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A REVIEW ON THERMAL AND CONTACT STRESS ANALYSIS OF DISC BRAKING SYSTEM

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Abstract- This paper reviews numerical methods and analysis procedures used in the study of automotive disc brake. It covers Finite element Method approaches in the automotive industry, the complex Contact analysis. The advantages and limitations of each approach will examine. This review can help analysts to choose right methods and make decisions on new areas of method development. The complex eigen value method is choose for contact analysis of car disc brake. The essence of such a method lies in the asymmetric stiffness matrix derived from the contact stiffness and the friction coefficient at the disc interfaces. This paper presents the analysis of the contact pressure distributions at the disc interfaces using a detailed 3-dimensional finite element model of a real car disc brake. It is also investigates different levels in modelling a disc brake system and simulating contact pressure distributions at varying load. It points out some outstanding issues in modeling and analysis of disc brake squeal and proposes new research topics. Wear can take place when two or more bodies in frictional contact slide against each other. It is found that the complex Contact analysis is still the approach favored by the automotive industry.

keywords— noise and vibration, automotive disc brake, coefficient of friction, simulation of disc brake,

INTRODUCTION

In general, there are three main functions of a brake system, i.e., to control a vehicle's speed when driving downhill, to minimize a vehicle's speed when necessary and to keep a vehicle stationary when in parking. At present, most passenger vehicles are fitted with disc braking systems. The elements disc brake system are floating caliper design typically consists of a caliper, two pads, two guide pins, a disc, a piston, a carrier bracket. The major requirements of the caliper is to press pads against the disc and it should ideally achieve as uniform interface pressure as possible. It is known that uniform pad wear, brake temperature, and friction coefficient could play vital role in braking action. In addition, to this it also reduces the life of the braking pads. This will cause the customers dissatisfaction and they often required to go to the garage more frequently to replace these brake pads.

As the brake disc, usually made up of cast iron or ceramic composites is connected to the wheel or the axle. To stop the rotation of wheel, friction material in the form of brake pads is forced hydrolytically, mechanically, pneumatically or electromagnetically against both sides of the disc. The friction causes the disc and attached wheel to slow or stop. As soon as the brake applied friction causes which leads to convert into frictional heat. When large amount of heat is generated brakes can't perform satisfactory work.

Brake noise is mainly caused by frictionally induced dynamic instability. There are two main types of numerical methods that are used to solve this problem: (1) transient dynamic analysis and (2) complex eigenvalue analysis. Currently, the complex eigenvalue method is more preferred and widely used in predicting the squeal propensity of the brake system. Since the transient dynamic analysis is computationally expensive and hence not widely used. The main idea of the complex eigenvalue method is to involve symmetry arguments of the stiffness matrix and the formulation of a friction coupling. This method is more efficient and provides more insight to the friction-induced dynamic instability of the disc brake system.

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In the present study, an investigation of disc brake squeal is performed by complex eigenvalue method by using FE software. This FE method uses nonlinear static analysis to calculate the friction coupling prior to the complex eigenvalue extraction. Thus, the effect of no uniform contact and other nonlinear effects are incorporated. A systematic analysis is used to investigate the effects of parameters, such as the the stiffness of the disc, hydraulic pressure, the rotational velocity of the disc, the coefficient of frictional contact between the disc and the pads on the disc brake squeal. Hence, the simulations are to be done to reduce the brake noise of the disc braking system.

DESCRIPTION OF BRAKE NOISE

A. Classification of Brake Noise

The According to different vibration frequency range, the brake noise can be divided into low frequency and high frequency vibration noise. The vibration frequency of low frequency vibration noise was 200-400Hz.

B. Brake Noise Generation Mechanism

Brake noise is due to brake vibration during braking. If the change of friction force between friction plate and brake disc is too large and fast during the braking, it can cause the brake disc and the friction plate to vibrate. When the vibration frequency up to a certain value, they will produce different brake noise. At present, there were several opinions about the mechanism of brake noise. Generally, it can be divided into two types: one is “Self-Excitation Theory”; the other is “Hot Spots Theory ". “Self-Excitation Theory" considers the cause of brake noise as self-excited vibration or resonance in brake parts."Hot Spots Theory" considers that the hot spots which generate by brake disc during braking cause vibration noise. Hot spots refer to the spot temperature higher than other regions on the brake disc during braking process. The generation of spot due to the actual contact area is a very small area when brake disc and the friction plate relative velocity reach a certain value, so the friction surface has uneven heating. As the brake disc is a rotating, so hot spot is also changing and brake noise and vibration aroused.

