THE SIMULATION OF BRAKE AND MODELLING OF BRAKE PAD ALERT SYSTEM FOR TEACHING AND LEARNING PURPOSES BASED ON CURRENT AUTOMOTIVE BRAKE PAD DESIGN

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ABSTRACT

Brake Pad Testing Apparatus was design for help student and instructor in teaching and learning application. The most important objective in this design is to differentiate the pressure effect and braking temperature condition of different pad. Before this, student and instructor only exposed by theory and not by practical which can give more knowledge and easy to understand the principle of braking system. This apparatus also can use to compare with data from calculation theory. This project involves three main parts such as structure, movement mechanism and related sensor. The main concept in this apparatus is thermocouple used to detect the temperature gain while braking process. Thermocouple attached to the pad on the same position for every pad and it will show the same error. Speed Motor Controller used for set the angular velocity of the motor in braking process. Pressure applied at brake pedal detect by Pressure Gauge and Data Logger functions as a connector to show the temperature gain at pads which detect by thermocouple in temperature versus time graph. Infrared Thermometer used for detect temperature at disc brake when brake applied. This apparatus also design base on anthropometric data for average of teenagers in Malaysia which made on a sample of university student. Results show that apparatus can function effectively by defines the different temperature when applied the different pressure and different pad. Pad C show the 88°C for Thermocouple 1 and 79°C for Thermocouple 2 at the 20 psi and infrared thermometer show 113°C for Pad C. Graph from calculation show that pad A have 216.48°C at 1000 rpm which have low temperature than pad B, C and D. High coefficient of friction and pressure applied will cause more heat generate than low coefficient of friction and pressure applied.

CHAPTER I

INTRODUCTION

1.1 Background Of Study

The braking system is considered by many people to be most importance system involve in the operation of a vehicle. The braking system provides the mean to slow down or to stop a vehicle. There are two main options in car braking system such as 'disc brake' and 'drum brake'.

Disc brake usually use for front wheels while the drum brake usually use for rear wheels. The advantages of disc brake are more stable, brake rotor will stay cleaner-more free of water, dust, or dirt and it will cause no distortion of the rotor than drum brake. "It also have much cooler operations than a drum brake because of the increased are that is exposed to the air flowing past it (Thomas W. Birch, 1999)."

The simplest way to stop a car is to convert the kinetic energy to heat energy. Brakes are essentially heat machine. They generate heat from friction by rubbing the

lining against the rotating rotors or drums. This friction can generate a large amount of heat but it's depending on brake pad & disc material.

1.2 Problem Statement

Different pad will give the different friction effect and heat generate. There are four types of brake pad that usually use such as organic linings, semi metallic linings, metallic linings and synthetic linings. All those four type of pad have different coefficient of friction, heat transfer ability, pressure effect, structure strength and working temperature.

As generally known, until now there are no testing apparatus which can determine all these different of pad and help in teaching and learning application. If only depends on theory, the detail information and knowledge which are importance things in teaching and learning application will not achieve.

This design focuses on of several sensors such as thermocouple, pressure gauge, tachometer and other sensor. These sensors will be a medium to give the importance data when the brake pedal pushed. The data also can be determined for suitable speed and pressure which can set for each experiment. This design also focuses on one caliper holder which can make easy to user to change the different brake pad.

1.3 Rational & Significance Of Study

Rational for this design is to design a testing apparatus which can show the result of temperature and pressure when applied the force for the different pad and disc. It also can be an experiment technique for compare with data which get from calculation. This testing apparatus is importance for teaching and learning application for give more knowledge and information to student.

This apparatus also can show to student what the suitable pad and disc depends on situation. The suitable pad and disc will give the high performance in braking system.

1.4 Objective

Design a testing apparatus which can differentiate the pressure effect and braking temperature condition of different pad.

1.5 Scope

1) Study the entire component involved in braking system and suitable sensor to detect the temperature, speed and pressure.

2) Study the best shape of testing apparatus depends on ergonomics factor.
3) Study the several types of brake pad and disc for example and manual documentation.

1.6 Importance Of Study

Importance of this study is the testing apparatus will be an experiment technique and will help student to get more knowledge and information about what they do. Data shown after experiment will be a comparison between manual calculation (theory) and experiment (practical). Student who uses this testing apparatus will be more understanding than others who just learn from theory.

