STUDY AND ANALYSIS OF A PANTOGRAPH ATTRIBUTES FOR AN ELECTRIFICATION OF HIGH SPEED TRAIN

NUR' RABIATUL TADAWIYAH BINTI MOHAMMAD ADI

A report submitted in partial fulfillment of the requirements for
the degree of Bachelor of Mechatronics Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

I hereby declare that I have read through this report entitle “**Study and Analysis of a Pantograph Attributes for an Electrification of High Speed Train**” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering.

Signature : ……………………………………………………………

Supervisor’s Name : Dr. MUHAMMAD HERMAN BIN JAMALUDIN

Date : 18.5.2018

I declare that this repot entitles “**Study and Analysis of a Pantograph Attributes for an Electrification of High Speed Train**” is the result of my own research except as cited in the references. This report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :……………………………………………………………………..

Name : NUR’ RABIATUL TADAWIYAH BINTI MOHAMMAD ADI

Date : 18.5.2018

To my beloved mom and dad.

ACKNOWLEDGEMENT

In preparing this report, I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thought. In particular, I wish to express my sincere appreciation to my main project supervisor, Dr. Muhammad Herman Bin Jamaluddin for encouragement, guidance critics, motivations and friendship. Without their continued support and interest, this project would not have been same as presented here.

My fellow friends should also be recognized for their support. My sincere appreciation also extends to Mohd Murtadha Bin Roslan for helping me in doing this final year project 2(FYP 2). Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space.

I am grateful to all my family members especially both of my parents for the non-stop encouragements and advices that always inspired me in finishing this report.

ABSTRACT

Pantograph is part of train that mounted on the roof top of the train to collect the current from the overhead line into the train systems which controlled by the actuator to uplift the arm to touch the catenary. The aim of this study was to analyze the attributes of pantograph for an electrification of high speed train which are the material used for contact strip and the force needed to uplift the pantograph. A simulation was constructed by using Matlab and SolidWorks software to test the performance of the pantograph system based on the materials used and the force applied. The materials used in MatLab are copper-magnesium and copper-cadmium. The material used in SolidWorks are pure carbon, and copper for the pantograph and the force was fixed to 54N which is the nominal force. The measurements were shown to measure the condition of the materials after the simulation. This study showed the performance can be improved by using material that has the best attributes for pantograph. This indicates that there is possibility to increase the maximum speed of the train so it can minimize the travel time.

ABSTRAK

Pantograf adalah sebuah alat yang terletak di bahagian bumbung kereta api bagi mengumpul arus dari wayar sentuhan ke sistem kereta api yang digerakkan oleh penggerak untuk mengangkat pantograf untuk menyentuh wayar sentuhan. Tujuan kajian ini dijalankan adalah untuk menganalisis sifat-sifat pantograf untuk kereta api elektrik berkelajuan tinggi yang digunakan untuk jalur hubungan dan daya yang diperlukan untuk menaikkan pantograf. Satu simulasi dilakukan dengan menggunakan perisian Matlab dan SolidWorks untuk menguji prestasi sistem pantograf dengan daya yang telah ditetapkan. Bahan yang digunakan dalam MatLab adalah "copper-magnesium" dan "copper-cadmium". Manakala bahan yang digunakan dalam SolidWorks adalah "pure-carbon" dan "copper" untuk pantograf dan daya telah ditetapkan kepada 54N yang merupakan kuasa nominal. Pengukuran ditunjukkan untuk megukur keadaan bahan selepas simulasi. Kajian ini menunjukkan prestasi boleh diperbaiki dengan menggunakan bahan yang mempunyai sifat terbaik untuk pantograf. Ini menunjukkan bahawa terdapat kemungkinan untuk meningkatkan kelajuan maksimum kereta api supaya dapat memendekkan masa perjalanan.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF FORMULA

Chapter 1

Introduction

1.1 Introduction

To study and analyze of pantograph attributes for an electrification of high speed train is the purpose of this project by analyzing every single characteristic that can affect the performance of pantograph and develop a model of pantograph based on the desired design. This chapter will explain about motivation, problem statement, objective, and scope of this project.

1.2 Motivation

These days, most people uses public transport rather than their personal transport. In term of economical factor the public transport travel is cheaper than using personal car [12]. Thus, it can save money and just pay for each trips [12]. While, due to the oil stock decreasing it might help to reduce dependent on it. It is because the journey is less stressful compared to driving. Besides, can used the time to read, listen to music or simply relax [12]. Lastly, by using public transport can improve the environment rather than driving motor vehicles. This is because the train are using electrical and not producing any smoke. In addition, this might help to reduce the number of pollution air [12]. Besides, in term of social it can reduce the amount of injuries by car accidents [13]. It also requires less land use than road infrastructure [13].

The train has the fastest speed for this time being. This shows inventor right now are racing to invent a train with very high velocity. So, any research that relates to improve the speed and the performance of the train is a highly valuable research. In addition, developing lightweight manufacture techniques for the carriage bodies, for the nose sections of multiple-unit trains which are particularly vulnerable in collisions as well as for the interior of high-speed trains [11].

Pantograph is the important thing while operating the train. Formerly, the pantograph geometry was seen in the foldable parallel linkage used on electric locomotives to keep a current-collector bar in contact with the overhead wire [14]. The pantograph needs to be improved for a better performance so that it can works at the best of its state. Besides, it also to reduce any disturbances or noises so that the system can rid out any waste in the system such as electric, current, and the damage taken on the material. This makes the study on the attributes is an important thing to choose the best materials and method to operate the pantograph.

This analysis of study about attributes of pantograph can be kept for reference to next generation's research. This also will provide them with ideas and inspiration. Besides, this is one of the guideline for them to study about pantograph of high speed train. So, the next generation can come out with a better research of study if there is any lack or mistakes in this research. Or they can produce any new idea and new material for designing a pantograph.

1.3 Problem Statement

Pantograph can be classified into several type which are the contact strip, the type of pantograph either single arm or double arm, controller and the catenary. Nowadays, high speed train is one of the most things people want to develop because train is the most used transportation for travelling even in short distance. In order to design a good pantograph, selecting the best material is the first thing that must be considered. The first thing is to select the best material for contact strip either pure carbon, carbon/carbon fiber, carbon/metal fiber, carbon/copper, or Ti3SiC2. By selecting the best material for contact strip, it may longer the life time of the catenary. In addition, the contact strip also will last longer. So, the pantograph can work perfectly and can prevent any damage that may occur.

Second problem that came out while studying this research is how to design a pantograph either using single-arm or double-arm. Many advantages and disadvantages in both design. By considering all of the pros and cons, the best design will be used in designing the pantograph. This is because when the high speed train is operating the mechanism of the pantograph should work properly to avoid any circumstances such as contact loss that will produce sparking which can cause damages to pantograph and the electricity of the whole system. If this damage happens, the cost to repair and cover the broken part will take a lot of budget, so that the damage must be avoided.

Next, choosing the suitable material for catenary was the one of the big problems had been faced. Catenary is a cable wire to supply the current to the pantograph. It is a medium for current to pass through to the pantograph. Material that can be used for the catenary are copper-cadmium, copper-tin alloy, copper silver, and aluminum. But which material is the most suitable for the catenary to work evenly on supplying the current. The catenary works with the pantograph in contacting the contact strip. This relation same like the previous point mentioned before. The best material will longer the life time of the contact strip, so that it can reduce the possibility of the pantograph of being collapsed.

Last but not least, analyzing the stiffness of the spring is a need to take serious factor in succeeding this research. The spring is to uplift the pantograph from its initial state until it touch the catenary and return to initial state. The spring must lift the pantograph smoothly, so that the contact strip can touch the catenary at any conditions to avoid sparking. The attributes that affect the stiffness of the spring are the material of the spring, the force to extend and retract, and the thickness of the spring.

1.4 Objective

The objective of this project are:

1) To study the attributes of an efficient pantograph so that it can work at the best performance.
2) To analyze the attributes of pantograph that had been studied by simulation.

