ANALYSIS OF THE EFFECT OF ROUNDNESS ON DRUM BRAKE SQUEAL USING THE FINITE ELEMENT METHOD

by

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NOMENCLATURES

A	:	Area of the *n*th element
$C, [C]$	:	Damping matrices
CP	:	Contact pressure
E	:	Young's Modulus of the material
F_L	:	Lateral force
F_N	:	Normal force
F_{max}	:	Maximum force
F_T	:	Tangential force
f	:	Frequency
h	:	Thickness of the lining
j	:	$\sqrt{-1}$
$K, [K]$	:	Stiffness matrices
K_c	:	Total contact stiffness
$k_{c_{ith}}$	:	Local contact stiffness at i-*th* node
$M, [M]$	:	Mass matrices
m	:	Coefficient of friction
m_s, m_k	:	Static and kinetic coefficient of friction
u_s	:	Sliding velocity
w	:	Eigen frequency or natural frequency
y	:	Eigenvector or mode shape

r : Density kg/m^3

g : Poisson Ratio

$\bar{x}$: Centroid of geometry

s : Real part of the system

l : Complex eigenvalue of the system

ANALISIS KESAN KEBULATAN KE ATAS KEBISINGAN BREK GELENDONG MENGGUNAKAN KAEDAH UNSUR TERHINGGA

ABSTRAK

Kebisingan brek adalah dikaitkan dengan ketidakstabilan dinamik bagi pasangan mod komponen-komponen individu sesuatu sistem brek. Ketika proses menekan brek dilakukan, taburan tekanan sentuhan di sepanjang antaramuka bahan geseran didapati tidak seragam. Di samping itu, kesan kebulatan gelendong brek menunjukkan hubungan yang kuat terhadap taburan tekanan tersebut. Kesan kebulatan gelendong brek terhadap keupayaan kebisingan dikaji dalam penyelidikan ini. Satu pendekatan pemodelan berangka dibangunkan dan ditentusahkan dengan kaedah modal eksperimen untuk mengkaji taburan tekanan sentuhan dinamik dan seterusnya mengkaji permulaan kebisingan dalam sistem brek. Ciri-ciri getaran sistem brek ini dianggarkan dengan analisa nilai eigen kompleks. Analisis menunjukkan bahawa perubahan tekanan yang berlaku menyebabkan pusat tekanan berubah di antara pinggir depan dan pinggir mengekor kasut brek dan didominasi oleh kasut depan berbanding kasut mengekor. Hasil keputusan menunjukkan bahawa ketidakstabilan berlaku pada zon 90, 180 dan 270 darjah putaran gelendong dan mencapai maksimum ketidak stabilan pada 180 darjah. Analysis juga menunjukkan bahawa kasut depan lebih cenderung menyumbang kepada ketidak stabilan berbanding kasut mengekor.

ANALYSIS OF THE EFFECT OF ROUNDNESS ON DRUM BRAKE SQUEAL USING THE FINITE ELEMENT METHOD

ABSTRACT

Brake squeal is associated with the dynamic instability of a coupled mode of individual components of brake system. During the braking process, the contact pressure along the friction material interface is not uniformly distributed. Furthermore the effect of roundness on drum brake shows the strong relation towards contact pressure distribution. In this research, the effect of roundness on drum brake towards squeal propensity was studied. A numerical modeling approach was developed to determine the dynamic contact pressure distribution and subsequently to investigate the onset of squeal in a drum brake system. The vibration characteristics were determined by a complex eigenvalue analysis. Analysis showed that changes in contact pressure distribution would change the center of pressure between the leading edge and trailing edge of the brake shoe. The results showed that instability occurred at 90, 180 and 270 degrees drum rotation. The analysis showed that the leading shoe is dominating the instability rather than the trailing shoe.

CHAPTER ONE
INTRODUCTION

1.1 Background

Brake is one of the most important elements in automotive which are designed to absorb the kinetic energy in the process of slowing down or stopping the vehicles. The brake system is designed mainly for the safety of drivers and passengers on the road. Most of the cars brake system consists of drum and disc brake which are fitted at the rear and front wheel respectively. The actuation mechanism which is actuated by hydraulic system provides a displacement to the brake shoe to have a contact between lining and inner drum wall, hence applying the friction for reducing the speed of the vehicle's wheel. The contact established between the drum and shoe lining becomes a major concern in this research. Brake capacity depends upon the unit pressure between the braking surfaces, Coefficient of friction, and the ability of the brake to dissipate heat equivalent to the energy being absorbed.

The study of the brake system is very challenging as it involves a friction forces generated during the braking process. Pressures which are distributed along the mating surface will influence the stability of the brake system and lead to the squeal noise problem. The consideration of out of drum roundness towards contact behavior in drum brake assembly is studied in this thesis. The complexity in determining the contact pressure distributions are also shared by other researchers such as Hohmann et al.(1999) and Huang and Shyr (2002). They claimed that contact pressure distribution is difficult to obtain directly from the experiments. A few ideas were developed to predict the contact pressure by finite element method and some of them were validated through experimental method as conducted by Abu Bakar et al. (2005). However, this method is limited to the static contact pressure. To date, it remains impossible to measure dynamic contact pressure distributions by experimental methods. The prediction of dynamic contact pressure distributions were mostly done by finite element method.

