2000 rpm respectively. 4 different brake pressure was applied under each initial speed, 5 bar , 10 bar , 20 bar and 30 bar respectively. Before the formal test, a running-in which contains 60 times brakes from 700 rpm to 300 rpm at the brake pressure of 30bar was applied to the brake disc.

RESULTS

Basic Characteristics of Hot Spots

Hot Spots Generation and Critical Speed

According to the TEI theory by Barber, the occurrence of friction-induced hot spots requires a critical sliding speed. Barber got the critical speed from quasi-static equations, which correspond the drag brake condition. In the stop brake of this study, in the operating condition of 2000 rpm and 1750 rpm brake initial speed, 9 obvious hot spots can be observed under all brake pressure. Correspondingly, no matter what the brake pressure is, no hot spots appears in the operating condition of 1500 rpm , 1250 rpm and 1000 rpm brake initial speed, as shown in Table 1. Thus, there is also critical speed of hot spots for stop brake condition. For the disc brake studied in this paper, the critical speed is between 1500 rpm and 1750 rpm .

Table 1. Appearance of friction hotspots under different operating condition.

Number of friction hot spots	Operating condition of stop brake (initial speed /rpm, brake pressure /bar)
9	(2000, 30), (2000, 20), (2000, 10), (2000, 5) (1750, 30), (1750, 20), (1750, 10), (1750, 5)
0	(1500, 30), (1500, 20), (1500, 10), (1500, 5) (1250, 30), (1250, 20), (1250, 10), (1250, 5) (1000, 30), (1000, 20), (1000, 10), (1000, 5)