FINITE ELEMENT (FE) ANALYSIS OF DRUM BRAKE SYSTEM

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)"

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Date : 26 June 2015

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This Report is submitted to
Faculty of Mechanical,
Universiti Teknikal Malaysia Melaka
In partial fulfillment for Bachelor of Mechanical (Automotive)

Fakulti Kejuruteraan Mekanikal

Universiti Teknikal Malaysia Melaka

JUNE 2015

DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature: …………………………..

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"Mum and dad, thank you for loving me and never stop teach me to always be grateful and better person"

ACKNOWLEDGMENT

First of all, gratefulness of thanks to our Creator, “Allah” for this continuous blessing, which make this work become easier and can be finished in time.

I would like to express my sincere gratitude for my supervisor Dr. Mohd Azman Bin Abdullah for his valuable guidance, support and encouragement throughout this project.

I would like also to thank my Industrial Training supervisor, Dr. Abdul Rahim Bin Abu Bakar for all of the advices that he had shared with me especially on how we should done our job effectively. Besides, he also introduced and teaches me a lot on how to use ABAQUS software. The experiences that I gained from my Industrial Training are one of the precious things in my life and I will try my best to always “do the best” in everything that I do.

Last but not least, to my parents, my sibling, my niece and nephew, my friends, and all of my classmates, thank you for brighten my day and being with me all the time when I need help.

I love you all.

ABSTRACT

In Malaysia, statistic had shown that motorcycles are the transportation that widely used on the road. Affordable price and efficient transport in term of fuel consumption and less in the traffic jam problem are the reason motorcycles was mostly be chosen compared to other vehicles. However, with a large number of motorcycles on the road, it may create some problem such as noise and air pollutions. One of the noise pollutions is contributed by brakes system. Brake squeal noise produced by transportation is an annoying sound that can affect the comfort feeling of people surrounding. Thus, this project aims to tackle such an issue by introducing brake insulator into the brake assembly. For this project, will focus on motorcycle brake and the type of system is a drum brake system. There are two stages have been followed to achieve the objective, which are: i) develop the finite element model of the rear drum brake system that based on the real system components, ii) run the stability analysis with and without insulator to analyze the effectiveness of the insulator in squeal suppression. The stability analysis performed using ABAQUS software through complex eigenvalue analysis (CEA), the positive real part of the (CEA) indicate unstable frequency (the propensity of squeal occurrence). Different types of material for the insulators have been proposed to reduce the squeal generation and it was found that the method is efficient to suppress the squeal occurred but it does not fully eliminate the squeal generated.

ABSTRAK

Di Malaysia, statistik menunjukkan motosikal merupakan kenderaan yang berleluasa di gunakan di atas jalan raya. Harga yang murah dan kecekapan dari segi penggunaan bahan api serta mudah untuk keluar daripada kesesakan lalu lintas merupakan antara faktor orang ramai lebih memilih untuk menggunakan motosikal daripada kenderaan lain. Namun, bilangan penggunaan motosikal yang banyak di atas jalan raya membawa kepada beberapa masalah seperti kebisingan dan pencemaran udara. Salah satu yang menyumbang kepada kebisingan adalah sistem brek. Kebisingan decitan brek yang di hasilkan oleh kenderaan mengeluarkan bunyi yang sangat mengganggu dan akan membawa ketidakselesaan kepada orang ramai. Oleh itu, projek ini bertujuan untuk menangani isu tersebut dengan memperkenalkan penggunaan penebat brek dalam sistem brek. Projek ini akan lebih fokus kepada sistem brek motosikal dan jenis brek yang akan digunakan adalah brek drum. Terdapat dua peringkat akan dilaksanakan untuk mencapai objektif tersebut, iaitu: i) menjana model unsur terhingga bagi sistem gelendong brek belakang berdasarkan komponen sistem sebenar, ii) menjalankan analisis kestabilan dengan dan tanpa penebat untuk menilai keberkesanan penebat untuk pengurangan decitan brek. Analisis kestabilan dijalankan menggunakan perisian ABAQUS melalui analisis nilai eigen kompleks (CEA), bahagian sebenar positif bagi (CEA) menunjukkan frekuensi sistem yang tidak stabil. Penggunaan bahan yang berbeza untuk penebat brek telah di cadangkan untuk mengurangkan decitan yang berlaku dan didapati bahawa kaedah penggunaan penebat berkesan mengurangkan decitan tersebut, tetapi tidak sepenuhnya dapat menghapuskan bunyi itu.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Brake is one of the important components in transportation. In advancement of vehicle, the improvement of brake has focused on increasing brake power and reliability. However, purification of vehicle acoustic and comfort has greatly increased the benefaction of brake noise to this aesthetic and environmental concern. Brake noise is an irritant to the users. Most of them believed that brake noise is symptomatic of a defective brake and this problem will lead them to claim a warranty from the company that produced the vehicles although the brake functioning as well as it had been designed. Brake noise or generally called brake squealing has no precise definition. Thus, in brake part design and manufacture, noise generation and suppression have become conspicuous consideration. Despite, as noted by previous researchers (Abendroth, 2000), many makers of materials for brake pads spend up to 50 % of their engineering budgets on noise, vibration and harshness issue.