The methodology presented in this thesis uses the finite element solver known as ABAQUS v6.5-1 and ANSYS v9. The finite element ABAQUS is used to investigate the contact behavior whilst ANSYS will be used to solve the stability equation of drum brake.

1.2 Scope of works

A motorcycle drum brake with a diameter of 110 mm is chosen in this study. Finite element model is developed using ANSYS solver package and validate the model by using experimental modal analysis. The validated model then is used to predict the instability in drum brake system by including the effect of drum roundness.

1.3 Research objectives

The objectives of the research are:

1. To develop a finite element model of a motorcycle drum brake system
2. To validate the finite element model with experimental modal analysis
3. To study the effect of contact pressure distribution on stability

1.4 Overview of Thesis

This thesis is written to fulfill the Master programme requirement. In addition, it is hope that this thesis provides useful information for future reference in the related area of research. The objective of this research is to increase the understanding of the contact pressure distribution under dynamic condition. The information is vital in order to analyze and ultimately predict the squeal propensity of the coupled drum brake system.

The work comprises a number of investigations relating to drum roundness, contact pressure, friction and squeal generation in brake system. It is presented according to the following outline:

Chapter One is an introductory chapter which indicates the purpose for the research. In this chapter, a brief description of the brake system is mentioned and the significance of roundness on drum brake is explained.

Chapter Two discusses a review of recent and past literatures on brake squeal studies. The critical review on previous literatures mainly focuses on the contact problems, friction sliding, squeal, discussion and conclusion of the reviews.

Chapter Three discusses the details of the methodology used for the analysis. The methodology for modal analysis, contact and stability are explained.

Chapter Four provides the natural frequency extracted from modal analysis for drum and shoe. The mode shapes data are used for correlation of squeal analysis.

Chapter Five explains the detail on results and discussions for contact pressure distribution and squeal analysis.

Chapter Six provides a brief summary of findings, and provides suggestion for future research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Brakes are machine elements used to slow the speed, maintain the speed during downhill operation and hold the vehicle stationary after it has come to a complete stop. The brake is designed to ensure the safety of drivers and passengers on the road. The common brake system used nowadays is a friction type that can be found in drum and disc brake which includes caliper, disc rotor, internal shoe and brake drum (Limpert, 1999). Generally, drum brake is installed at the rear wheel and the disc can be found at the front wheel of the vehicle. The main difference between drum and disc is the geometry of the rotor and linings. Automotive brake system can be divided into three main parts namely rotor, brake lining and the hydraulic system. This system is used extensively in all passenger cars.

Drum and disc rotor are fabricated as round and circular element for brake system. Farago and Curtis (1994) defined the rotor as perfectly round which have all points of its perimeter equidistant from its axis. When the braking process takes place, frictional contact area between the drum is formed and heat energy is generated. For the perfect round drum, contact area distribution could be assumed higher and fewer hot spots formed. Abd. Hamid (2007) measured the motorcycle drum brake using roundness machine Mitutoyo RA-100. He found that the drum was not perfectly round and lead to the non-uniform contact distribution during the braking process.

2.2 Drum brake system

Drum brake has two internal semicircular shoes lined with friction materials matches up to the internal rubbing surface of the drum. The shoes are mounted on a back plate between a pivot and actuation point. A typical drum brake system is given in Figure 2.1. The mechanism of brakes is controlled by hydraulic actuating piston located at backing plate. Returning spring hold both shoes to retract to the initial position when the brake pedal is released.