1.5 Scope

The scope below should be focused in order to achieve the objectives of this project:

1) The best pantograph performance is chosen by studying the attributes which are speed, temperature, material, and its effect at high and low temperature, high and low speed.
2) The method is measured by using formulas to calculate critical speed, friction force, heat produce, and temperature on catenary.
3) The attributes are simulated by using SolidWork and MatLab.
4) The material used for the contact shoe is pure carbon and there are two types of material for catenary which are copper-cadmium and copper-magnesium.

Chapter 2

Literature Review

2.1 Introduction

This chapter will discuss on the previous project research that related to attributes of pantograph. The collected information will be arranged to some literature review by analyzing the information to interpret them.

2.2 Project Background

A force that requires any contact is called contact force. For commonly seen connections, contact forces are occur and take part in macroscopic group. Usually contact forces will appear in daily life such as when kicking a ball, pushing or pulling object and even walking or running. The first situation shows contact force is applied in a short moment of impulse while the second situation presents a continuous force applied when pushing or pulling an object. The fundamental natural forces are known as non-contact forces. The connection are high and low that mainly deal with forces and atoms of matter. Besides, using the macroscopic rule, the only thing that clearly be seen is gravitational effects. Based on the electromagnetic force that connects the contact force between molecular with quantum of physics, the connection from protons and electrons with the macroscopic objects are hardly to describe. To overcome this problem, the contribution of a function by flattening the disruption impact of the forces. This situation is well described in Hertzian theory of contact force law. 30 years ago, a lot of train system had been replaced with copper magnesium alloy. This is because the use of copper-cadmium is hazardous with contain of carcinogenic which a substance can cause cancer.

Another name for contact strip is the contact shoe. This contact shoe is located at the surface of a pantograph pan head and it slide along the overhead line. The contact strip is used to collect the current from the overhead line. The material for the contact shoe can be any type of material [6]. The contact strip can be thinness cause of friction occur during the sliding between catenary and contact strip. On a stud contact system the contact shoe is called a *ski collector*. Other than pantograph that used a contact strip the bus at UK also use the contact strip it is called as guides bars or on trolley wires.

In the train system, for an electrification high speed train the locomotive is move by the electricity current supply from the substation to the catenary. A 25 kV, 50 Hz AC has become an international standard in railway electrification use. A pantograph, bow collector and so on is use on the electric trains or electric bus to collect the current from the overhead line.

The pantograph is on the apparatus that mount on top of the body electrification train. The pantograph is a device that help the contact strip to touch the overhead line all the time during the train is operate [1]. The friction between a pantograph and catenary produce a noise due to the aerodynamic theory. Some experiment will be construct to analyze the noise or vibration data in different sector.

Temperature that presence due to the friction between the overhead line and contact shoe. The friction can be reduce by minimizing the contact force between catenary and sliding plate. The shape of the contact surface might be change because of the friction and heat. In addition, the temperature also might be increase due to R.HoLM method. Experiment is conducted by using respectively different supply current and force given is measured. The voltage also will increase if the voltage drop increase.

2.3 Previous Research of pantograph attributes for an electrical high speed train.

2.3.1 Contact strip

There are many type of contact strip that be used on the train pantograph to collect current from overhead line which are carbon fiber, metal fiber, copper and Ti3SiC2. For each of them have their own advantages and disadvantages itself**.** Carbon fiber is the one of material used for a sliding plate at the pan head of a pantograph, this material has excellent in anti-friction, damage resistance and self-lubrication with low density, high strength and suit for high temperature. But this carbon fiber takes a long time assembling to produce it and high cost [4]. Next, other material is metal fiber composite is manufacture by cold pressing after sintering. This material contact shoe is fitter than metal-impregnated carbon contact strip in term of the conductivity and impact resistance. This metal fiber material the overall conductive quality of contact strip will decrease perilously once there is reinforce damage [6]. Next, copper material is an excellent sliding conductivity physical this is because the material has a good self-lubrication, electrical, thermal conductivity [7], high strength and toughness. Disadvantage of copper material is this material is not damp or react at high temperature. Lastly, this material manufactured and was first made with method of chemical vapor deposition in 1970s by Jeitschko and Nowotny is known as Ti3SiC2 new ceramic material [8]. This material have many advantages which is not only good self-lubrication, electrical conductivity, high temperature resistance, oxidation resistance, thermal conductivity but it easy machining identical to metal physical and the mass is light similar to ceramic material. Ti3SiC2 on a pantograph contact shoe for prevent the wear and friction, arc burning erosion and coupling damage as having great guiding significance [9]. To become the production material for pantograph contact shoe there's a list of industrial technology transmission issue needed to resolve.

2.3.2 Contact Force

Between the pantograph and the catenary the contact force variation occurs [1]. Besides, due to the vibrations between the pantograph and overhead line it might be a contact [2]. Maximizing the contact force can prevented the loss of contact occur [2]. The contact losses, electric arc formations and sparking when it had a contact [3]. Besides large contact force causes mechanical damage to the pantograph [4]. Developing an active pantograph with a pneumatic actuator, and proposed a sliding mode with a rigid frame model in order to regulate the contact force [20]. The contact force should never descend to zero to avoid contact loss in active condition [1]. By minimize the variation in the force by providing closed loop control an active pantographs have the quality of improving the current collection [2]. While in active conditions, the contact force should never descend to zero to avoid contact loss. It has been estimated that 30% of the contact force variation is contributed by the vertical vibration at frequency of lower than 16Hz [1]. At static conditions, the pantograph should be designed to provide a constant nominal contact force of about 54N [13] between the contact strip and the overhead contact wire. The force equation can be written as,

$$f_1 = (y_c - y_{p1})k_c + (\dot{y}_c - \dot{y}_{p1})C_c \tag{2.1}$$

Where,

f_1 = contact force

y_c = contact point displacement

y_{p1} = contact strip displacement

k_c = contact spring stiffness

$\dot{y}_c$ = change of contact point displacement

$\dot{y}_{p1}$ = change of contact strip displacement

C_c = damping parameter respectively

The evaluation of control force is calculated using cost function (CF) with formulation of the sum of area under the graph of contact force about the nominal contact force (f_{1N}) [4] :

$$CF= \sum[\frac{v}{3.6}\left(\frac{\Delta t}{2}\right)(|f_{1i} - f_{1N}| + |f_{1i+1} - f_{1N}|)] \tag{2.2}$$

Where,

CF = cost function

f_{1i} = force

f_{1N} = nominal contact force

v = travelling speed

Δt = time interval between data

It has been also estimated that 30% of the contact force variation is contributed by the vertical body vibration at frequency of lower than 16 Hz [16]. The contact force should never drop to zero to prevent contact loss [1]. Besides, in order to minimize the effect of the disturbance on the contact force, some of the closed-loop poles must be assigned in exactly the same location as the catenary poles, yielding pole-zero cancellation [3]. This loss of contact can be prevented by maximizing the contact force but it results in large wear and tear on the system [15].

2.3.3 Catenary

Catenary is the importance element of electric railway traction system [2] to supply current to the locomotive so that the train can move. The elasticity of the catenary is not fixed over the span [9]. Damping force depends on the material wire that be used [4]. Due to different stiffness of the catenary, the pantograph will be subjected to upward and downward oscillation while moving [2]. Besides, dynamic damper with viscous damping element was added in order to avoid sparking [4]. The catenary conductor is usually made of cadmium-copper material to increase its tensile strength. The elasticity of the catenary is not fixed over the span [2]. The critical speed can be calculated by using the formula [5]:

$$c = \sqrt{\frac{T}{\rho S}} \tag{2.3}$$

Where,

C = Critical speed

T = Tension

ρ = Density of wire

S = Cross sectional area wire

In order to guarantee a continuous contact between the catenary and the head of pantograph is avoiding excessive power loss. Figure 2.1, 2.2 and 2.3 shows that the catenary must be maintain in a horizontal position [10]. It must also be rigid enough to interact in a dynamic way with the pantograph. Thanks to these droppers & tensioning loads. With the droppers & tensioning the wire will maintain in the horizontal axis. The support point is to support the messenger wires, hanger and droppers.

