

Review on Thermal Cracking Phenomenone in Brake Disc

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Abstract—Disc brake is one of the modern technology in the braking system. It converts the motion of the vehicle wheel into heat by using friction between disc rotor and pads in order to retard the vehicle's velocity. When sudden brakes are applied, friction between disc and pad tremendously increases due to which heat is generated in this system. Heat generated due to friction induces high-temperature regions over the disc. Because of localized heating of disc surface, a thermal gradient is developed over disc surface which may plastically deform the disc. Due to overheating, hotspots generation and thermal judders phenomenon occurring on the disc, failure of the disc is witnessed in the form of cracks over disc surface. This results in a decrement of braking efficiency and an overall drop in braking performance. This paper draws attention to selective issues regarding the failure of brakes due to overheating and methods to reduce such kind of failure.

Keywords—Disc Brakes; Hotspots; Thermal judder; Thermal cracking

I. INTRODUCTION

The braking system is a most important factor of design and manufacturing of any vehicle. The function of the braking system is to retard or stop the motion of the vehicle. The braking system is directly related to the safety of the driver, passengers, and people on the road. Generally, two types of braking systems are used in automobile sectors such as disc brakes and drum brakes. The basic principle of the braking system is to convert the kinetic energy of the vehicle into thermal energy. To stop the vehicle, friction is created between two mechanical components, giving rise to heat generated between those two components and reduction in kinetic energy of vehicle i.e. decreases vehicle velocity.

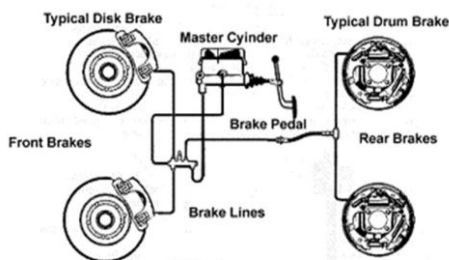


Fig.1 Hydraulic braking system [1].

A. Disc Brake

The disc brake is one of the latest technology in the automobile industry. Disc brake consists of four main parts such as disc rotor, caliper, pads and master cylinder which assembled together for the proper working of the disc brake. Disc rotor is rotating part of the disc brake assembly which is normally located on the front axle of the vehicle. Master cylinder is used to apply hydraulic pressure through brake fluid. When the brake pedal is pressed, the fluid from master cylinder pushes the piston from caliper and pad comes in contact with rotating disc. Friction between the pad and disc rotor retards the motion of the vehicle and finally vehicle stops.



Fig. 2 Disk brake rotor, pad, and caliper assembly [2].

II. HEAT GENERATION IN DISC BRAKE

When brake pads and rotor are physically in contact with each other friction is created between them and it results in the generation of heat. In normal braking, the amount of pressure generated in caliper piston is very less, therefore the amount of heat generated is less. So the performance of the disc brake is not severely hampered nor is there any significant reduction in disc's life. But when the sudden or hard braking force is applied, friction between pad and disc increases in order to stop the vehicle. This generates a large

amount of heat between disc and pad. When the amount of generation of heat increases, it affects the performance of the braking system. So, dissipation of generated heat is important for the proper working of the braking system.

Heat is dissipated from the surface in three modes of heat transfer such as convection, conduction, and radiation. Conduction is heat transfer mode in which heat is transferred through a solid. In the case of the disc brake, conduction takes place from disc to the hub and also through pads. Hub can be an extended portion of the disc or an entirely separate component, with comparatively smaller diameter but larger thickness while pads are packed with a composite material having a high coefficient of friction and are actually responsible for stopping the vehicle. Conductive heat transfers totally depending on the thermal conductivity of a material and area normal to heat flow in case of 1D analysis. As thermal conductivity is different for different materials, heat transfer rate depends on the material of disc brake.

In convection, heat is transferred between the solid surface and a fluid layer adjacent to the solid surface via conduction and then the heat flows through the fluid medium via convection. In the case of the disc brake, the air flowing over surface dissipates heat and reduces the temperature of the disc. When the vehicle is in motion greater turbulence is developed near the brake disc. Which increases heat transfer rate. The capacity of heat transfer depends on the coefficient of convection and area of the disc. The coefficient of convection is different for different fluids.