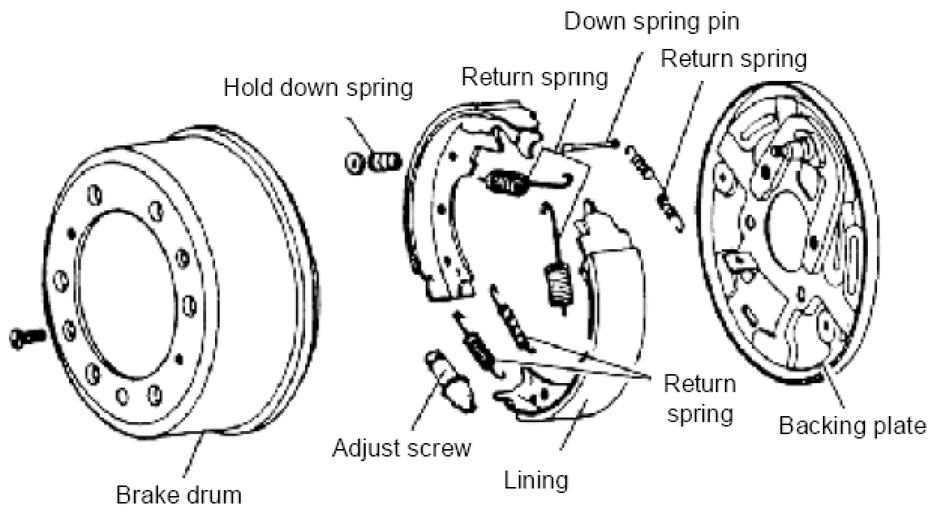
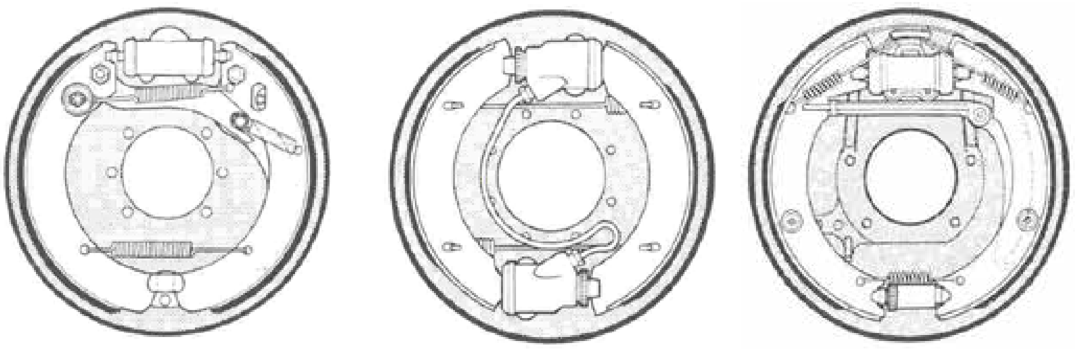


Figure2.1. Main components of drum brake system (Inokom, 2006)

2.2.1 Brake drum and shoe arrangement

Brake drums are made of cast iron or aluminum housing bolted to the wheel that rotates around the brake shoes. Drum brakes are classified into simplex, duplex and duo servo brakes depending on the brake shoe arrangement. Drum brakes are high temperature sensitive. The increasing temperature may affect the friction coefficient and also increase the diameter of the drum. This may lead to the improper contact between lining and drum, which results in the variation in pressure peaks and thus higher local lining pressure (Limpert, 1999). Drum brake with shoes arrangement can be seen in Figure 2.2.



(a) Leading-Trailing shoe (b) Leading-Leading shoe (c) Duo-Servo

Figure 2.2: Brake shoe arrangements (Limpert, 1999)

When the brake force is applied to drum rotation, shoe tends to rotate with drum due to frictional force. If the friction moment and the actuation have the same direction, the shoe is self-energizing and this is also known as leading shoe. De-energizing shoe (trailing) is when the friction moment and the actuation have an opposite direction. The arrangement of the shoes provided a different brake factor as can be seen in Figure 2.3. These types of shoe arrangement influence the contact force as well as contact pressure between the lining and the drum rotor.

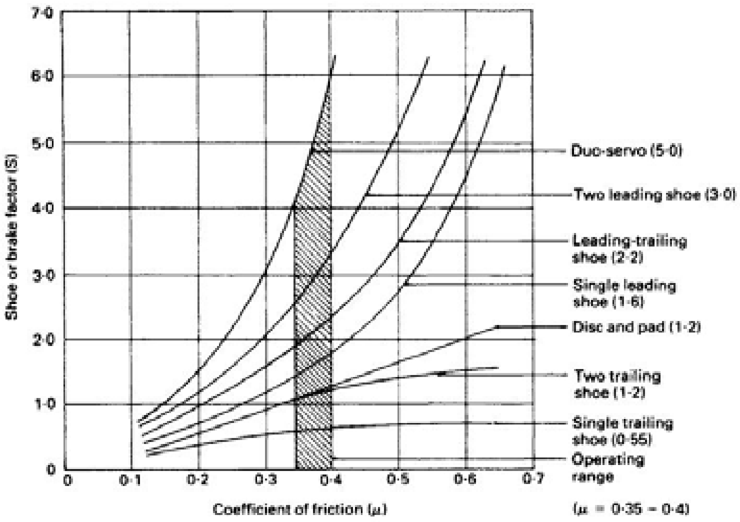


Figure 2.3: Relationship of shoe and brake factors and coefficient of friction for different shoe arrangements (Limpert, 1999)

2.3 Friction and squeal in brakes

The most important physical phenomenon related to braking systems is the lateral force between two rubbing surfaces, i.e. the friction force. Based on the Amonton's law of friction, the relation between the normal force, F_N and the lateral force, F_L can be mathematically formulated as: m = F_L / F_N, where m is the coefficient of friction. One of the biggest contributors for the braking system is the friction material. Friction materials can be considered as composite materials which are classified as organic, carbon-based, and metallic (Limpert, 1999). These compositions influenced the value of friction coefficient ranging from 0.25 to 0.7. In the selection for friction materials, priority is given to requirements such as braking performance, cost and ease of manufacture. They also should provide high thermal resistance, wear resistance, and stable friction coefficient to temperature change and water (Limpert, 1999). A good braking power is achieved for the higher friction coefficient. Besides the braking performance, the major concern of drivers is the annoying sounds also known as squeal generated during the braking process.