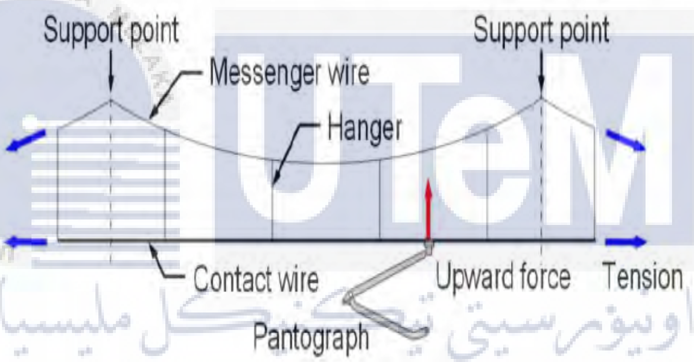


Figure 2.1: structure of contact wire system [10]

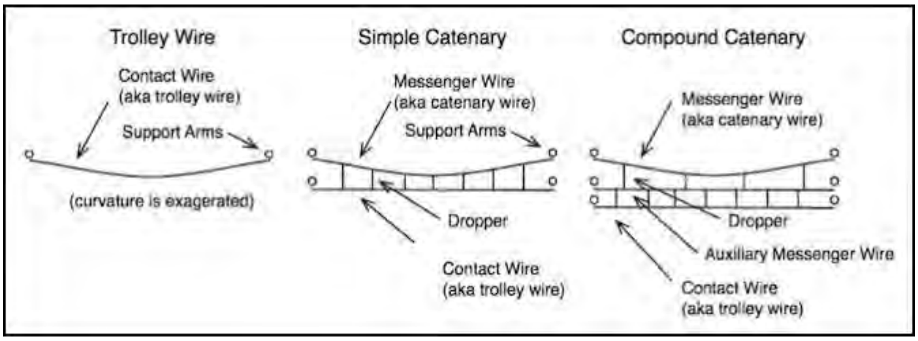


Figure 2.2: Catenary [10]

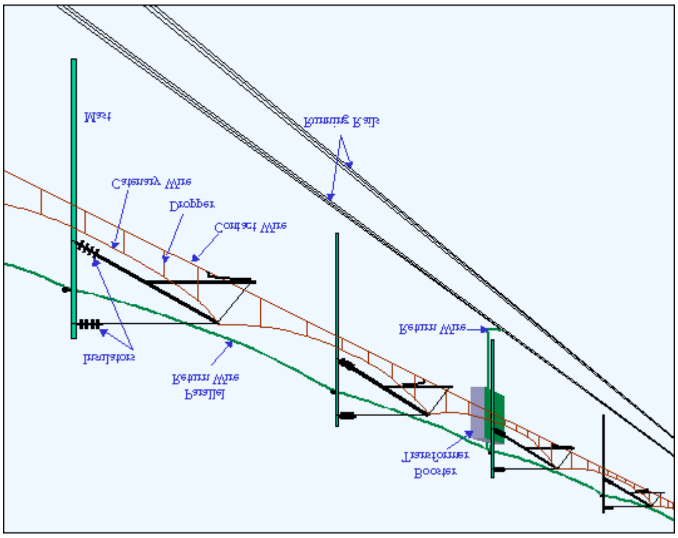


Figure 2.3: Transmission line [17].

.

In addition, there several type of material for catenary that can be used such as copper-cadmium, copper-tin alloy, copper-silver, and copper-magnesium [5]. Copper Magnesium has the highest tensile strength when compared to other alloys, making it the perfect alloy for contact wire in high speed lines with speeds well above 300 km/h. Together with the CuCd, it is the preferred alloy for the messenger cables, having the appropriate strength to carry the entire catenary system. Copper Cadmium combines high strength with good conductivity, making it the best-balanced bronze alloy available. With unsurpassed flex life, CuCd is highly resistant to the frequent vibrations that dropper wires need to withstand, and make it the ideal choice for high energy efficiency, reduced voltage drops and operational cost savings. The development of a high performance Copper-Tin alloy was an imperative, displaying the right balance of electrical and mechanical properties. CuSn has applications for use in the contact wires for both high-speed and conventional railway lines. Copper-Silver offers electrical and mechanical characteristics similar to those of ETP copper, but has better thermal stability [5]. This allows higher overcurrent on DC lines, without increasing the wear on the contact wire. Ideal for contact wires in high frequency, conventional railway lines. Copper ETP is still the most universal metal, but is increasingly being replace by alloys with better characteristics. Non-alloyed Cu offers the best possible conductivity, and is typically used in contact wires for tramways and conventional railway lines, but is most appropriate for auxiliary conductors and feeder cables [5]. Aluminium, with its lower weight and lower cost, is best used in return and feeder cables. Lamifil, with its expertise in Aluminium manufacturing, offers an extensive range of in-house produced aluminium cable types: All Aluminium Conductors (AAC), All Aluminium Alloy Conductors (AAAC) and Aluminium Core Steel Reinforces Conductors (ACSR).

In transmission line, Sag is an important this is to ensure the catenary under safe tension. If the catenary tension is too strain, so the conductor under unsafe condition this might be the conductor to break. In order to ensure the contact wire in safe strain condition, it can be minimize by providing the Sag [17]. Figure 2.4 shows the mechanism when Sag was applied at the same level of support conductor. Figure 2.5, shows that the very less Sag at same level for support conductor.

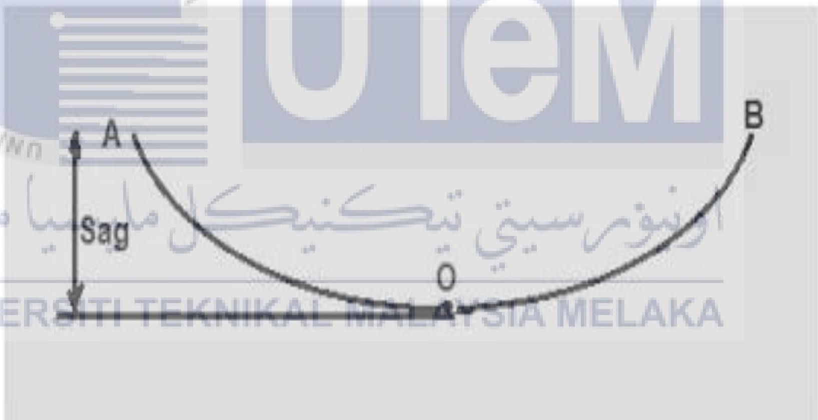


Figure 2.4: Sag with same level of conductor support [17].

Figure 2.5: Support of conductor at same level but the Sag is very less [17].

2.3.4 Vibrations

Nowadays, many problem happen during the train system is running. There might be many reason. In this case the train system faced a contact loss, this is because why the train delay and so on. The contact loss is happen because of the vibration on the overhead line [2]. In order to solve this matter, the value of the contact force must be reduce so that the vibration is less. Besides, there have a solution on how to reduce the vibration by applying the controller on the system such as fuzzy logic control [2]. Indeed, the vibration cancellation is might use to reduce the vibration. By using the Matlab Simulink the control system design was create, the input must be the amount of the vibration from the system given [2]. Moreover, the system also can be compared with the PID controller to differentiate which of the output is improving the system [2]. Figure 2.6 is the block diagram for the system.