There are few terminologies for brake noise such as squeal, groan, chatter, judder, moan, hum and squeak that can be found in literature. However, the terminology that often be used is squeal. The phenomenon of squeal is probably the most common, disturbing to users and environment, and its cost the manufacturer in term of warranty. There are no precise definitions for brake squeal, but it is frequently agreed that squeal occurred at frequency above 1000 Hz (Kinkaid et al.,2003).

There are a few approaches used in predicting the probability of the squeal occurrence which are theoretical, experimental and Finite Element (FE) approaches. Besides, there are several methods also proposed to suppress or reduce the squeal occurrence which are; structural modifications, active control and adding damper (Kinkaid et al.,2003). From the three methods, adding damper is the most efficient method and it may be applied by changing the material with high damping material or by adding insulator to the pad or shoe, which depend on what type of brake that will be used.

1.2 Problem Statement

Brake is one of the most important things that need to be considered when producing a vehicle. The squealing sound that produced from the brake not only contributed to the noise pollution, but also make the users are not comfortably used the vehicle. They thought that the brake might be broken down and the vehicle are not safely be used which will lead them to claim a warranty from the company that produced the vehicle. There are several types of transportations used on the road, but according from the statistic in **Table 1.1** which shows the total vehicles by type and state in Malaysia for 2012, motorcycles is the highest transportation used on the road in Malaysia. Thus, this project will focus more on motorcycles brake and the type of brake that will be used is drum brake.

Table 1.1: Total Motor Vehicles by Types and State, Malaysia, (Road Transport Department, Malaysia, 2012).

State	Types of Vehicles		
	Motorcycle	**Car**	**Bus**
Perlis	66,648	21,055	208
Kedah	773,671	292,997	3,334
Pulau Pinang	1,226,223	1,000,131	6,131
Perak	1,190,091	687,213	4,982
Selangor	1,150,029	1,052,353	7,798
Wilayah Persekutuan	1,536,607	3,332,767	20,112
Negeri Sembilan	481,513	309,135	2,860
Melaka	402,740	303,162	2,076
Johor	1,574,475	1,312,016	10,548
Pahang	499,887	345,883	2,099
Terengganu	320,658	183,793	1,178
Kelantan	452,800	267,542	2,055
Sabah	276,278	570,267	6,902
Sarawak	638,162	676,364	3,253
Total	**10,589,782**	**10,354,678**	**73,536**

Besides, the development to suppress and eliminate the squeal produced in the brake has been the target of many researchers for recent years. However, there is no fully solution for this problem and the squeal only can be suppressed but cannot be eliminated.

Theoretical and Finite element (FE) approaches are the methods that will be used to determine the squeal noise. In this project, theoretical approaches will be used to analyze the mechanism of squeal occurrence by setting up simple mathematical for brake noise. Finite element (FE) method of drum brake system for motorcycle will be used to predict the squeal occurrence from 1 kHz until 10 kHz and insulator will be used to reduce the noise.

1.2.1 Objectives of Study

The objectives of this project are to reduce the brake squeal occurrence and to determine the effectiveness of brake insulator by using different types of materials in reducing the squeal occurrence.