Brake squeal is widely accepted as friction induced dynamic instability. It is associated with the high level of vibration of the brake assembly when the friction force is activated during the braking process. Brake squeal can be described as an irritating sound with a main frequency between 1 to 15 kHz, generated by the brake components (Papinniemi et al. (2002) and Ouyang et al. (2005)). Previous researchers found that the presence of friction force into the brake assembly was a major contributor towards the squeal propensity. The influence of friction coefficient towards the squeal can be seen in Figure 2.4 as found in Kung et al. (2000), Flint and Hulten (2002) and Bajaj et al. (2006). It can be seen from Figure 2.4 that the real part of the complex eigenvalue which is the measure of instability increases with the coefficient of friction.

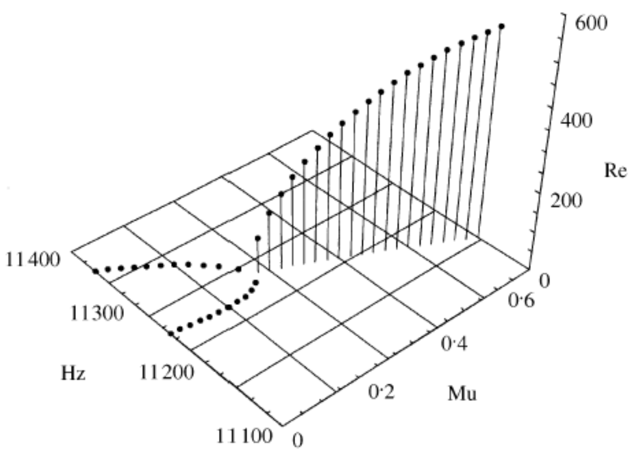


Figure 2.4: The effect of coefficient of friction toward stability analysis (Flint and Hulten, 2002)

2.4 The mechanism of the brake squeal

There are several mechanisms which can be used to explain the brake squeal phenomenon and these are described as follows:

2.4.1 Stick-slip theory

Friction produced by the contact of the shoe and drum in brake system causes a stick-slip situation to occur, which is the primary reason for squeal. Stick-slip refers to the phenomenon where friction coefficient μ_k was a decreasing function of v_s (Mc Millan, 1997). It is known that this relationship can result in negative damping and lead to unstable oscillations. Stick condition is occurs when the static friction coefficient is larger between two surfaces. If an applied force is large enough to overcome the static friction, the reduction of the friction to the kinetic friction can cause a sudden variation in the velocity of the movement. In the stick phase, the applied tangential force F_T is exactly balanced by the frictional force F. This simply indicates that the greater the applied force is, the greater the force due to static friction will be and this can be described as:

$$\left|F_T\right| \le F_{max} = \mu_s mg \qquad (1)$$

In the case of slip, the effect of friction is to produce a force which opposes the direction of motion. This relation can be described as:

$$\frac{d\mu_k}{dv_s} < 0 \qquad (2)$$

2.4.2 Sprag-slip theory

Sprag –slip or kinematics constraint or geometrically induced is used to describe the theory of brake squeal. This theory was developed by Spurr(1961) as mentioned by other researchers such as (Kinkaid, et al. (2003), Ouyang et al. (2005) and Dai and Lim (2008). This model is very significant in order to relate with the squeal propensity. The deformation of a strut as it undergoes displacement due to friction causes the normal load to increase and this in turn will increase the friction. The cycle continues until it reaches an orientation known as sprag angle where further motion is impossible. This action does not depend on a coefficient of friction varying with the slipping velocity, but result from the geometric arrangement and flexibility of the pad. He claimed that the variable contact both between the piston and the backing plate and between the lining pad and rotor as a cause of squeal propensity. The observation made by explaining how a pad with a tapered shape achieves instability as the contact point shifted to the front of the pivot. The developed idea was an important aspect in the design of disc brake as the geometry of the pad should be as flat as possible to avoid the pressure distribution from shifting to the pivot point.

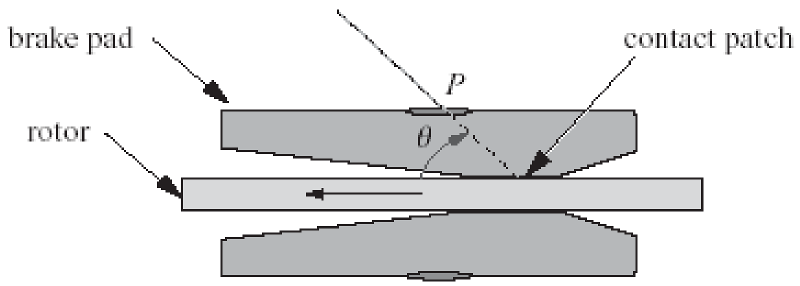


Figure 2.5: Schematic of the tapered brake pad contacting a rotor used to explain the sprag-slip theory (Kinkaid et al. (2003)).