By that, hopefully this testing apparatus will give more knowledge for instructor and student to be more understanding in teaching and learning application.

CHAPTER II

LITERATURE REVIEW

2.1 Brake

Brakes are heat machine. They provide stopping power by generating heat from rubbing of a friction material, the brake lining, against a rotating drum or rotor. The car slows down as friction produced by this rubbing action converts the energy of the moving car into heat.

The brake lining is attached to the brake shoes, often called pads when disc brake linings are discussed as shown at **Figure 2.1**. The lining must be able to rub against the drum or rotor without causing an excessive amount of wear to the drum or rotor surface. It also must be able to operate at very high temperature as several hundred degrees without failing.

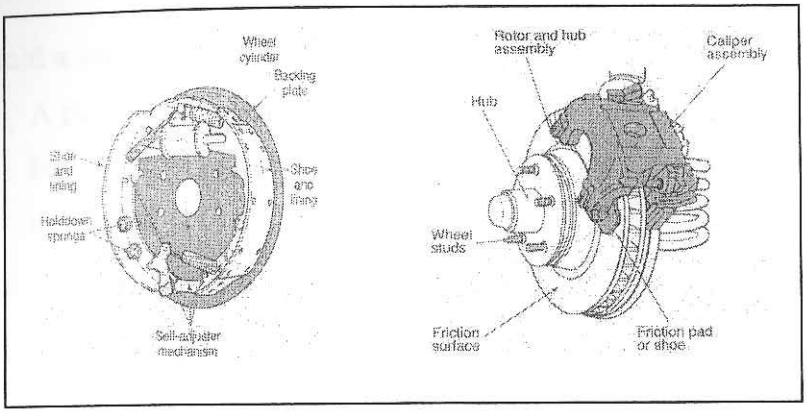


Figure 2.1: Basic Component on Disc and Drum Brake

2.1.1 Function Of Braking System

The safe operation of a motor vehicle requires continuous adjusting of its speed to changing traffic condition. The brake and the tires along with the steering system are the most importance safety-critical accident avoidance components of a motor vehicle. These general uses of the brake can be formulated in terms of three basic functions a braking system must provide;

1. Decelerate a vehicle including stopping
   - Involved the change of the kinetic and potential energy (if any) of a vehicle into thermal energy (Rudolf Limpert, 1999).
2. Maintain vehicle speed during downhill operation
   - Involved the transfer of potential into thermal energy. Importance considerations are brake temperature, lining fade, brake fluid vaporization in hydraulic brakes, and brake adjustment of air brakes (Rudolf Limpert, 1999).

3. Hold a vehicle stationary on grade.
   - A parking brake may be used for vehicle deceleration in an emergency, both thermal and vehicle dynamic factors must be considered by the designer (Rudolf Limpert, 1999).

2.1.2 Calipers

The caliper is the casting that is mounted over the rotor. It contains the brake pads and the hydraulic piston(s) that apply the pads. It must be strong enough to transmit the high clamping forces needed and also to transfer the braking torque from the pads to the steering knuckle as **Figure 2.2**.

The pressure between the brake pads and each side of the rotor should be equal to prevent flexing and bind at the wheel bearings and flexing or distortion of the rotor or caliper. There are two major types of caliper design that are found on both front and rear brakes.