1.2.2 Scope of Training

There are a few scopes that had been arranged for student to finish this project during the training period:

i. **Finite element (FE) model of a baseline drum brake unit.**

A 3D (CAD) model of a drum brake system shall be developed that based on a real brake system. This CAD model will be used in the finite element (FE) software called ABAQUS to create a baseline brake FE model. The component and assembled FE model will be analysed using modal analysis to predict its dynamic properties such as modal frequencies and modes shapes.

ii. **Stability analysis of the baseline FE model.**

Stability analysis shall be performed on the FE model in order to predict squeal noise using complex eigenvalue analysis within 1 to 10 kHz frequency range. Various friction coefficients, wheel speeds and cable forces should be considered in the stability analysis. The positive real parts of the eigenvalue indicate degrees of squeal noise in the brake unit. Both squeal frequencies and modes of the brake shoes will provide useful information to establish FE model of the insulator and to determine appropriate amount of damping for the insulator to prevent squeal occurrences.

iii. Finite element (FE) model of brake insulators.

The insulator FE model shall be developed based on different design configuration such shapes, number of layers and thickness of layer. Damping properties of the insulator can be estimated using Rayleigh damping, structural damping and loss factor.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Brake squeal is a phenomenon of dynamic instability that occurs at one or more of the natural frequencies of the brake system. The research on this field had started since 1950's where the busses was banned from using the road because producing a squealing or noisy sound from the brake (Crolla and Lang,1991). Research in this field is still active until now. From the start, research on brake squealing has been carried on using theoretical, experimental and computational approaches. Theoretical approaches are used to analyze the mechanism of squeal by setting up simple mathematical for brake resonance.

Experimental approaches are normally used to measure brake vibrations frequencies and mode shapes, determining noise sources, and verifying solution. Computational approaches are the effective technique to model the brake system for squeal prediction, structural modification, and parameters studies. Through this section will present more about the squeal mechanisms, brake insulator, and analysis study for this project.

2.2 Brake Squeal Mechanism

It is very important to understand what are the mechanisms involved because it can be considered as the first step to solve brake squealing problem. Unfortunately, there is no a full of solutions for this problem until now and this is come from the lack of understanding brake squeal generation. However, there are a few mechanism have been proposed to explain squeal generation. Some of the basic mechanisms are illustrated in the following:

2.2.1 Friction Characteristic

This is one of the early mechanism trays to explain the squeal generation, where it assumes that the friction properties of the contact area are the reason squealing occurred. There is a relationship between coefficient of friction, μ and the relative velocity, v_s and depend on this relationship, there are two basic characteristic: First, the Coulomb characteristic as shown in **Figure 2.1 (a)**, consists of a specific static coefficient of friction and a lower constant dynamic coefficient of friction. This friction model results in stick-slip oscillations of the single degree-of-freedom model of the elastic system with such an interface. These motions are characterized by intermittent periods of sticking and slipping between the two surfaces (Huang, 2005).

The second friction model shows a negative slope of the friction-velocity curve at low speeds, seen in **Figure 2.1 (b).** A negative slope results in a decrease in the apparent damping for the single degree of freedom dynamic system. If the magnitude of the negative slope exceeds the structural damping, there exists a negative damping, which can lead to self-excited vibrations that are unstable oscillations in the single degree of freedom models.

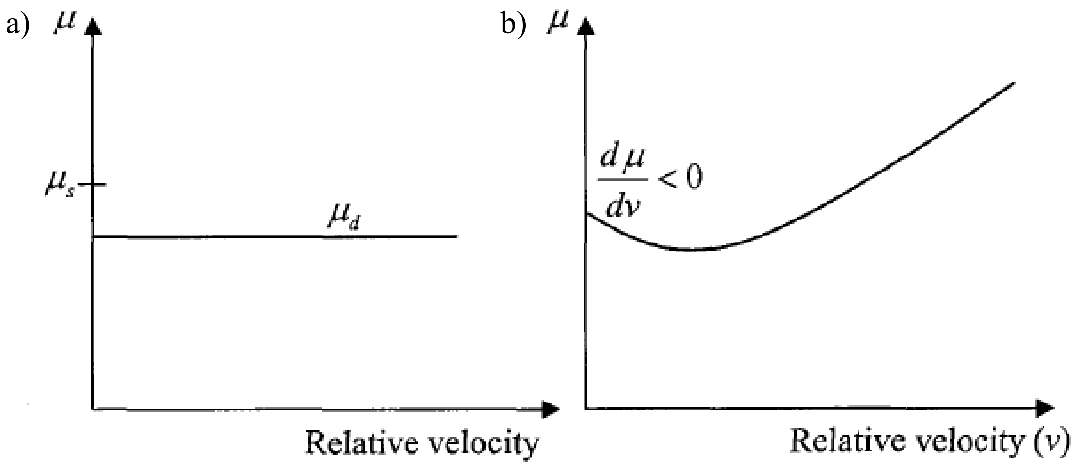

Figure 2.1: Friction Coefficient Models (Huang,2005)