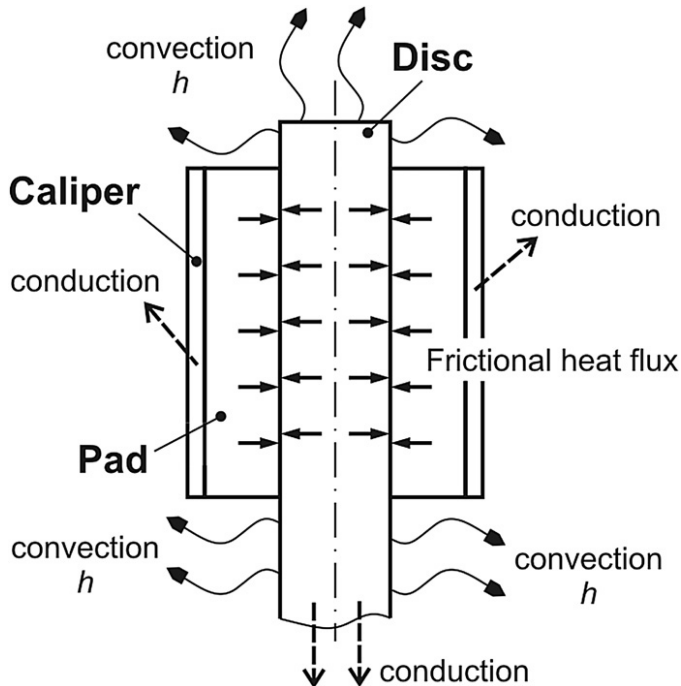


Fig. 3 Heat dissipation from a pad/disc [3]

III. HOT SPOTS GENERATION IN DISC BRAKES

Development in vehicle chassis along with the engines have also led to the development of the braking system. To provide adequate braking force the disc and pad as a friction pair operate at temperatures up to 300°C, interface pressures up to 5 Mpa and rubbing speeds up to 22m/s. Under some conditions an automotive distorts thermally, which leads to

the visual evidence of hot spotting, thus creating problems of rotor cracking and judder. Thermal analysis may reveal one notable cause of the presence of hotspots at regular intervals on the rotor.

Thermal imaging measurements reveal that heat generation is restricted narrow bands, representing the presence of a localized pressure distribution. Temperature developed near hotspots is too high about 500°C. These rapid fluctuations in temperature, of about thermal gradient 300°C to 600°C lead to permanent phase change from pearlite to martensite. It could also lead to distortion and variation in disc thickness due to the volume of martensite being higher than pearlite. Near the hotspots due to high-temperature circumferential stresses also known as hoop stresses are developed in bands type patterns. They can be accounted for crack generation and propagation in the rotor. Such failure occurs in commercial vehicles. As the shape of the original components changes and their thickness variations in the disc, the normal force can vary. Thus deviations in normal force are caused by variation in disc thickness which leads to variation of braking force and also braking torque variation, together with developing thermal judders.



Fig. 4 Hotspot Generation in Disc Brakes [10].

IV. THERMAL JUDDER

Thermal Judders have forced vibration generated on the brake disc. As the thickness of the rotor varies it leads to physical interference between the rotor and pads while passing over the brake lining which causes variation of the normal forces between the rotor and brake. The stack of vehicle and brake part deform to allow that interference to pass through the brake, and internal forces and moments vary accordingly. The frequency is consequently directly proportional to the wheel speed and therefore also to the forward velocity of the vehicle. It is thus usual to relate judder frequencies to wheel speed. The frequency of judder which is thermally excited has frequencies of typically 6 to 20 cycles per revolution. Low-frequency vibrations are transmitted from the disc brake to the body as body shake and steering shake, and are audible, causing discomfort to both driver and passengers. As the low frequencies are involved, they are practically felt

rather than being audible. At the vehicle design stage, it is important to approach a situation where the brake and the other adjacent components do not have a critical natural frequency or harmonic corresponding with the operational frequencies generated by disc thickness variation or unstable thermal deformation. Judders are also classified as Hot Judders and Cold Judder. Some of the common causes of judder are:

A. Uneven Wear

Off brake wear, sometimes called 'cold erosion', is coupled to disc thickness variation and can lead to 'cold judder'. Brake discs can develop the variation in thickness as the brake pads in the off-brake mode lightly touch the rotors in some parts but not at all in few others of them thus resulting in non-uniform wear. The off-brake wear may be caused by disc run-out and can be reduced by increasing the distance that the caliper piston is retarded after application of the brake that is the rollback.

B. Uneven Heating

Thermal deformation of a disc consists of the following:

- Waving or warping of the disc.
- Uneven thermal expansion
- Transformation of phase
- Deposition of heated pre-material on disc

With the increase in radius frictional heat and rubbing speed increases. This may lead to the formation of hotspots.