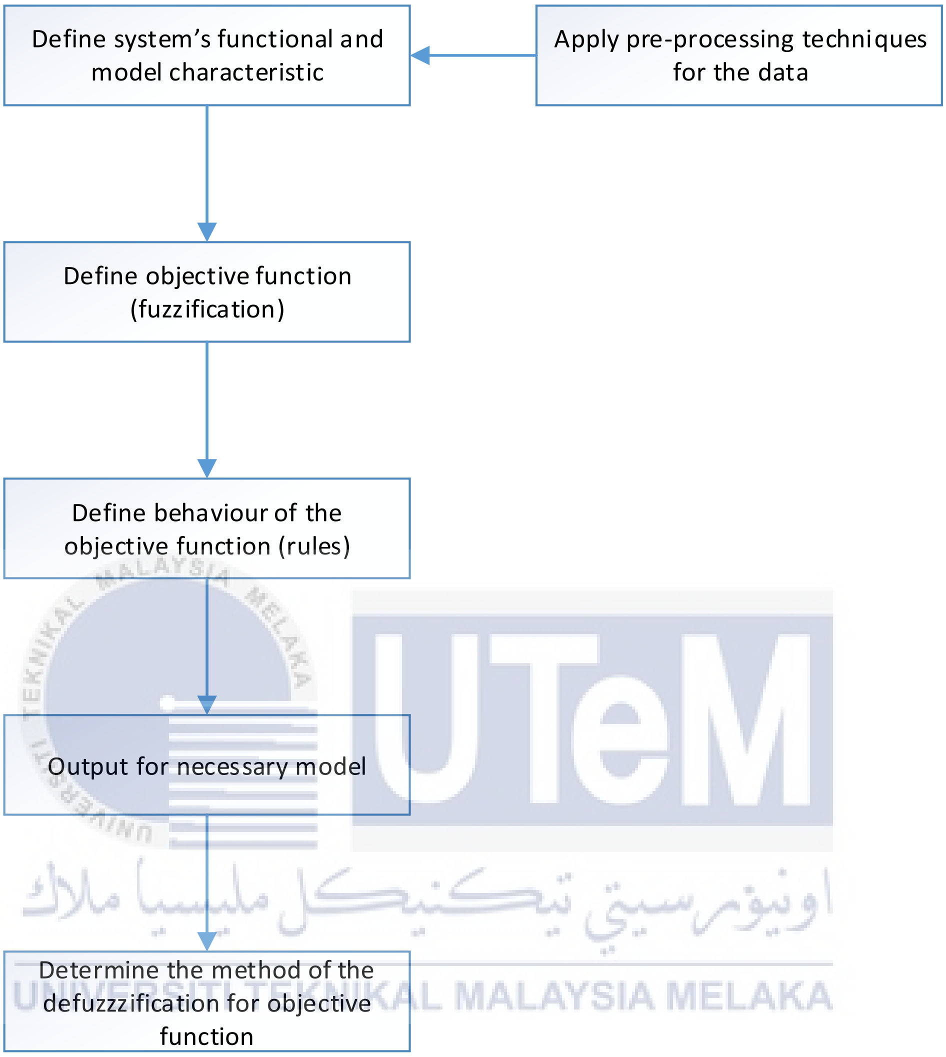


Figure 2.6: Block diagram for fuzzification [2]

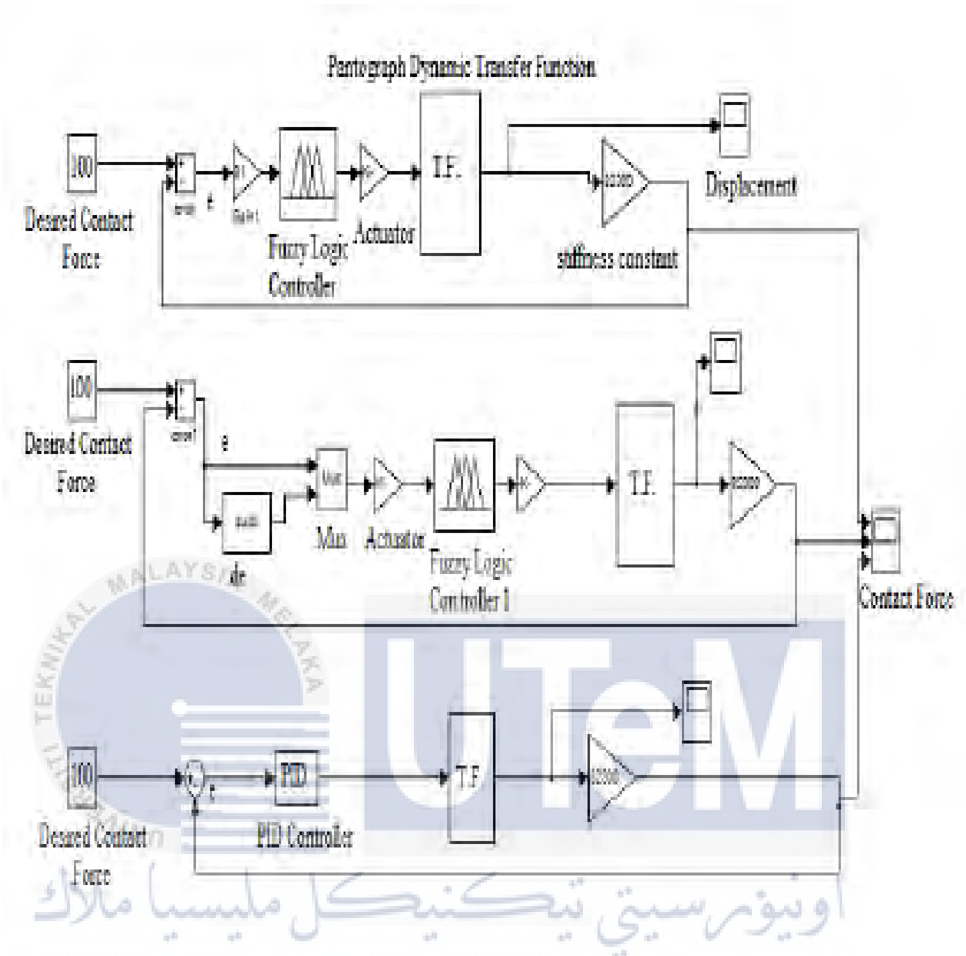
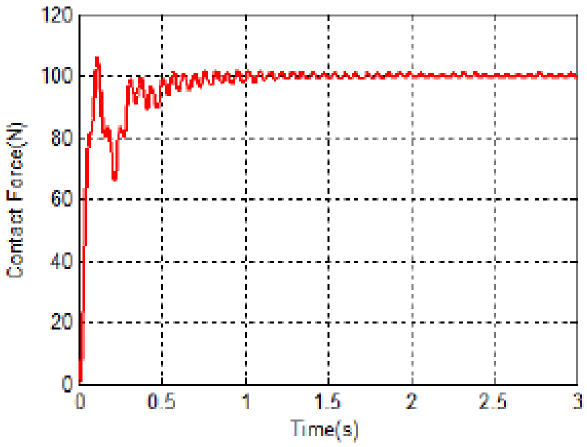
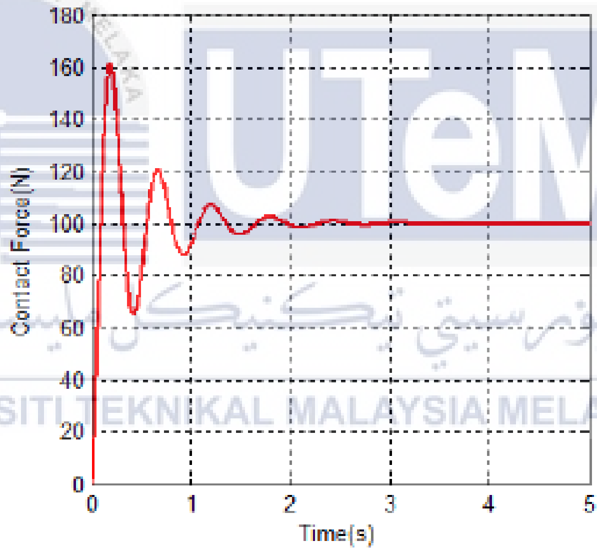


Figure 2.7: Simulink model of PAC system [2]

Figure 2.7 is the design of fuzzy logic controller and the PID controller are simulated in Matlab-Simulink. In this systems the force given is set to 100N as the input to the pantograph-catenary systems [2]



(a) PID controller [2]



(b) Triangular functions [2]

Figure 2.8 the output for one input fuzzy logic

Figure 2.8 (a) shows the response using PID controller for the system. The values of K_p, K_i, and K_d are 0.89, 11.5, 0.005 respectively [2]. Figure 2.8 (b) show the results of single input fuzzy logic controller with sigmoid with five input membership functions. It is observed that the response with sigmoid membership function is best with less overshoot and settling time [2].

