Vibration and Thermal Analysis of Squeal in Disc Brakes of Four-Wheeler Automobiles

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Abstract

The automotive industry has dealt with weight reduction and minimizing of the squeal noise as a way of improving braking results. A brake pad consists of steel backing with friction material attached to it. Application of the brakes produces hydraulic pressure that causes the brake pads (via brake calipers) to clamp down on the rotors creating friction. The friction acting between the pads and the rotors slows and stops the vehicle. Vibrations in the caliper and rotor cause the squeal noise in the brakes. This noise increases with increase in speed, until it reaches a pitch and volume detectable by the human ear. The initial step taken in order to stop squeal is to find and eliminate the source of vibration in a disc brake system. It is generally observed that the pressure distribution is uneven between the disc (rotor) and the pads, i.e. the pressure is found to be higher on the leading side as compared to that on the trailing side of the pads, hence it results into uneven wear of pads which then become a source of vibration in the system. The purpose of this paper is to study the disc brake squeal problem for automotive vehicles.

Keywords: Vehicle braking system, brake squeal, unstable frequencies, Thermal Analysis of Squeal.

Introduction

Disc brakes are one of the equipment used to stop or slow down vehicles. A disc brake consists of pads, caliper and disc (rotor). The function of the caliper is to press the pads against the rotor in order to generate friction and hence slow down or stop the vehicle. The hydraulic pressure is generated in order to squeeze the rotor with the help of brake pads. Brake squeal is one of the main problems for the automotive industry. The brake squeal is considered as a disturbing problem with the braking system.

A lot of workarounds have been applied to prevent the brake squeal by engineers. One of the solutions is the introduction of damping material into the braking system in order to minimize the vibrations. To find out the effects of friction coefficient and rotor stiffness, many studies have been carried out. It is important to understand the mechanism of the system so that the component(s) can be altered accordingly, in order to eliminate squeal.

1. Literature Review

The work done by En-Cheng.Liu, Shih-Wei Kung, Syh-Tsang Jenq, Chie Gau, Hsin-Luen Tsai, Cheng-Ching Lee, Yu-Der Chen [1], focusses on the disc brake squeal problem for automotive vehicles. As per the study, to carry out the dynamic contact vibration analysis of the system, a finite element numerical model was constructed.

Specific chamfer patterns on a brake pad and a ventilated brake disc with cooling ribs for heat dissipation were numerically constructed. The pad was uniformly pressurized to 200 psi (1.379 MPa) on the brake shoe and at the very moment, the disc was rotated at velocity of 2.5 rad/sec. Such case might result in the squeal phenomenon. The Lanczos method was used to find the natural frequencies of brake system in question. To determine the brake squeal, vibration frequencies with specific chamfer patterns, a lining of friction coefficient of 0.4 was selected in the analysis. The frequency of the brake noise can be classified into three categories as judder, groan/moan, and squeal as shown in Figure 1.

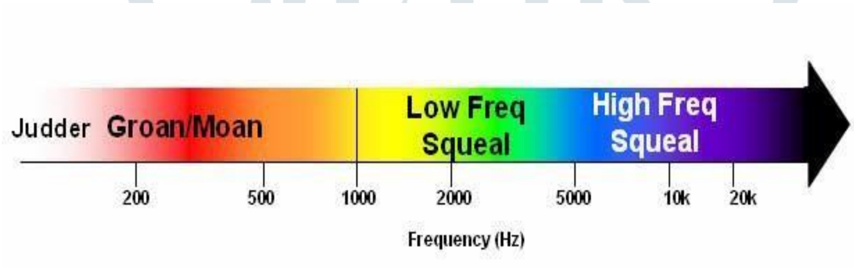

Figure-1: Brake squeal range.

In order to analyze and reduce the squeal problems among these frequencies, the experimental, analytical and computational methods were used. To determine the brake squeals in the unstable regions, complex eigen value method was used. The study dealt with the minimization of high frequency squeals which ranged from 5 kHz to 16 kHz. Nearly 200 modes were requested in the complex eigenvalue calculation to cover a wide range of frequencies. Friction coefficient and brake disc rotation speed are the basic parameters which are chosen for the study.

The calculated eigenvalues were plotted on a complex plane as shown in Figure 2. The left half plane displays the stable region while the right half plane deals with the unstable region. In conclusion, the frequencies of 6, 7, 10, 13 and 16 kHz are predicted as unstable in the results, also the chamfer design minimized the instability of most of the unstable modes.

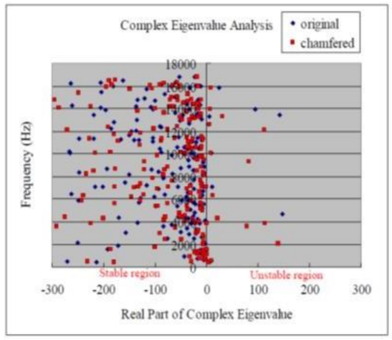

Figure-2: Complex eigenvalues of original and chamfered model.