2.5 Previous brake squeal Prediction and testing

The mechanisms of squeal can be investigated, analyzed and validated through methodologies such as vehicle testing, dynamometer test, modal testing and finite element simulation. Studies of brake squeal can be categorized into two methods which can be presented as experimental and numerical analysis.

2.5.1 Experimental analysis

The experimental works on brake squeal have been carried out since the mid-1970s. In 1978, work of Felske as reported by Kinkaid et al. (2003) and Papinniemi et al. (2002) was carried out by using dual pulsed holographic interferometry (DPHI). This experiment was successfully applied to squealing brake systems. The mode shape from the vibrating object can be determined by interpreting the fringe pattern. Fringe pattern can be considered as topographical lines which give the absolute displacement of all points on the object. The same method was also employed by Nishiwaki et al. (1993), followed by Fieldhouse and Newcomb (1996) to investigate disc brake noise. They conducted a parametric and geometric characteristic study to determine the effect of component to the squeal propensity. They found that pad leading edge abutment is extremely prone to squeal and concluded that the noise can be linked to the coupling of the natural frequencies of the individual parts when there are closed together.

McDaniel et al. (1999) studied acoustic radiation from a stationary brake system. The methodology used in this study was the Laser Doppler Vibrometer (LDV). The stationary brake was shaken by using the shaker excitation at a certain frequency while LDV was directly scanned to one side of the brake system. The methodology presented was independent of the friction law, as the mechanical excitation used to excite the stationary brake has created the interaction forces between the pad and rotor. The result shows the good agreement as found in vibration patterns observed on squealing brake system. They claimed that the rotor leads to flexural wavelengths that are on the order of acoustic wavelengths.

Lee et al. (2001) studied the non-uniform cross sectional shoe which was found to have an effect on the instability. They conducted an experimental dynamometer test on a car drum brake. Modal analysis was carried out for individual components followed by modal analysis for coupled drum brake with an applied brake pressure. They found that the frequency extraction for individual components is close to the coupled brake under an applied braking pressure but only a small variation in shoe frequency. They then conducted a theoretical model by including the kinetic and potential energy between drum and shoe. According to Lee at al. (2001), squeal is reduced when there is an increase of cross sectional area and a decrease of bending stiffness. The minimum decreases of the cross section area could be done by considering the strain energy distribution at the shoe back plate.

2.5.2 Analytical and numerical analysis

Most researches on brakes squeal focused on the numerical and analytical methods due to a few reasons (Kinkaid et al, 2003) such as;

1) Expensive, this is mainly due to hardware cost and long turnaround time for design iterations experimentally.
2) May predict the event at early design stage before production runs
3) May simulate different types of structure, operating condition and materials compositions.

Brake squeal can be modeled by using analytical and numerical methods to predict its occurrence. Modeling of the brake squeal is quite challenging because brake system consists of a few components which may contribute to a large number of degrees of freedom (d.o.f). Complex eigenvalue analyses have been used to study the stability of the brake system and predict the occurrence of the brake squeal. Through the complex eigenvalue analyses the modal characteristic of the components can be obtained. A latest review of brake squeal by Ouyang et al. (2005) revealed that the analytical and numerical methods are still significant for brake squeal studies. FEM was used to model the individual components of brake system for the analysis.

Kung et al. (2000) studied on reducing low frequency squeal using complex eigenvalue. They claimed that by changing the rotor material, it may decouple the modal interaction and eliminate dynamic instability. Bajer et al. (2003) combined a nonlinear static analysis and complex eigenvalue extractions to study friction induced dynamic instability and proceed with including lining wear effect to have a realistic contact patterns in Bajer et al. (2004). According to Bajer et al. (2003, 2004), by including the positive damping can result in eliminating some unstable modes at higher frequency whilst including negative damping which does not trigger additional unstable modes.

Work conducted by Fuadi (2003) used the finite element ANSYS for modeling the drum brake system with three dimensional solid element. The material properties are modeled in his analyses as linear elastic and homogenous. He also incorporated the friction interface between the drum and shoe by using the stiffness matrix and assuming that the contact stiffness (k_c) is uniformly distributed. By considering the contact stiffness ranging from 70MN/m to 450 MN/m in his analysis resulted in 3 different modes around 1300 Hz and 2000 Hz where these two modes tend to coalesce when the coefficient of friction increases. Squeal occurred at the minimum contact stiffness 90MN/m. He incorporated the damping effect and found that squeal can be eliminated at higher frequency. Modification on the shoe and drum back plate were made by changing their stiffness and found that stiffening the drum and shoe back plate improves the system instability. However his model did not validate with the experimental data.

Chung et al. (2003) conducted a virtual design of brake squeal. Their work focused on design direction where they used baseline model to perform sensitivity study and use the calculated sensitivity data to determine the optimum combination to improve squeal noise. By introducing mode convergence speed and examine the critical modes and its strain energy was help to determine the effective changes to shift the natural frequency. They found that by removing some material structure may shift natural frequency and make minor influence on its mode shape and claimed that by separating 1.5% natural frequency is efficient way to suppress the system instability.