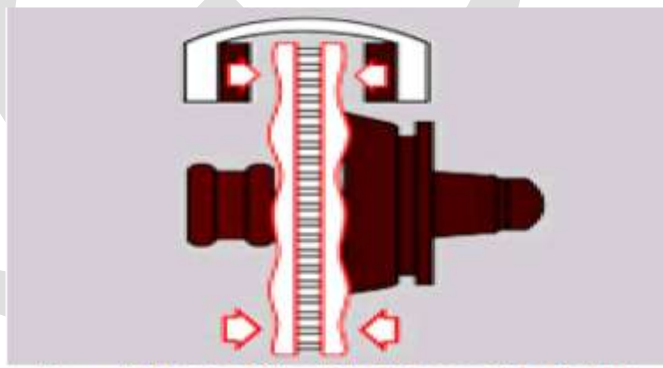

Figure1 Brake Disc Thickness Variation

BRAKE TORQUE VARIATION

As the friction force changes between the brake disc and friction plate results in the brake torque fluctuations, this phenomenon called as the brake torque variation. It will cover the following aspects.

A. Brake Disc Thickness Variation

The brake disc thickness variation refers to the brake disc thickness change when brake disc contact with the friction plate along circumference. In the braking process it will always close contact with the brake disc surface at both ends so the disc thickness changing will lead to the both the end. . When the change value of disc thickness over a certain range (generally considered to be when 15 ~ 20 μ m). The change of brake disc thickness mainly generated by following aspects:

1) Manufacturing errors. Mainly refers to the brake disc surface processing errors, including two parallel faces.

2) Using wear and tear. In some situation, the used disc may have different wear everywhere and resulting in uneven thickness.

3) Brake thermal expansion and thermal erosion. The brake disc heat expansion when braking will impact on casting microstructure and result in uneven thickness of the brake disc.

B. Brake Disc Side face Run-Out (SRO)

Brake disc side face run-out refers to the axial direction change along circumference of brake disc. When disc rotating, the ends location of the friction will changes. It will cause brake pressure and brake torque fluctuations. The side face run-out phenomenon will cause the brake disc thickness change because of uneven brake wear. Side face run-out has some the formation situations:

1) Manufacturing errors. Beside the side face run-out, the processing error between vehicle wheel hub and brake disc connected surface will further enlarge DTV.

2) Installation error.

B. Brake Vibrate under High Temperature

Because of the frequent braking action heat is generated as the results in which brake disc temperature raises. Although brake disc thickness variation and brake side face run-out are the main factor in brake vibrate, the brake disc thickness variation and side face run-out meet the requirements under static condition, is still possible occur brake variation during braking. Because braking is heat generated processing. With the brake disc temperature raise, it will cause disc surface thermal expansion and thermal deformation. Temperature differences on disc surface generate different level of thermal expansion and thermal deformation as a result thickness of brake disc may be varies.

Methodology and numerical model

1. Complex eigenvalue extraction

For brake squeal analysis, the most important source of nonlinearity is the frictional sliding contact between the pads and disc. ABAQUS allows for a convenient, but general definition of contact interfaces by specifying the contact surface and the properties of the interfaces. Starting from preloading the brake, rotating the disc, and then extracting natural frequencies and complex eigenvalues, this new approach combines all steps in run. The complex eigen problem is solved using the subspace projection method. The governing equation of the system is as