2.3.5 Temperature

Traction current cause the temperature rise. This is because the contact surface shape change. Temperature rises faster when the current increase. While, temperature decrease when the voltage drop decrease [8]. The voltage and maximum contact fore influence the temperature on the catenary and it can be calculated by the formula theory proposed by R.HOLM [8]:

$$T_m = \sqrt{\frac{U_j^2}{4L} + T_0^2} \tag{2.4}$$

Where,

T_m = Maximum temperature of contact spots

U_j = Voltage drop

L = Lorentz number ($2.4 \times 10^{-8} (V/K)^2$)

T_o = Room temperature ($22.5°C$)

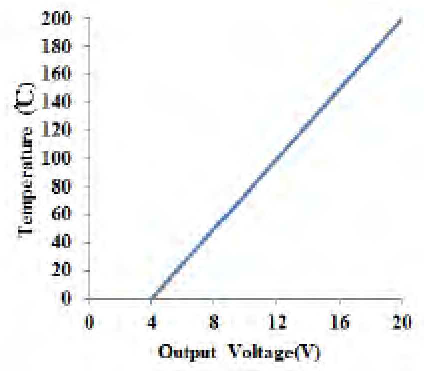


Figure 2.9: Temperature Measurement [8].

Figure 2.9 shows the relationship between output voltage and the temperature. When the voltage increases, the temperature also increase.

Figure 2.10 and 2.11 are the result of the slipper temperature versus time with different loads and current supply. When the contact pressure reduces, the pantograph temperature shift faster, the final temperature is higher. The graph shows that when the supply current is high the slipper temperature rise according to time.

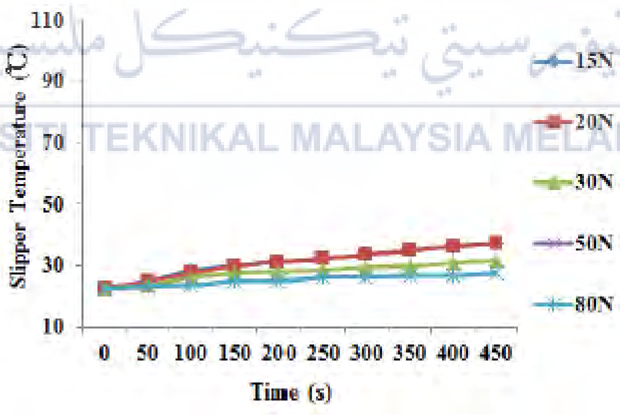


Figure 2.10: 60A [8]

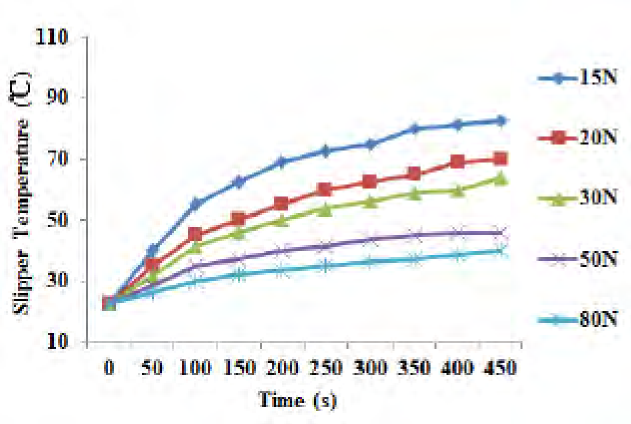


Figure 2.11: 120A [8]

2.4 Synthesis of information

Based on table 2.1 above, design for a few fuzzy controllers for the pantograph-catenary system is selected to cancel reduce the vibration from the system. It is selected based on the needs to improve the performance in the system. This is because the vibration is the cause for the lost contact of pantograph with the overhead line. In addition, this method can use to minimize the vibration by using the fuzzy logic control. Besides, the material of contact shoe also play a big role to collect the current collection from the catenary.

Table 2.1: Different method of a pantograph system

Paper	Attributes	Explanation	Experimental setup
Research status and Development Trend of Pantograph contact strip materials [6].	• Material of contact strip.	1. List of material for contact strip: • Carbon/carbon fiber, • Carbon/metal fiber, • Carbon/copper, • Ti3SiC2	No experimental setup.
Design and study of active controllers for pantograph-catenary [2].	• Vibrations . • Contact loss.	• Fuzzy logic control is use to minimize the vibrations. • Contact loss occur with presents of vibrations.	• Design a few fuzzy controllers for the PAC system.
Optimization of high-speed railway pantographs for improving pantograph-catenary contact [18].	• Contact force. • Contact loss.	• Minimize the mean pantograph contact force. • Using the lower stage pneumatic actuator can be controlled the contact force.	• Constructio n of the FRF from the dynamic response of the harmonic excitation.

The study on electrical temperature caharacteristics of high speed pantograph [8].	• Temperature of catenary.	• Maximum temperature calculated according to theory proposed by R.HOLM.	• Measurement of pantograph-catenary contact pressure drop.
Active control of high-speed railway vehicle pantograph considering vertical body vibration [1].	• Contact force. • Vibration	• Contact force occur between the pantograph and catenary causes of vertical vibration	• Vibration cancellation control is applied.

Chapter 3

Methodology

3.1 Introduction

In this chapter, the methodology to obtain the intent of this project is discussed. This chapter contain about the method used for choose the best pantograph attributes for high speed train. The flow chart below shows how the step that need to done during organize this project.

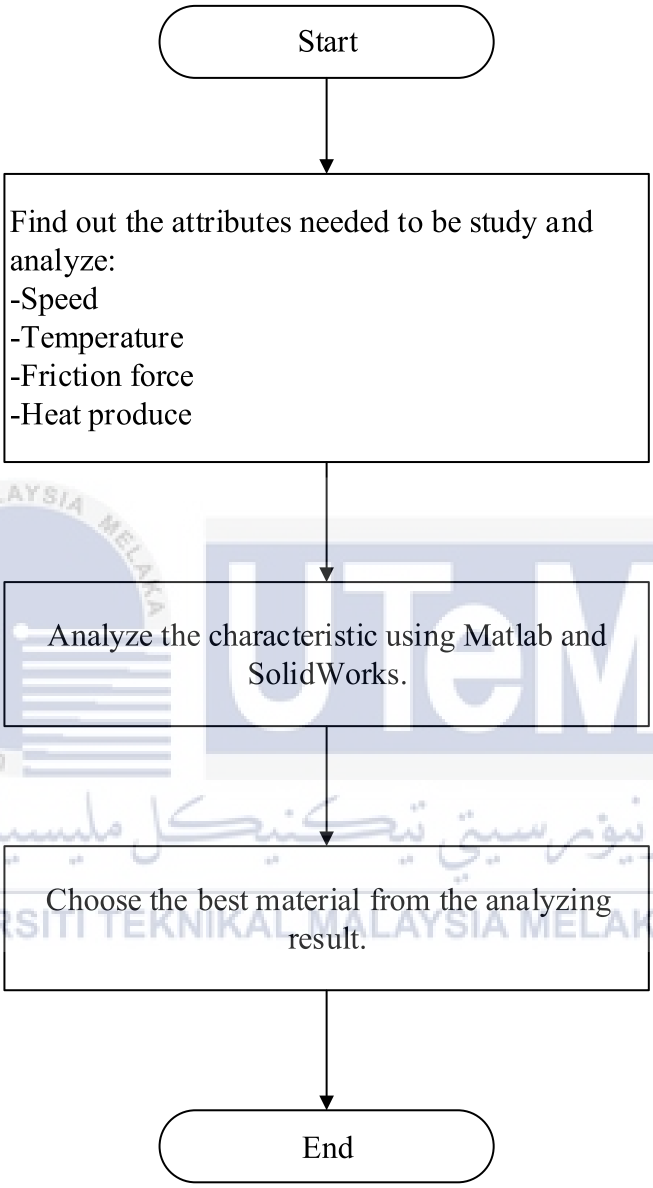


Figure 3.1: Methodology of the project.