Bajaj et al. (2006) study the parametric sensitivity analysis on car drum brake using complex eigenvalue. The purpose of their study is to understand the mode “merging” and “veering” on the occurrence of brake squeal. According to Bajaj, there were two conditions for mode merging: (1) the separation between the frequencies of two modes of a statically coupled system is sufficiently small, and (2) their component wise mode shapes exhibit movement in opposite radial direction. When these two conditions are met, the two modes have strong possibility to merge and can cause squeal in the presence of friction coefficient. They found that the stability boundaries are sensitive to changes in parameters such as lining stiffness. Decrease in lining thickness increases in lining stiffness and may have different squeal propensity. By incorporating the effect of hydraulic cylinder stiffness may influence the stability of the system. However they did not furnish the experimental results.

Liu et al. (2006) developed a finite element model of disc brake and study the stability analysis using finite element ABAQUS. They found that significant pad bending vibration may be responsible for causing the brake squeal. They also investigated a few parameters such as brake pressure applied and the stiffness of the rotor may also influence the stability of the brake system. Increase the hydraulic pressure from 0.5 MPa to 2.0 MPa increased the damping ratio and squeal propensity is increased. This is due to the larger pressure inducing more friction between pad and disc. By increasing the stiffness of the rotor can reduce the squeal propensity. Stiffen the pad back plate cause a higher squeal propensity due to larger deformation and vibration magnitude of the pad.

2.6 Study on brake contact pressure analysis

When the brake is applied, the brake line pressure acts on part of the shoe back plate. This mechanism presses the friction material to form contact to the inner drum wall. Contact distribution occurred at the shoe lining and it has been reported that they are not uniformly distributed as established by Day (1991), Hohmann et al. (1999), Eriksson (2000) as represented in Figure 2.6. This non-uniform pressure distribution is due to forces and moment acting on the arrangement of brake shoes.

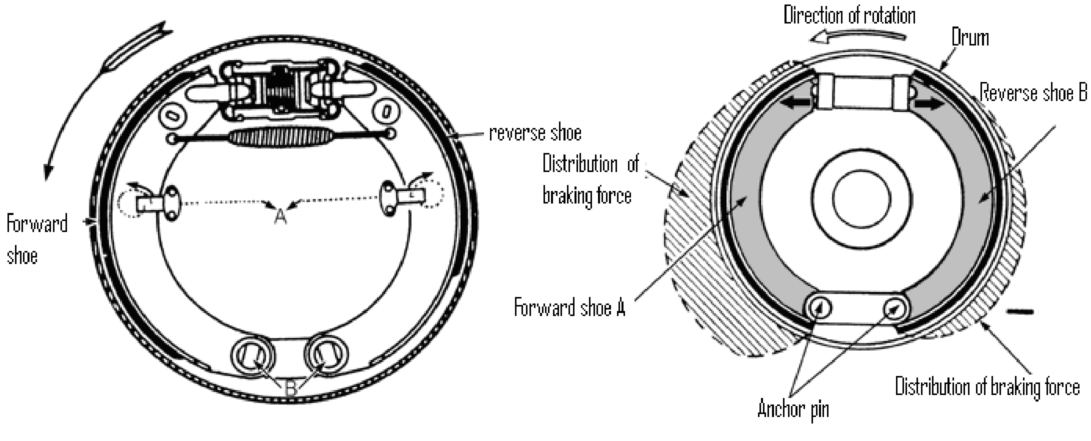


Figure 2.6: The distribution of braking force on brake shoe (Inokom, 2006)

Day (1991) investigated the drum brake interface pressure distribution and found that the pressure distributions continually changed by the lining wear. Heel and toe contact as described could result in increase of the brake shoe factor whilst crown contact may decrease the brake shoe factor. He also mentioned that drum flexure and shoe deformation will induce different contact pressure distribution and resulted in non-uniform wear pattern. He conducted an analysis on contact pressure for different shoe arrangements and found that shoe sliding abutment show a greater tendency towards a U-shape distribution than pivoted shoe drum brake as shown in Figure 2.7.