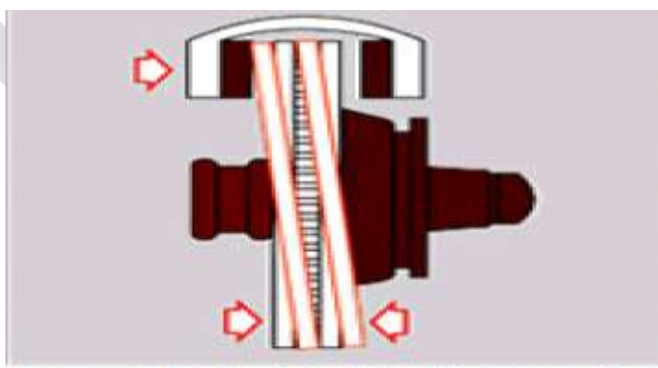

Figure.2 Brake Disc Side face Run-Out

$$Mx + Cx + Kx = 0$$

Where M is the mass matrix, C is the damping matrix, which includes friction-induced contributions, and K is the stiffness matrix.

The governing equation can also be rewritten as

$$(\mu^2 M + \mu C + K)\Phi = 0$$

Where μ is the eigen value and Φ is the corresponding eigenvector. Eigen values and eigenvectors may be complex. In order to solve the complex eigen problem, the system is symmetrised by ignoring the damping matrix C and the unsymmetric contributions to the stiffness matrix K. The N eigenvectors obtained from the symmetric eigenvalue problem are expressed in a matrix as [Φ /1, . . . Φ /N]. Next, the original matrices are projected onto the subspace of N eigenvectors.

$$M^{*} = (\Phi_1,\ldots,\Phi_N)^{T} M(\Phi_{1\ldots\ldots}\Phi_N)$$

$$C^{*} = (\Phi_1,\ldots,\Phi_N)^{T} C(\Phi_1,\ldots\ldots,\Phi_N)$$

And

$$K^{*} = (\Phi 1,\ldots\ldots,\Phi_N)^{T} K(\Phi_1,\ldots\ldots,\Phi_N),$$

Then,

The projected complex eigen problem becomes

$$(\mu^2 M^{*} + \mu C^{*} + K^{*})\,\Phi^{*} = 0$$

Finally, the complex eigenvectors of the original system can be obtained by

$$\Phi = (\Phi_1,\ldots,\Phi_N)^{T}\,\Phi^{*}$$

A more detailed description of the algorithm may be found in. The complex eigenvalue can be expressed as $\mu = \alpha \pm i\omega$ where α is the real part of, indicating the stability of the system, and ω is the imaginary part of μ. The generalized displacement of the disc system x, can then be expressed as

$$X = Ae^{\mu t} = e^{\alpha t}(A_1 \cos \omega t + A_2 \sin \omega t)$$

This analysis determines the stability of the system. When the system is unstable, becomes positive and squeals noise occurs. The term damping ratio is defined as –α/(Π|ω|). If the damping ratio is negative the brake system becomes unstable, and vice versa. The purpose of this analysis is to reduce the damping ratio.

2 Finite element model

A disc brake system consists of a disc that rotates about the axis of a wheel, a calliper– piston assembly where the piston slides inside the calliper that is mounted to the vehicle suspension system, and a pair of brake pads. When hydraulic pressure is applied, the piston is pushed forward to press the inner pad against the disc and simultaneously the outer pad is pressed by the calliper against the disc. The brake model used in this study is a simplified version of a disc brake system which consists of a disc and a pair of brake pads. Two brake pads which consist of the contact plates and back plates are pressed against the disc so as to generate a friction torque to reduce the disc rotation. The contact plates are made of an organic friction material and the back plates are made of steel material. The FE mesh is generated using 3- dimensional continuum elements for the disc and pads, where a fine mesh is used in the contact regions. The contact frictional interactions are defined between both sides of the contact plates of the pads and the disc. A constant angular velocity and constant frictional coefficient of the disc are used for simulation. The disc is completely fixed at the five counter-bolt holes.

METHODS OF CONTROL BRAKE NOISE

It shows some important conclusions and put forward some suggestions about controlling the brake noise based on the analysis of various factors. The conclusions are as following:

1) Using more precise manufacturing and installation demand, reducing the variation of original brake disc thickness and jumpiness of end face to reduce variation caused by the original size;

2) Using good heat dissipation and good heat fading performance materials to manufacture the brake discs or friction plate in order to reduces the deformation caused by temperature changes and braking torque variation;

3) Using appropriate friction plate to reduce the coefficient of friction under keep the enough braking torque, and control the speed stability and temperature stability of the coefficient of friction.