3.2 System Overview

Figure 3.2 shows the overview of the system. The pantograph is designed based on August Stemman pantograph to illustrate the methodology. Copper-Magnesium had been choose as a catenary material. The attributes of pantograph had been analyze such as temperature, density of catenary, tension of contact wire, voltage drop, and friction coefficient. The performance of the attributes of the pantograph is analyzed by using MATLAB software. While, SolidWorks is used to run some tests to analyze the material used in designing the contact strip.

3.3 Software Selection

3.3.1 MATLAB Software

For those planning to design their system by using any controller, Matlab is one of the good software to simulate the control system. By using the Matlab, any calculation will calculate by the software it just need to key in the value. Next the Matlab will give the output in term of graphical.

3.3.2 SolidWorks

SolidWorks is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program that runs on Microsoft Windows. Furthermore, this software also can do many type of test such as stress test, displacement test, deformation test, factory of safety, and center of gravity. In addition, Solid Work also can do animation to study the motion of the pantograph movement. Besides each part of the pantograph is designing by using this software.

3.4 Experimental Setup

To obtain the mechanism data such as contact loss and vibration of pantograph, the model of pantograph is referring based on August Stemman pantograph. After referring to the pantograph from Figure 3.8, the first thing should be done is collecting the parameters from previous researches of the pantograph such as the mass of each parts, the length of each link, and the stiffness. Table 3.1 shows the pantograph parameter.

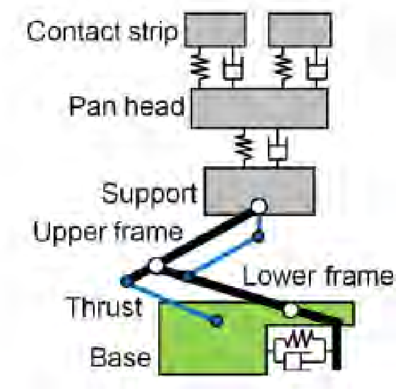


Figure 3.8: Pantograph physical model [1]

Table 3.1: Pantograph parameters

Parameter	Symbol	Value and unit
Mass of contact strip	m_{1T}	12kg
Mass of pan head	m_2	5kg
Contact spring	k_c	39000 N/m
Contact strip spring	k_{1T}	32992 N/m
Pan head spring	k_2	14544 N/m
Contact damper	c_c	12.31 Ns/m
Contact strip damper	c_{1T}	12.31 Ns/m
Pan head damper	c_2	0.11 Ns/m
Mass of the frame	m_3	10.38 kg
Frame spring	k_3	611.85 N/m
Frame damper	c_3	50.92 Ns/m

3.4.1 SolidWorks

3.4.1.1 Pressure Test

The selected material which are pure carbon as the contact strip and copper as the catenary also will be analyzed by running certain tests in SolidWorks software to evaluate the material characteristics. Each of the material will undergo two times of test with different force which is maximum and minimum force:

Maximum force = 100N

Minimum force = 54N(nominal force)

3.4.1.1 Static Friction Force Test

In this experiment, the friction force test will undergo by using two different material which is Copper and plain Carbon. This test were test by setting the value of the force given at the top and the right side of the material. This test were repeated three times with different force given to see the friction occur on the material.

3.4.2 MatLab

Table 3.2: Contact wire parameters [1]

Parameter	Symbol	Value and unit
Length of span	s	50 m
Density CuCd/CuMg	ρ	8900/1700 kg/m^3
Velocity	u	0~350 km/h
Friction coefficient	μ	0.75/0.8
Wire tension	T	10000 N

By using the collecting data, some specific formulas are used to analyzed its performance by entering the data in the MATLAB software.

Critical speed for the catenary can operate [5],

$$c = \sqrt{\frac{T}{\rho S}} \tag{2.3}$$

where,

c = Critical speed

T = Tension of the wire

ρ = Density of wire

S = Cross sectional area wire

Heat equation [19],

$$Q = \mu u \mathrm{N} \tag{3.1}$$

where,

Q= Heat

μ= Friction coefficient

u= Velocity

N= Tension

Max.temperature [8],

$$T_m = \sqrt{\frac{Uj^2}{4L} + T_o^2} \tag{2.4}$$

where,

T_m = Maximum temperature of contact spots

U_j = Voltage drop

L = Lorentz number ($2.4 \times 10^{-8} (V/K)^2$)

T_o = Room temperature ($22.5°C$)

Sag equation [17],

$$\text{Sag} = \frac{WL^2}{8T} \tag{3.2}$$

where,

Sag= Difference in level between the point of support and the lowest point on the conductor.

W= Weight pr unit length of conductor

L= Horizontal distance between the towers (span)

T= Tension in the conductor

Chapter 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will discuss about the result of data collected from SolidWorks and MatLab. All the results obtained are tabulated in table or figure to provide a better understanding of the result.

At the first part, the results taken from the analysis using MatLab is analyzed and discussed. The analysis included the temperature, critical speed, and heat produce. The experiment on the friction force, pressure, and stress strain is taken by using the SolidWorks.

4.2 SolidWorks Analysis

4.2.1 Pressure Test

Figure 4.1 shows that the pantograph design referring the August Stemman design. This design had been choose due to the mechanism from this design suitable for this project. This is because some of the pantograph design include spring in their design and the design quite complex and difficult to analyze.

Figure 4.1: Pan-head of pantograph

The purpose of this analysis is to determine the pressure test that this pantograph can achieve when sentence value of pressure is given. By knowing the maximum pressure is 400Pa that the pantograph can withstand, the damage of the pantograph can be avoided. The overview of pressure test of pantograph is shown in Figure 4.2 and Figure 4.3.

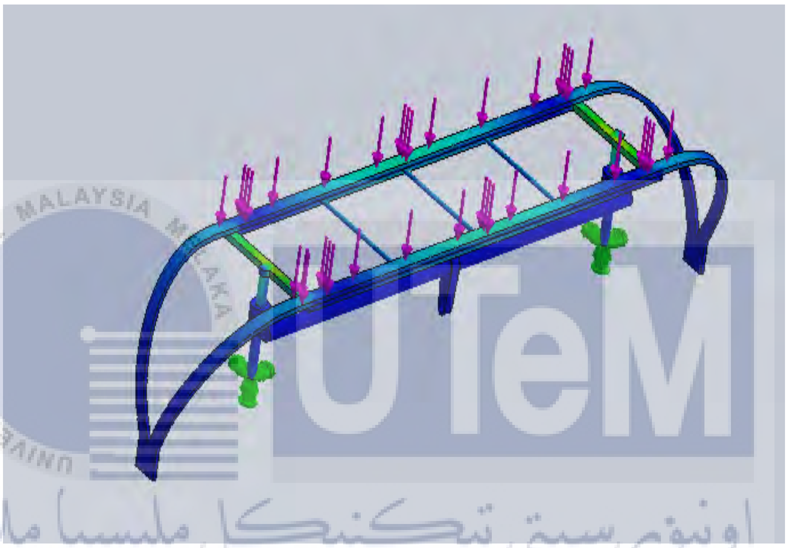


Figure 4.2: Pressure test

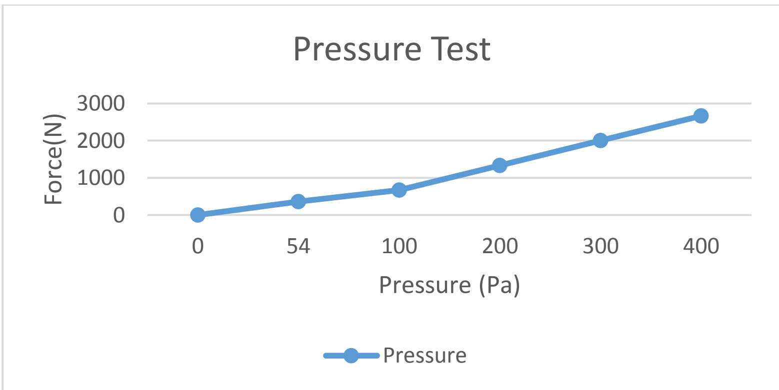


Figure 4.3: Pressure test graph.