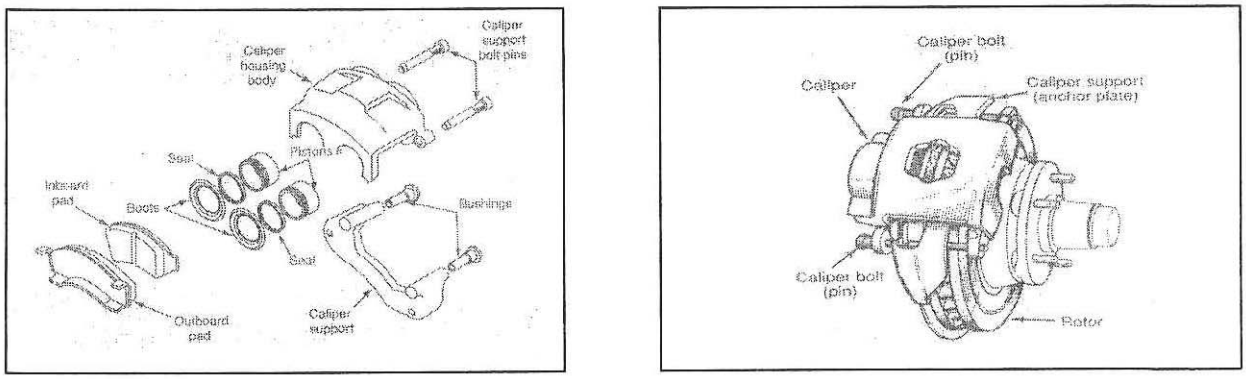


Figure 2.2: Disassembly Caliper & Floating Caliper

2.1.3 Brake Pads

Brake pads are the parts of a car's braking system that actually take the brunt of the frictional force necessary to stop the car. In a disc brake system, the brake pedal activates a hydraulic line which squeezes calipers against the rotors of the car's tires. Brake pads are positioned between the calipers and the rotors to absorb the energy and heat, and then provide enough grips to stop the car.

Disc brake pads have friction material attached to a steel backing. There are three methods used to attach the friction material to the steel backing: riveted, bonded, or integrally molded. Integrally molded linings have holes in the steel backing to allow the friction material to become a part of the steel backing. This process result in a brake pad that has a lot of strength and is resistance to sheering the friction material from the steel backing [5].

- **Riveted**. Holes are drilled through the friction material block, and brass rivets hold the block to the steel backing.
- **Bonded**. Friction blocks are glued to the steel backing.
- **Integrally molded**. The friction material is molded with the steel backing, rather than molded separately and then attached to the steel backing to allow the friction material to become a part of the steel backing.

2.1.3.1 Types of brake pads

There are four general types of brake pads for cars and trucks [2]:

Table 2.1: Advantages & Disadvantages of Lining Types (Thomas W. Birch, 1999)

Friction Material			
Type	**Ingredients**	**Advantage**	**Disadvantages**
Organic	Early: wood& leather Recent : asbestos +	Quiet, cheap, low abrasiveness, good cold friction	Asbestos content, Brake fade when hot
Metallic	Powdered metal	Fade-resistant	Poor cold friction, high pedal pressure, abrasive, noisy
Semimetallic	Combination	Fade-resistant, long wear life	Expensive, brittle, poor cold friction
Synthetic	Fiberglass Aramid	Good lining life, quiet, nonabrasive Very good lining life, quiet, nonabrasive	Expensive, not good for very high temperature Poor cold performance

Full race organic pads are available but they only work well at race temperatures (1100 F) and have drawbacks too severe for street use, such as at low/no friction at low temps. Softer organic race pads are available, and they do work better at lower temps, but their wear rate can be extreme. Typically only EE rated for friction.

Asbestos has not been used on new domestic cars since 1993, but it's still used in replacement linings. Asbestos is known to cause health hazard (Thomas W. Birch, 1999).

2.1.3.2 Friction Material Selection

The letters and numbers identify the manufacture of the lining material and the material used and the last two letters identify the cold and hot coefficients of friction.

These codes are not the primary factor for selecting replacement linings, they do not address lining quality or its hardness, but they do indicate the coefficient of friction, as follow as table above (Jack Erjavec, 2004).

Table 2.2: Code of Brake Pad Friction [2]

Kod C	Over 0.00 but not over 0.15
Kod D	Over 0.15 but not over 0.25
Kod E	Over 0.25 but not over 0.35
Kod F	Over 0.35 but not over 0.45
Kod G	Over 0.45 but not over 0.55
Kod H	Over 0.55
Kod Z	Not clasiffied

Although the coefficient of friction and hardness of lining can vary quite a bit for a same kind of material, approximate coefficient of friction values can be assigned to different lining materials;

Table 2.3: Approximate Coefficient of Friction [2]

Type	Cold	Warm
Organic	0.44	0.48
Semimetallic	0.38	0.40
Metallic	0.25	0.35
Synthetic	0.38	0.45

2.1.4 Disc/Rotor

The disc brake is a device for slowing or stopping the rotation of a wheel. A brake disc as shown at **Figure 2.3**, usually made of cast iron or ceramic, is connected to the wheel or the axle. To stop the wheel, friction material in the form of brake pads (mounted in a device called a brake caliper) is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of disc brake. Frictions cause the disc and attaches wheel to slow or stop.