However, these hypotheses could not explain some characteristics found to exist during squeal. For example, with the same friction materials and under similar operating conditions, one brake may squeal and the other may not. It is believed that since brake systems are much more complex, these friction characteristics are not sufficient and even not necessary for squeal to occur (Huang, 2005).

2.2.2 Sprag-slip model

Sprag-slip model was introduced by Spurr to describe a geometric coupling hyphothesis in 1961. Consider a strut inclined at an angle θ to a sliding surface as shown in **Figure 2.2 (a)** (Spurr, 1961). The magnitude of the friction force is given by:

$$F = \mu L/(1 - \mu \tan \theta \qquad (2.1)$$

Where μ is coefficient of friction and L is the load. The friction force will approach infinity as μ approaches cot θ. When μ = cot θ, the strut locks and the surface cannot move. Spurr's sprag-slip model consisted of a double cantilever as shown in **Figure 2.2 (b)**.

It was hypothesized that the arm *O'P* will rotate about an elastic pivot *O'* as *P* moves under the influence of the friction force *F* once the locking angle has been reached. Eventually *0"P* replaces *O'P*, and the inclination angle is reduced to *0''*. Then *O'P* swings back, and oscillation occurs.

An important aspect of this model is that it requires at least two degrees of freedom, and a sufficient amount of friction at the interface. No consideration of the negative slope feature of the friction-velocity curve is required for the occurrence of squeal. Though this model is very simplistic and is not well suited to model a complex brake system, it inspired many researchers that friction-induced geometric coupling may be important in explaining squeal (Huang, 2005).

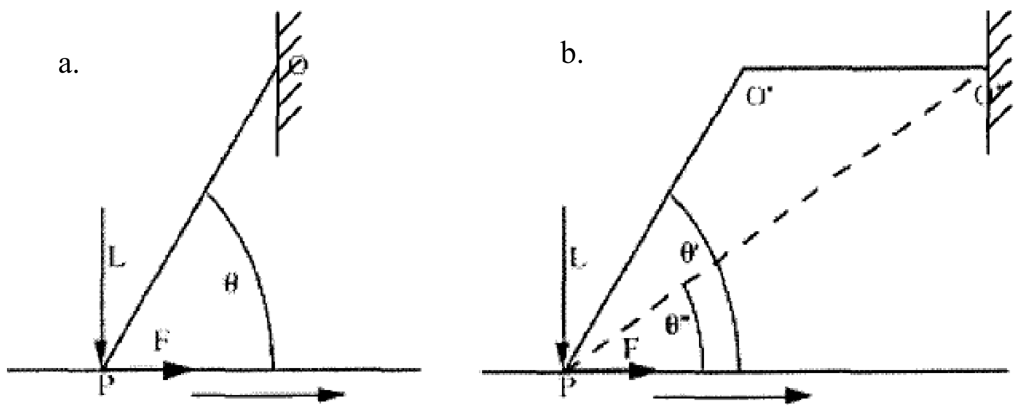

Figure 2.2: Sprag-slip model, (a) single strut rubbing against moving surface (b) sprag-slip system (Huang, 2005).

2.2.3 Self-excited vibration (friction induced vibration)

Variable friction forces may lead to friction-induced oscillations. Researchers recognized that variable friction forces occur not only when the coefficient of friction is varied, but also when the normal forces at the friction interface are varied due to geometric coupling. Even if the coefficient of friction is constant, variable friction forces are still possible and are sufficient to cause instability.

Mathematically, this geometric coupling leads to non-symmetric "stiffness coupling" in the equations of motion in contrast to the common symmetric coupling due to structural stiffness. Under some conditions for such asymmetric systems, a pair of natural frequencies may merge, and then become complex with further changes in system parameters. Hence modal coupling provides a mechanism for the beginning of squeal oscillations.