Based on the test that had be done in SolidWorks, the data were collected and had been shown in figure 4.4 and figure 4.5. The figure shown that the minimum force applied on the pantograph which is 54N. 54 is the nominal force for the pantograph to touch the contact catenary.

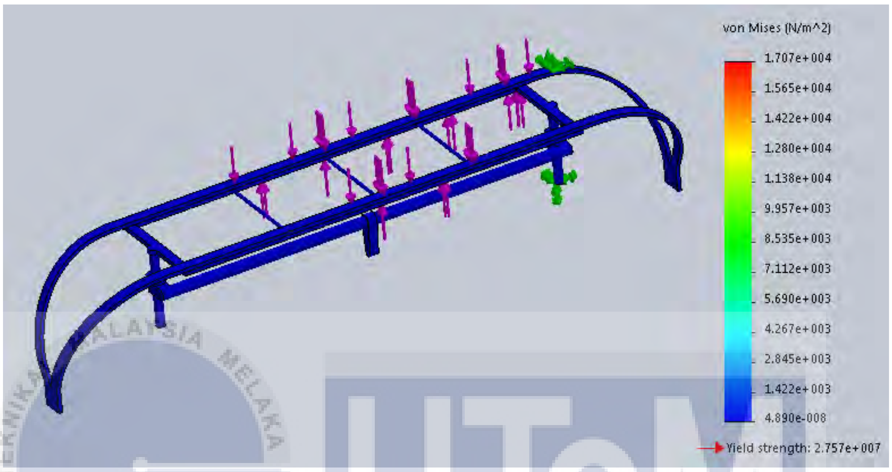


Figure 4.4: Minimum force applied on the pantograph.

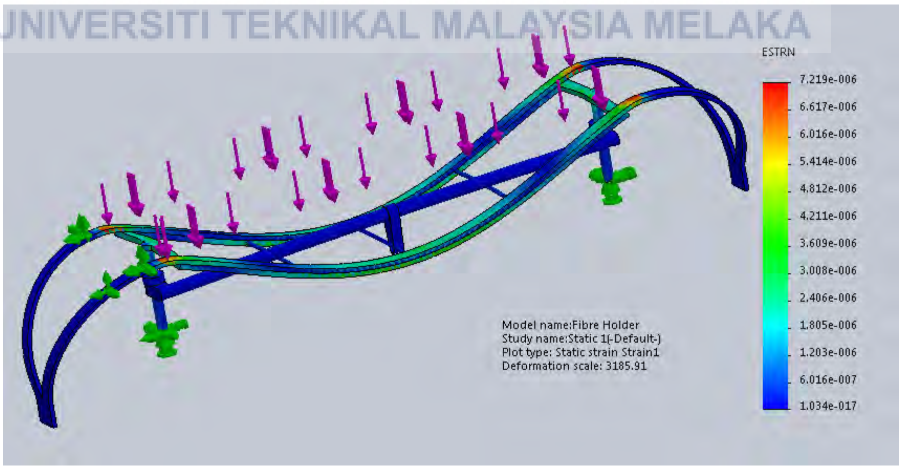


Figure 4.5: Maximum force applied on the pantograph.

4.2.3 Static Friction Testmmm

Figure 4.6 shows that the friction force occur during the catenary and pantograph contact each other. The applied force to the top of catenary is 50N and the applied force right side is 100N. From the simulation on the SolidWorks the friction force produced is 0.02N.

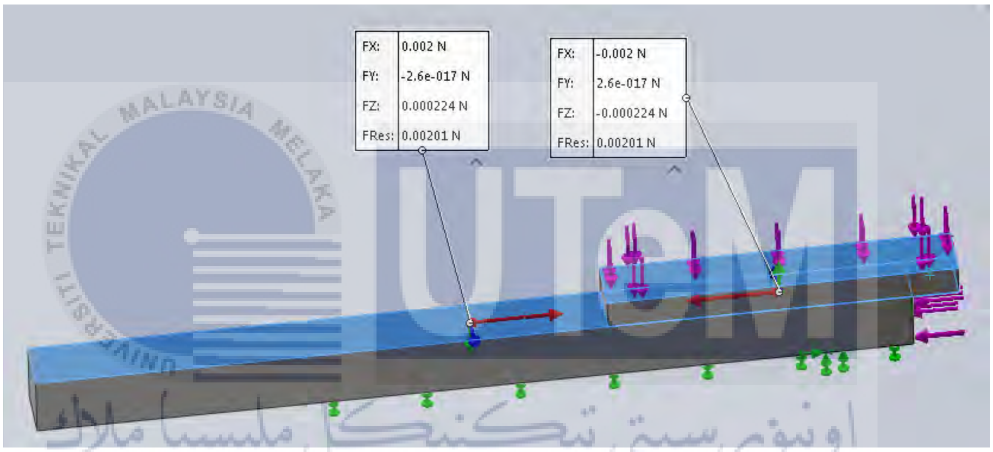


Figure 4.6: Friction force between contact wire and pantograph.

4.3 Matlab Analysis

4.3.1 Analysis of Relationship Speed that Catenary can operate with Different Type of Material.

Figure 4.7 shows that the critical speed for the catenary can operate by using formula (2.3), it depends on type of the material and the tension for the catenary. The lower the density, the higher the critical speed that catenary can operate. Thus, the higher the tension the higher the critical speed. This is because when the tension is low, it can produce vibration when the catenary is in unstable condition so that sparking might occur The graph shows that CuMg can operate at higher critical speed than CuCd because at 959.8N the CuMg can operate at 54.8m/s but for CuCd it only can operate at 23.95m/s Table 4.2 is the parameter for the contact wire.

$$c = \sqrt{\frac{T}{\rho S}} \tag{2.3}$$

Table 4.2: Parameter of the contact wire.

Parameter	Symbol	Value and unit
CuCd density	ρ	8900 kg/m^3
CuMg density	ρ	1700 kg/m^3
Cross-sectional area wire	S	150 mm^2
Range for wire tension	T	0-1000 N
Range for critical speed	c	0-60 m/s

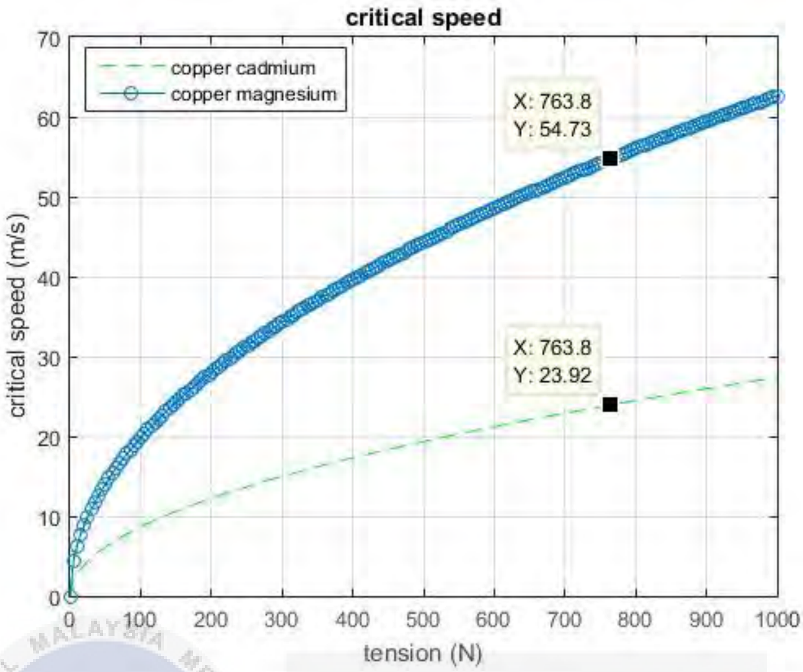


Figure 4.7: critical speed.