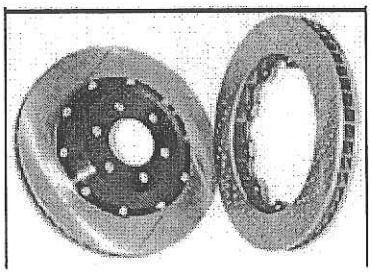


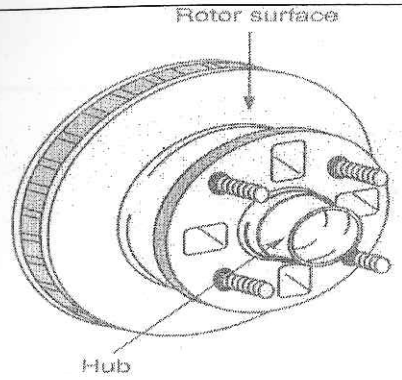
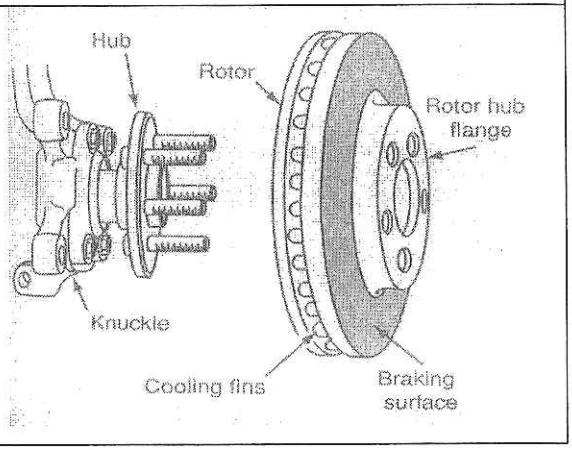
Figure 2.3: Disc/Rotor

Traditionally, brake rotors were manufacture as a single iron casting. The development of floating, two piece rotors and the need to reduce vehicle weight led to development of composite rotors. Composite rotors usually made from different material such as cast iron and steel.

2.1.4.1 Types Of Rotor

Rotor can be classified by the hub design as fixed (with an integral hub) or floating (with a separate hub).

Table 2.4: Different Between Fixed and Floating Rotor (Jack Erjavec, 2004).

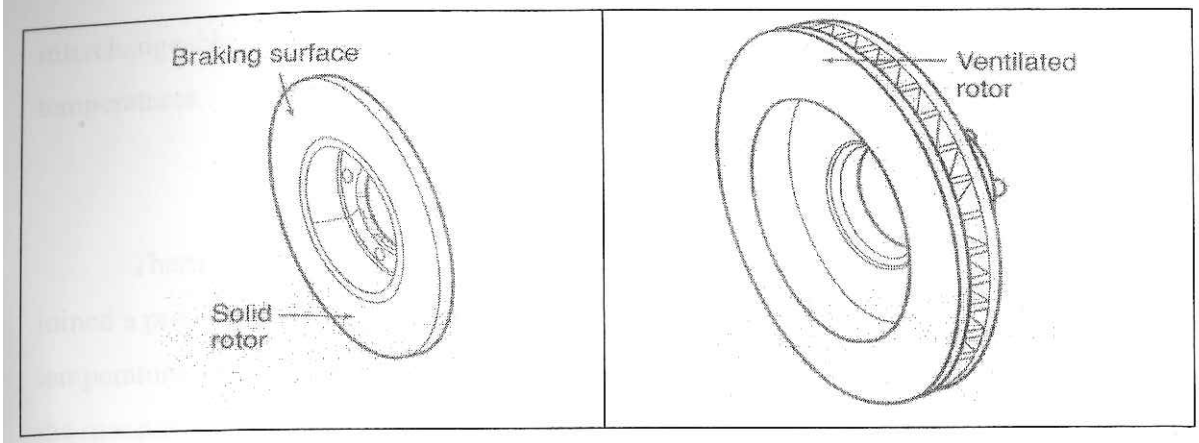
Fixed Rotor	Floating Rotor
Hub and rotor cast as a single unit	Rotors and their hubs made separately
More expensive	Less expensive
Heavier than floating	Replaced easily
	