The beginning of oscillations due to modal coupling can be predicted with linear analysis of models having two or more degrees of freedom, only taking constant levels of friction into account. Moreover, the influence of structural properties on the stability as many experiments have shown is included in this mechanism. In recent years, the idea of modal coupling has been adopted by most researchers and widely used to model the brake systems and predict the onset of squeal.

Therefore, in this study, the analysis and prediction of onset of brake squeal will be based on the concept of modal coupling between the modes of the drum and shoes in drum brakes. A variable normal force due to lining deformation with a constant friction coefficient will provide the coupling mechanism for the drum brake for squeal analysis (Huang, 2005).

2.3 Conditions Under Which Squeal Occur

According to the investigation that was done, drum brake squeal is excited more at low than at high speeds and squeals occur only over limited ranges of pressures and are most common at temperatures below 100C. Mainly the brake noise is generated by the sliding phenomenon of the brake lining in the lower range of sliding speeds and during the course of running-in of the lining (Felske et al., 1980).

Among the components of the brake system, drum is most generally the outstanding part which generates the vibrations causing the noise of the drum brake assemblies. In some papers it is appreciated that the brake shoe, especially the primary brake shoe is the source of vibrations. Other factors affecting brake squeal are distortion and flexibility of shoes and their back plates (Chimakori, 1969).

2.4 Brake Squeal Studies for Motorcycles

2.4.1 Experimental Studies

A lot of techniques have been made use of to prevent the brake squeal by users or dealers in front of future customers in market (Ichiba and Yuji., 1993, Matsuzaki and Toshitaka., 1993). A good way to reduce the vibrations and the brake noise is by adding of a damping material into disc or drum brake system (Mihai and B., 2007, Sergey and Vladimir, 2009). Addition of damping material into the brake system is one of the method which has been known to put brake pad insulators consisting of a sandwich of some steel plates separated by a damping material into a disc brake system for reduction or prevention of the squeal (Triches and Jordan, 2006).

The insulator is subjected to mechanical deformations changing a part of energy of vibration into heat by shear damping when the pad vibrates in the bending modes. The damping material of insulators was degenerated by thermal redundancies when the brakes are applied.

Kubota Y., Okubo K. and Fujii T. did an experiment to evaluate frequency response of laminated disc to prevent or suppress the squeal for motorcycles. In the beginning of the experiment, they prepared the laminated brake disc from two thin discs fastened with several bolts, as they were in the same normal disc thickness to keep same condition of total thickness, also a convex shape of thin discs were used to change the brake pressure distribution (Kubota et al., 2010).

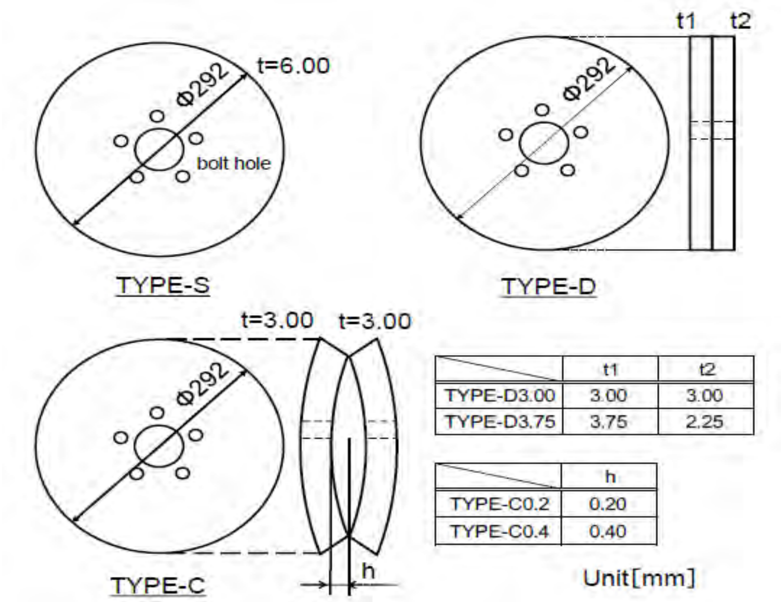

Figure 2.3: Configuration of brake discs (Kubota et al., 2010).

Figure 2.3 shows the different type of the brake discs were used in the experiment, where the type S was the normal disc and type D and C were the modified discs, which were in different thickness but the total thickness still same as the normal disc (Kubota et al., 2010).