C. External Forces

Unbalanced and variation in tyre force may induce a tumbling rigid body motion of the disc, because of elasticity of the wheel hub and bearing unit. Such dynamic deflections cause the same type of vibrations as geometrical irregularities. Thus, they may contribute to judder. The wheel hub-bearing design and stiffness contribute to the magnitude of the disc deviation.

D. Time-Scales

Brake judder depends strongly on the braking history, on the short as well as on the long time-scale. There are different three time-scales involved in brake judder:

- Revolution time of wheel
- Brake application time or the time between two braking
- Lifetime of brake components

E. Uneven Friction Films

The third body layer, friction film is of few micrometers thick consisting of material produced by attrition. The ferrous particles produced by the wear of the cast-iron disc are transformed and oxidized by the atmospheric oxygen and deposited as a grey-black layer on the braking surface of the disc. This layer, together with the corresponding layers on the pads, determines the frictional behavior of the brake. When hot brakes are applied on a stationary vehicle, the pads can adhere to the rotor. At very high temperatures of almost above 500C, the melted friction material can be burnt into the disc.

Disc brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking.

F. Friction Characteristics

The variation of friction with velocity results in braking-induced vibrations, including brake judder. To achieve a given brake torque, a pad material with a lower friction coefficient needs a higher brake pressure level. This induces more evenly distributed pressure and temperature fields on the contact surface. Similarly, a reduction of the friction coefficient level decreases the judder problems and at the same time reduces the crack probability. The relation between brake torque variation and brake pressure variation is affected by the absolute friction level. This is because brake torque variation is proportional to the coefficient of friction while brake pressure variation is independent of friction.

G. Disc

The thermal stability of the disc shape is influenced by the quality of the material and the heat treatment before machining as well as the basic design of the disc rotor. Selection of high carbon disc materials and introducing thermal stress relief treatment during manufacturing can minimize the problems of thermal instability.

Ventilated brake discs are widely used for weight reduction and additional convective heat transfer. However, they may increase judder problems by inducing an uneven temperature field around the disc. Because the material suffers from low thermal capacity, it can only be used for relatively light passenger cars, say below 1000kg. The introduction of aluminum composite discs or pure aluminum covered by a composite layer will probably increase judder problems, because of the high coefficient of thermal expansion and the low heat capacity. The high thermal conductivity has therefore relatively little influence on the hotspots. However, there are composite materials that might have the ability to reduce judder, like ceramic materials. Judder is avoided because of the low coefficient of thermal expansion and low wear. Also, the low elastic modulus should promote uniform contact and reduce thermal DTV and hot spots. The excellent resistance to thermal damage of the material makes it suitable for disc brakes of heavy vehicles, where normally used cast-iron disc cracking is a problem. However, it is not widely used in industries due to its high cost.

H. Structure Of Vehicle

The front suspension is designed to admit large vibrations in the vertical direction. However, there is a vibration in the fore-aft direction which is related to brake judder, as well as a proportional angular vibration. Brake judder is strongly related to the suspension design and the fore-aft flexibility is a dominating parameter. Modern suspensions have become more and more flexible in the fore-aft direction because of the introduction of radial tyre's. This is necessary in order to absorb the longitudinal vibrations from the stiff belt of the tyre's. It is essential to measure the Eigen frequency and damping in the brake-on mode. The instantaneous center of motion of the structure changes with the brake pressure level.

V. THERMAL CRACKING

Disc brakes are exposed to large thermal stresses during normal braking and very high thermal stresses during sudden and hard braking. Typical passenger vehicles generate almost as high as 900 °C temperature in a fraction of a second. The possible outcomes of high-temperature excursions are: Surface cracks developed due to thermal stresses; and/or large amounts of plastic deformation in the brake rotor. In the absence of thermal shock, a relatively small number of high-braking cycles are found to generate macroscopic cracks running through the rotor thickness and along the radius of the disc brake [5].



Fig.5 Thermal Cracking in Disc Brakes [11]

VI. CONCLUSION

When the vehicle is in the motion it possesses the kinetic energy to stop the vehicle. This kinetic energy should be converted into another form. Disc brakes are used to stop the vehicles or to reduce the speed of the vehicle.

In this process, when brakes are applied, brake pads come in contact with the disc so that friction is created and heat is generated.

To get proper braking efficiency and avoid failure of disc proper dissipation of heat is required. Heat can be dissipated in the form of conduction, convection or radiation. If the heat generated in the system is not dissipated in adequate amounts it results in the formation of hot spots and thermal judder which ultimately results in the formation of cracks.

To reduce this failure, the proper material should be selected for manufacturing of disc. Proper ventilation, if provided in the disc, can increase the airflow and improves the convection rate.

Thus heat dissipation gets faster.

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