2.1.4.2 Style Of Rotor

Basically, there are two styles or rotor used on passenger cars as **Table 2.5**:

Table 2.5: Different Between Solid and Vented Rotor [1]

Solid	Vented
Used on smaller cars	Used on heavier car (more braking heat)
Smaller in width, lighter and less expensive	Thicker, heavier and more expensive
Easy to manufacture	Can effect wheel balance (have balance weight installed)



2.2 Sensor

To design this apparatus, several sensor needed to show the data when the apparatus running. These sensors will show what happened during and after testing. There are two main sensors such as:

a) Thermocouple
b) Pressure Gauge

2.2.1 Thermocouple

Thermocouple is a temperature sensor and can also be used as a means to convert thermal potential difference into electric potential difference. They are cheap and

interchangeable, have standard connectors, and can measure a wide range of temperatures.

Thermocouples are based on the principle that when two dissimilar metals are joined a predictable voltage will be generated that relates to the difference in temperature between the measuring junction and the reference junction (connection to the measuring device).

Different thermocouple types have very different voltage output curves. It is also required that thermocouple or thermocouple extension wire, of the proper type, be used all the way from the sensing element to the measuring element (ISE, Inc., 2006)

2.2.1.1 Type of Thermocouple

There are several types of thermocouple and the selection of the type must consider wire size of thermocouple, length of thermocouple probe and location of thermocouple. Thermocouple types as shown at **Figure 1** at **Appendix A** can be identified based on wire insulation color.

2.2.2 Pressure Gauge

Pressure gauge is a sensor to detect the pressure applied. There are two main type of pressure gauge such as:

a) Analog Pressure Gauge
b) Digital Pressure Gauge

2.3 Ergonomic

Ergonomic is a most importance factor that must consider in design a new product. The anthropometric data as shown at **Appendix A** will make the design suitable for the expected user. Anthropometric data will give the designer detail dimension of the user and it will make the product perfectly.

2.4 Drive

There are three main equipments to make this apparatus rotate properly such as:

a) Motor
b) Pulley
c) Belt

2.4.1 Motor

There are many types of electric motors, some smaller than a human hair others large enough to power a locomotive. Common types of motors have no brushes and work only on alternating current. They may range in size from 0.25 up to 5 horsepower and they may reach about 100 horsepower or over (http://sawdustmaking.com/)

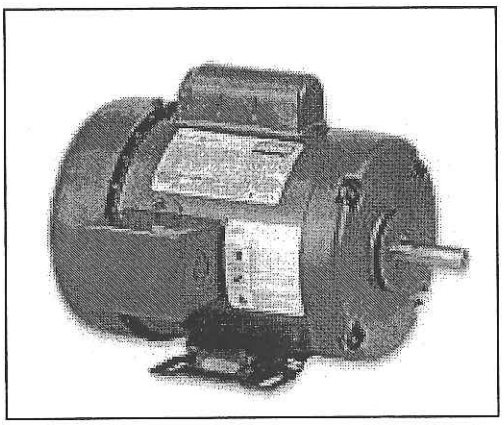


Figure 2.4: Electric Motor

2.4.1.1 Types of Motors

There are two common types of motors such as (http://sawdustmaking.com/)

a) Split Phase

The split phase motor is mostly used for "medium starting" applications. It has start and run windings, both are energized when the motor is started. When the motor reaches about 75% of its rated full load speed, the starting winding is disconnected by an automatic switch.

b) Capacitor Start

This motor has a capacitor in series with a starting winding and provides more than double the starting torque with one third less starting current than the split phase motor. Because of this improved starting ability, the capacitor start motor is used for loads which are hard to start. It has good efficiency and requires starting currents of approximately five times full load current. The capacitor and starting windings are disconnected from the circuit by an automatic switch when the motor reaches about 75% of its rated full load speed.

2.4.1.2 Phase, Voltage & Rotation

There are two type of phase such as (http://sawdustmaking.com/):

Single Phase

Ordinary household wiring is single phase, alternating current. Each cycle peaks and dips as shown. To run a three phase motor a phase converter must be used, usually this is not practical, it is often less expensive to change the motor on a machine to a single phase style.