Types of disc brake friction material

A commercial brake lining usually contains more than 20 different constituent. There are four types of brake lining which are commonly used

- Organic brake lining with asbestos material.
- Semi metallic or resin bonded metallic linings :> 50 weight % metal content.
- Low metallic linings: < 50weight % metal content.
- Non metallic linings: non metal content

Design considerations

- Larger diameter rotors more will be brake power with the same amount of clamp force than a smaller diameter rotor.
- The higher the frictional coefficient of the pad, more brake power will be generated.
- Depends upon the type of material used for the brake rotor.
- Speed Sensitive – Coefficient of friction drops as the speed of the vehicle increases.
- Pressure Sensitive - Coefficient of friction typically drops as more clamp force is generated.
- Temperature Sensitive - Coefficient of friction typically drops as the temperature of the brake system increases.
- More surface area of brake system, better heat dissipation via convection.

Conclusion

This paper reviews the studies of the contact pressure distribution of a solid disc brake as a result of structural modifications. Before modifications, the simulation is done on the basis different models of different degrees of complexity for contact analysis and stress analysis. Base on the analysis, it not only just replacing the friction plate, but also change the structural design and careful selection of brake friction parts in order to minimize brake noise. The sequel can be reduced by modifying the shape of the brake pads. The damping material also helps to reduce the brake noise.

SR .NO	TITLE OF PAPER	NAME OF AUTHOR	NAME OF JOURNAL	PURPOSE OF WORK	REMARK
1	Analysis of disc brake squeal using the complex eigenvalue method	P. Liu, H. Zheng, C. Cai, K.H. Ang, G.R	[1] Applied Acoustics 68 [2] (2007) 603–615	In this paper an investigation of disc brake squeal is performed by using the new complex eigenvalue capability of the finite element (FE) software ABAQUS version 6.4	The squeal can be reduced by decreasing the coefficient of friction, increasing the stiffness of the disc, using damping material on the back plates of the pads, and modifying the shape of the brake pads

2	Prediction of Disc Brake Contact Pressure Distributions by Finite Element Analysis	Abd rahim abu bakar & Huajiang Ouyang	Jurnal Teknologi, 43(A) Dis. 2005: 21–36	This paper presents the analysis of the contact pressure distributions at the disc/pad interfaces using a detailed 3-dimensional finite element model of a real car disc brake.	Modifications on the geometry and materials of disc brake components were performed to search for a more uniform contact pressure distribution
3	Analysis of heat conduction in a disk brake system	Faramarz Talati,Salman Jalalifar	2010 IEEE	In this paper analysis of heat conduction in disc brake and factor affecting brake fluid vaporization is observed.	temperature of the pad increases and consequently heat soaking to brake fluid increases and this may cause brake fluid vaporization. Therefore another provision that should be taken into account is to use a brake fluid with an appropriate DOT rating regarding to minimum dry and wet boiling points.
4	Research on Brake Noise of Air Disc Brake	Li Jin, Xu Jianchang, Luo Fang	2010IEEE	to control brake noise of disc braking system.	In this paper different methods are suggested for controlling the noise of disc brake.
5	Performance of a Disc Brake Friction Material	Pradnya Kosbe, Chittaranjan More	2010IEEE	In this paper the performance of disc brake friction material tested on the basis of experience and trial and error method.	This paper investigate the coefficient of friction variation is determined at various speeds and pressures.
6	A Study on Optimal Braking Control Using Adhesion Coefficient	Hanmin Lee & GildongKim	2007IEEE.	In these paper vibration characteristics of automobile disc brake and pad is studied.	Based on the review of researcher four degrees of freedom nonlinear dynamics model of brake disk and pads is established. Numerical method is taken to study the impacts of brake pressure, shape parameter and the brake disk's initial velocity on the vibration characteristics of brake disk and pads. The results show that the vibrations in the tangent directions intensify corresponding to the increase of brake pressure, and decrease when the relatively velocity excels certain values.

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