As per the research done by S. Sarip [2], the thermal performance on lightweight disc brake models was determined. Using the 3D model in Finite Element Analysis simulations, study on the thermal performance was done. According to the research, it has been determined that up to 70% of kinetic energy of a four-wheeler could be dissipated through the friction brakes. The remaining 30% could be recuperated in the form of electric power.

While designing a vehicle, weight reduction is considered as one of the most important factors. To reduce weight, the components can be replaced with lighter materials such as aluminum. Electric vehicles (EVs) and Hybrid electrical vehicles (HEVs) can generate braking energy using the electrical part of the power train as a Regenerative Braking System (RBS). In conclusion, in terms of mechanical and thermal strength, stainless steel is a suitable material for a lightweight brake disc, it is suitable to be used for disc thicknesses less than 8 mm because stainless steel has three times the tensile strength of cast iron (Table-1). Because of the high thermal conductivity and low Young's modulus, cast iron is suitable for use in the discs having thicknesses greater than 8 mm.

Table-1: Maximum Stresses and Conductivity.

Discs	Min. Tensile Strength (MPa)	Conductivity (W/mK)
Cast Iron	310	53.3
Stainless Steel	910	25.0

Gökçe S. Sarıyerli, Atilla Bozacı [3], discovered a method for determination of pressure distribution on the disc and pads in mathematical equations, by linear and non-linear changes. Because there is no method for measuring the pad pressure when it is in working condition, the real time pressure changes cannot be determined. During braking, two edges are considered namely leading edge and trailing edge. The pressure appears to be greater on the leading edge than that on the trailing edge.For a good life of pads and elimination of squeal, it is important to thoroughly analyze the pressure distribution during the braking process. Due to the non-uniform pressure distribution, un-even wear of the pad takes place, hence shortening its life.

During the braking process, the direction of the motion of the disc and the friction force is the same for the pad. The friction force is responsible for the tilting moment which acts on the pad forcing against the disc. Due to this moment, the additional force acting is more on leading edge and less on the trailing edge. Hence due to this phenomenon, the pressure is higher on leading side as compared to the trailing side. There's no specific suggestion for the position point A as shown in Fig.3. In conclusion, it was seen that severe wear appeared on the leading side as compared to the trailing side.

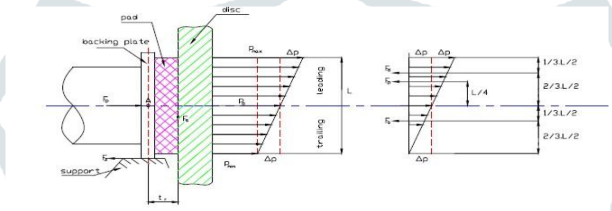

Figure-3: Pressure changes in linear pressure distribution.

In the study done by Y. Kubota, K. Okubo, T. Fujii [4], in order to prevent brake noise in motorcycles, laminated disc's frequency response function was evaluated. Two thin laminated discs, fastened by bolts were considered. For comparison, a normal disc was used. In order to keep constant condition of total thickness, the thickness of laminated disc was half of that of the normal disc. Addition of damping is one of the ways in which vibrations can be reduced, resulting in the reduction of brake noise. One similar method consists of steel plates separated by damping material, which are then placed in the braking system.

When the pad vibrates during braking, the insulator goes through mechanical deformations which changes a part of vibration energy into heat because of damping. But due to the high thermal iterations while braking, the damping material of the insulator got deteriorated. Hence, significant peak of Sound Pressure Level (SPL) was observed at about 14.4 kHz of frequency on both of TYPE-S at squeal, while there was difference in averaged SPL where 77.1dB and 53.6dB were observed by each disc, respectively. In conclusion, lamination of two discs was effective in reducing the brake squeal.

As per the study done by Ahmed Abdel-Naser, Ibrahim Ahmed, Essam Allam, Sabry Allam, Shawki Abouelseoud [5], the high-performance brakes contain slots and hollows of different patterns on the surface of the disc and its edges. The squeal or the brake noise is one of the major problems faced by the automotive industry.

Squeal is a high frequency (100 Hz or higher) noise which leads to irritating sound pressure levels. At mode 16 and frequency of 4083 Hz with instability of 480 sec-1, the highest index of squeal was observed.

2. Conclusion

From theoretical study, it was concluded that, the thermal deformation and squeal results are very important, since race car brakes operate at high temperatures. The pressure change at the leading and trailing areas is affected seriously from lining thickness.

The total braking moment won't be changed because the pressure distribution at leading side and trailing side are symmetrical. The lamination of the discs was effective to minimize the squeal.

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