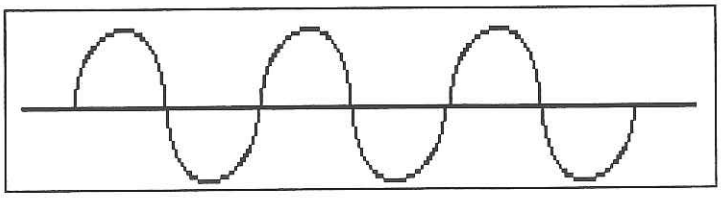


Figure 2.5: Cycle for Single Phase

Three Phase

This is used in industrial shops, rather than peaks and valleys the current supply is more even because of the other two cycles each offset by 120 degrees.

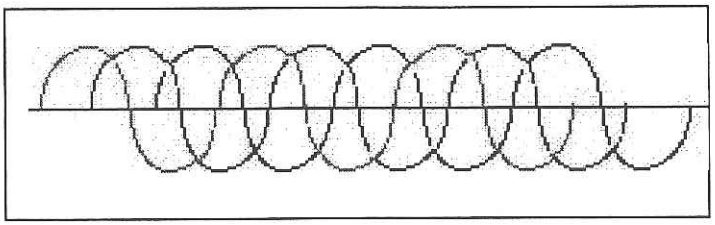


Figure 2.6: Cycle for Three Phase

Voltage

Many motors are dual voltage, by simply changing the wiring configuration they can be run on 110 volts or 220 volts. Motors usually run better on 220 volts, especially if there is any line loss because of having to use a long wire to reach the power supply.

Motors are available for both AC and DC current, your typical home wiring will be AC, there are DC converters available which are used in applications where the speed of the motor is controlled.

Rotation

The direction the shaft rotates can be changed on most motors by switching the right wires, there is usually a diagram on the motor. The direction of rotation is usually determined by viewing the motor from the shaft end and is designated as CW (clockwise) or CCW (counter-clockwise). Some manufactures may have a different method of determining shaft rotation but will usually make a note of it.

2.4.2 Pulley & Belt

Power can be transmitted to from one shaft to other shaft with belt (figure 2.8) which driven by drive pulley (figure 2.7) to another pulley. The loss in this system will make it not perfect power transmitted (Roslan Abd. Rahman, 2001).

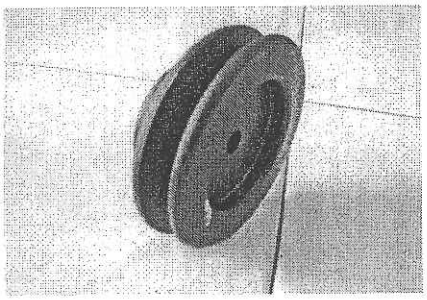


Figure 2.7: Pulley

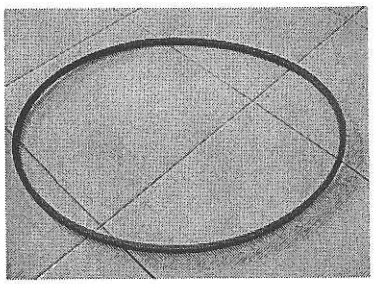


Figure 2.8: Belt

2.4.2.1 Pulley & Belt Selection

Belt selection are importance to make sure the power will transmitted perfectly. These are the factor which must be consider before choose the belt (Roslan Abd. Rahman, 2001).

a) Speed of the drive and driven pulley
b) Velocity ratio
c) Power transmitted
d) Distance of both pulley

2.4.2.2 Type Of Belt

The common type of belt are (Roslan Abd. Rahman, 2001).

a) Flat Belt
- Use in industry and workshop.
- Medium power transmitted
- Distance of both pulleys less than 8m.

b) V- type Belt
- Use in industry and workshop
- Medium power transmitted
- Distance of both pulley closer than round belt and flat belt.

c) Round Belt
- Use for industry and workshop
- Large power transmitted
- Distance of both pulleys about 8m.