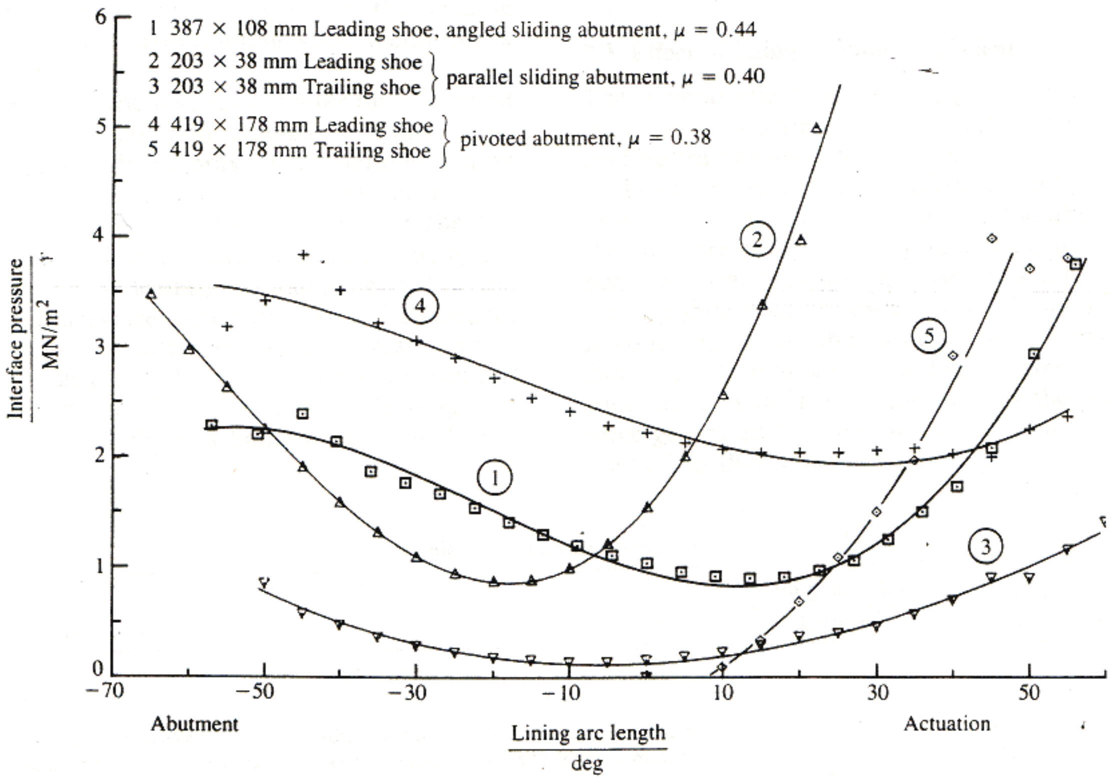


Figure 2.7: Drum brake pressure distributions (Day, 1991)

Hohmann et al. (1999) conducted a numerical simulation for drum brake and has included applied brake pressure to press the lining plate to the drum wall followed by rotating the drum for sliding motion to see the pressure distribution pattern. This method considered the effect of stick-slip condition that can explain the behavior of the contact pressure distribution. They used an S-cam brake shoe for actuation mechanism. They found that contact pressure distribution is higher on the lining plate close to the center of leading edge for leading shoe whilst trailing shoe exhibit peak contact pressure at cam side.

The surface roughness of the brake pad is a factor that lead to the non-uniformity of the contact force and resulted in the highly localized pressures. Eriksson (2000) revealed that only small parts of the surfaces were in real contact. Sherif (2004) investigated the effect of surface topography of pad/disc assembly towards squeal generation. He performed an experiment to determine surface parameters of pad/disc assembly using the Talyserf-5. When the squeal triggered both frictions pad and disc were measured, he found that the glazed pad surface and worn-out disc were likely to generate squeal but for glazed pad and abraded disc, no squeal appeared. However, pad with the smooth disc is not suitable for squeal establishment.

Huang and Shyr (2002) analyzed a drum brake using boundary element method (BEM). A two-dimensional drum brake was modeled. Drum was modeled as rigid body. Their early work was based on the similarity between the calculated results and existing data before conducting the analysis. The analysis was conducted by neglecting wear and thermal effect and assumed that there was the perfect initial contact between the contact surface of the lining plate and the circular profile of drum. Their report showed that maximum pressure distribution was shifted from the supporting point (pivot) towards the actuation side when the Young's modulus of metal shoe increased and resulted in more uniform pressure distribution. By increasing the arc length of metal shoe, more pressure distribution was achieved by decreasing the pressure close to the pivot point. They also reported that the increase of thickness of the lining plate resulted in more uniform pressure distribution. They also found that larger actuation force with the actuation angle of 35^o may improve the braking effort.

Ioannidis et al. (2003) conducted a non-linear analysis of a leading-trailing shoe drum brake. A three dimensional finite element model of drum brake was coupled with flexible-to-flexible surfaces contact algorithms. They included the static contact at the first step followed by gradually applied rotation to the drum. By considering uniform installation gap, they found that there was still non-uniform pressure distribution on lining under perfect contact condition. The location of the pressure distribution was higher at the leading edge then trailing edge. Applying 0.3mm installation gap has resulted in contact pressure pattern which was highly concentrated at the center of the friction material for leading shoe. It has shown that the installation gap can provide up to 60% of the maximum lining area in contact at leading shoe whilst 25% of the maximum lining area for the trailing shoe. Latter in their analysis, they also predicted the onset of squeal by using complex eigenvalue method and found that under perfect initial contact (zero initial gap), more unstable mode were produced compared to the initial uniform installation gap of 0.3mm under the same actuation loads.

Contact problem required contact stiffness between the two contact surfaces. The high stiffness value can lead to difficulties on convergence. But the low contact stiffness may cause excessive penetration and large relative displacement between the contacting nodes. This problem can cause inaccurate simulation for the contact behavior. The best contact stiffness can be estimated as:

$$K_n = E_{lin}.A_n / h_{lin} \quad (3)$$

Where:

K_n = contact stiffness at the nth element

A_n = area of the *n*th element

E_{lin} = Young's Modulus of the material for the contact problem (Smaller values of E are chosen)

h_{lin} = thickness of the lining.

The contact stiffness from contact analysis could affect the squeal to the brake system. E_{lin} is dependent on contact pressure at the friction interface Bajaj et al. (2006). The unsuitable contact stiffness could lead to convergence difficulties when performing analysis.

Work by Fuadi (2003) studied contact interaction between shoe lining and drum wall of a drum brake. He assumed that the distribution of contact stiffness along the mating surfaces as uniformly distributed and reported that the minimum value for contact stiffness was 90MN/m. This resulted in squeal generation even though uniform distribution was considered. Most of the finite element model incorporates the geometric coupling between shoe and rotor. This can be illustrated by a spring that links a pair of nodes on the surface of the rotor and the shoe or pad in contact as shown in Figure 2.8.

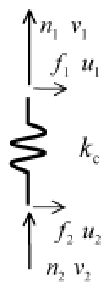


Figure 2.8: Interface model spring stiffness with friction loading (Ouyang et al. (2005))

Bajaj et al. (2006) modeled and studied the parameter sensitivity analysis of a car drum brake. They claimed that the interface pressure distribution depended on the local contact pressure as work conducted by Lee et al. (2003). Lee et al. (2003) performed the non-linear contact analysis to determine the pressure distribution at the friction interface followed by system linearization and a complex modal analysis. Contact stiffness depended on the Young Modulus of the friction material. According to Ripin et al. (2005), their work focused on the contact pressure of drum brake using ABAQUS and then the value obtained from the contact interaction was used to obtain the ratio for contact stiffness of Kc = 90MN/m as shown in the equation (4). A two-dimensional finite element model has been developed to carry out the contact pressure on the shoe lining.

$$k_{ci} = \frac{cp_i}{\sum_{i=1}^{n} cp_i} K_c \qquad (4)$$

The uniform contact which was obtained then was used to carry out the stability analysis using the complex eigenvalue method. The result showed that the non-uniform contact stiffness resulted in one unstable mode at frequency of 1452 Hz. This is a good sign for further analysis by using the contact stiffness ratio. However, there is a significant effect on the contact pressure from the leading edge to the trailing edge.

Abu Bakar et al. (2003) investigated the influence of contact pressure distribution on pad surface. The results showed that the higher contact pressure occurred at the leading edge than the trailing. Some modifications was made on the structures to improve the pressure distribution. The area of contact pressure may vary due to the orientation of the components installation. Increase in the contact area region would increase the uniform distribution, thus reducing the squeal index. The work based on tribology was also conducted by Abu Bakar et al. (2005). It was found that the contact area increased as wear progresses in time, hence more uniform distribution was achieved. It is a good reason for engineer to design the pad so that the geometry of the brake would be considered in order to have a good uniform contact and subsequently less partial wear at the certain portion of the pad.

The latest analysis conducted by Abd Hamid (2007) revealed that contact pressure distributions were not uniform due to out of roundness of drum brake. He measured the roundness of drum brake using Mitutoyo Roundtest RA-100 and the lining compression test using Universal testing Machine (UTM). He found that the inner drum wall exhibited an oval shape as shown in Figure 2.9. His study showed that the drum was not perfectly round as assumed by many researchers and resulted in the non-uniform contact pressure distribution, affecting the brake force and brake factor which was found to fall in the range of 0.5 to 2.0.

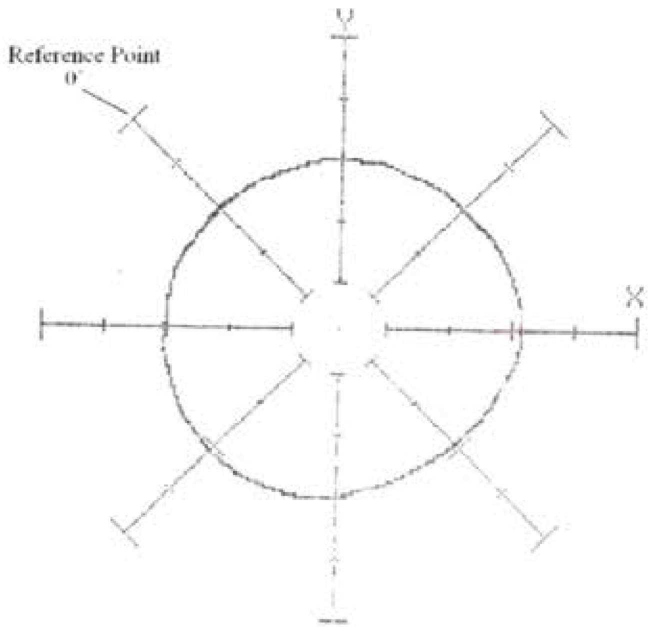


Figure 2.9: Inner profile of a motorcycle drum brake under 25mm scale using Mitutoyo Roundtest RA-100 (Abd Hamid, 2007)