2.4.2.3 Velocity Ratio of Belt

Length of belt over the drive pulley for one minute;

$$\pi N_1 d_1 \qquad \text{(Eq. 2.1)}$$

Length of belt over the driven pulley for one minute;

$$\pi N_2 d_2 \qquad \text{(Eq. 2.2)}$$

d_1 = Diameter of drive pulley

d_2 = Diameter of driven pulley

N_1 = Speed of drive puley

N_2 = Speed of driven pulley

$$\pi N_1 d_1 = \pi N_2 d_2 \quad \text{(Eq. 2.3)}$$

n = speed of drive pulley/speed of driven pulley (Eq. 2.4)

$$n = \frac{N_2}{N_1} = \frac{d_1}{d_2} \quad \text{(Eq. 2.5)}$$

So the ratio of velocity for driven and driven pulley can be conclude by;

$$n = \frac{drive \quad speed}{driven \quad speed} \quad \text{(Eq. 2.6)}$$

2.5 Friction And Heat Energy

The simplest way to stop a car is to convert the kinetic energy to heat. Heat is one of the more common, versatile forms of energy. This conversion occurs naturally when a car coasts to stop. Brakes are essentially heat machines. They generate heat from the friction by rubbing the lining against the rotating rotors or drums. Friction can generate large amounts of heat (Thomas W. Birch, 1999).

Because heat is a natural result of friction, the more friction energy needed to stop a vehicle, the greater the amount of heat generated during braking. The heat must be removed or it will damage the brake system (Jack Erjavec, 2004).

Braking performance of a vehicle can be significantly affected by the high temperature rise in the brake components. High temperature during braking may cause brake fade, premature wear, brake fluid vaporization, bearing failure, thermal cracks, and thermally-excited vibration (Kwangjin Lee, 1999)

Therefore, it is importance to predict the temperature rise of a given brake system and assess its thermal performance in the early design stage.

2.5.1 Temperatures

Temperature also affects the coefficient of friction, but it affects different materials in different ways. A moderate amount of heat increases the coefficient of friction of most brakes. The semimetallic and carbon fiber materials of some racing brake lining must be heated quite a bit to work their best. Too much heat, however, reduces the coefficient of friction, and as heat continues to increase, the coefficient of friction continues to drop. This lead to brake fade and braking efficiency is reduced (Jack Erjavec, 2004).

2.5.2 Thermal Analysis (Lee, Abd Rahim and Shahrulizam, 2007)

The dissipate energy convert into heat is specified as all the mechanical energy is converted into thermal energy. Heat is generated in surface between the disc and the

brake pad when disc rotates. Lee, Abd Rahim and Shahrulizam, 2007 state that this could be expressed as:

$$q = \mu V p \qquad \text{(Eq. 2.7)}$$

Where μ is the friction of coefficient, V is sliding velocity of the disc and p represents the contact pressure at the interfaces and q is the amount heat generated by friction.

For the exposed region of the disc and brake pads, it is assumed that heat is exchange with the environment through convection. Therefore, convection surface boundary condition is applied. This can be expressed as:

$$-k\left.\frac{\partial T}{\partial x}\right|_{x=0} = h[T_\infty - T(0,t)] = \mu V p \qquad \text{(Eq. 2.8)}$$

Where h is convection heat transfer coefficient. T_∞ is atmosphere temperature and T(0,t) is the current temperature at node. Finally, at the surface of the back plate, adiabatic or insulated surface boundary condition is used. This can be expressed as:

$$-k\left.\frac{\partial T}{\partial x}\right|_{x=0} = 0 \qquad \text{(Eq. 2.9)}$$

which means there is no heat transfer through the back plate. The reason of applying this kind of boundary condition is that it does not allow the heat transfer to the other disc brake component through back plate.

2.6 The Existing Tester

Actually, there are no existing testers for brake pad temperature for teaching and learning application. The already testers only focus on brake performance by overall. These are the several type of existing tester which can be some reference of this design.

2.6.1 On Road Brake Testing (V. Arunachalam, Gokul Dass T.V., 2001)

On-Road Brake Testing (Figure 2.9) focuses on an in-vehicle data acquisition system to test motorbike front-wheel disk brakes. It can record all the required signals from the motorbike during the trials and on-board analysis capabilities for the tester to see the results of the test while on the road.

The primary end result is the braking distance the minimum distance required for the motorbike to come to rest from a given speed on a level road. The braking distance measured by conducting road trials depends on several factors other than the brake system, such as the coefficient of friction between the tire and the road, the weight of the motorbike with the rider and the weight distribution, and the skill of the rider. By