4.3.2 Analysis of Relationship between Heat produce by the Catenary and Velocity of the Train.

Figure 4.8 represent the result of heat by using coefficient of two material which are copper-cadmium (CuCd) and copper-magnesium (CuMg) with different tension apply on the catenary. In this graph, the heat is higher due to the friction use is larger and the tension apply on the catenary. The higher the velocity, the higher the heat produce at the catenary. For 1kN, at 75m/s velocity the heat produced by CuCd is lower than CuMg. The friction coefficient for CuMg is higher than CuCd. When the friction coefficient is low, thefriction produce is lesser so that the heat produce is lower.

$$Q = \mu u \mathrm{N} \tag{3.1}$$

Table 4.3: Parameter to analyze relationship between heat produce by the catenary and velocity of the train.

Parameter	Symbol	Value and unit
Tension of contact wire	N	0~2000N
Velocity of train	u	0~100m/s
Friction coefficient (CuCd)	μ	0.8
Friction coefficient (CuMg)	μ	0.75
Heat	Q	0~16000 kj

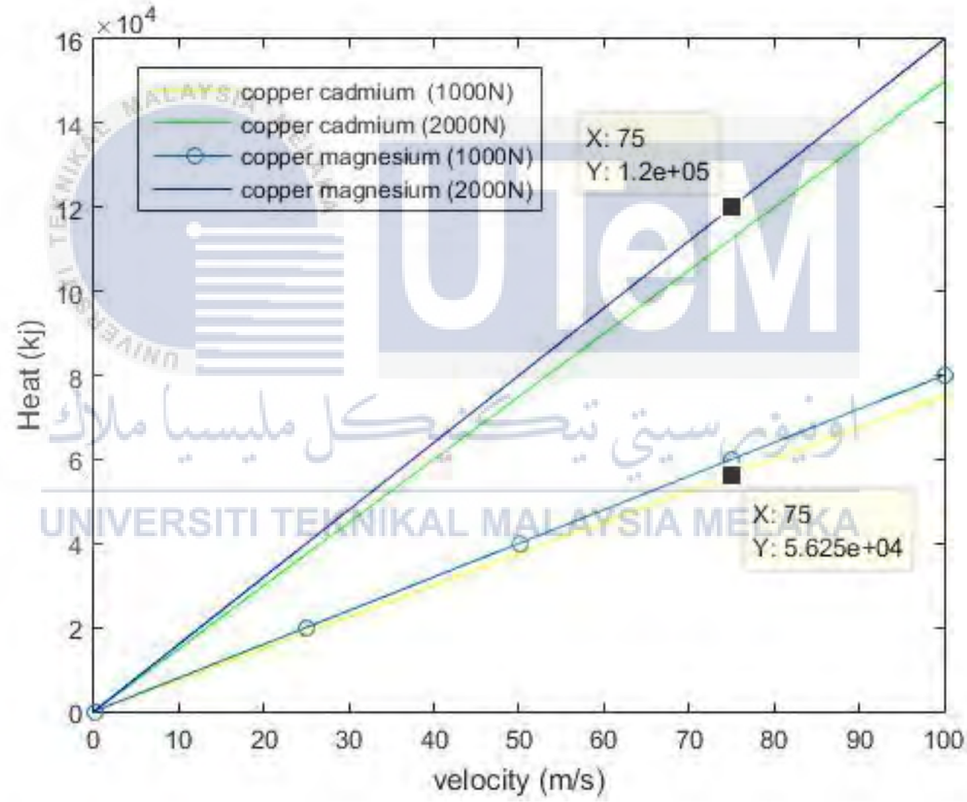


Figure 4.8: Relationship between heat produce and velocity.

4.3.3 Analysis of Relationship between Heat produce by the Catenary and Tension for the Catenary.

Based on figure 4.9 it is shown that the result of the heat versus tension with different velocity and material use. It shown that the higher the tension, the higher the heat produce. The higher the velocity, the higher the heat produce when the contact between catenary and pantograph occur. The purpose for this analysis is to ensure the heat produce not more than maximum value so that damaged on the pantograph and catenary can be avoided.

$$Q = \mu u \mathrm{N} \tag{3.1}$$

Table 4.4: Parameter to analyze relationship between heat produce by the catenary and tension for the catenary.

Parameter	Symbol	Value and unit
Tension	N	0~1000 N
Velocity	u	0~350 km/h
Friction coefficient (CuCd)	μ	0.8
Friction coefficient (CuMg)	μ	0.75
Heat	Q	0~80000 kj

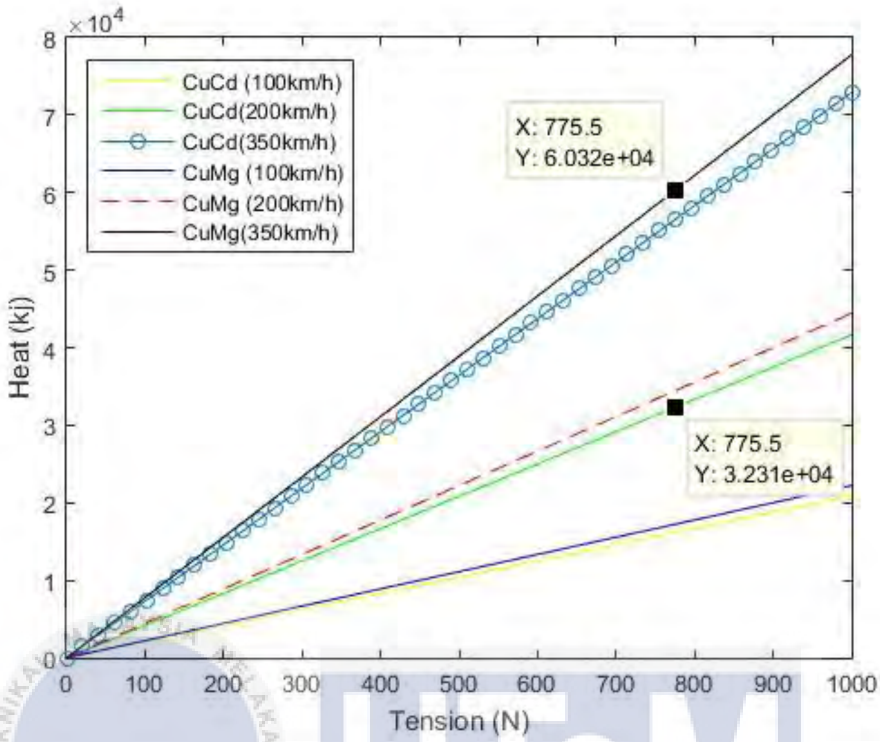


Figure 4.9: relationship between heat produce and tension.

4.3.4 Analysis of Relationship between Maximum Temperatures and Output Voltage.

Figure 4.10 explains about how the voltage drop reflected the temperature when the pantograph slipper with the contact wire. The result of temperature measurement shows that the temperature is higher when the voltage drop is higher either in hot or cold weather. The purpose of this simulation is to minimize the temperature so that the material of the catenary and contact shoe can be used for a long term.

$$T_m = \sqrt{\frac{Uj^2}{4L} + T_o^2} \tag{2.4}$$

Table 4.5: Parameter to analyze relationship between maximum temperatures and output voltage.

Parameter	Symbol	Value and unit
Room temperature	T_o	22.5^oC
Lorentz number	L	$2.4 \times 10^{-8}(V/K)^2$
Voltage drop	Uj	0-12.5V
Maximum temperature	T_m	$0\text{~}10\times10^{4o}C$

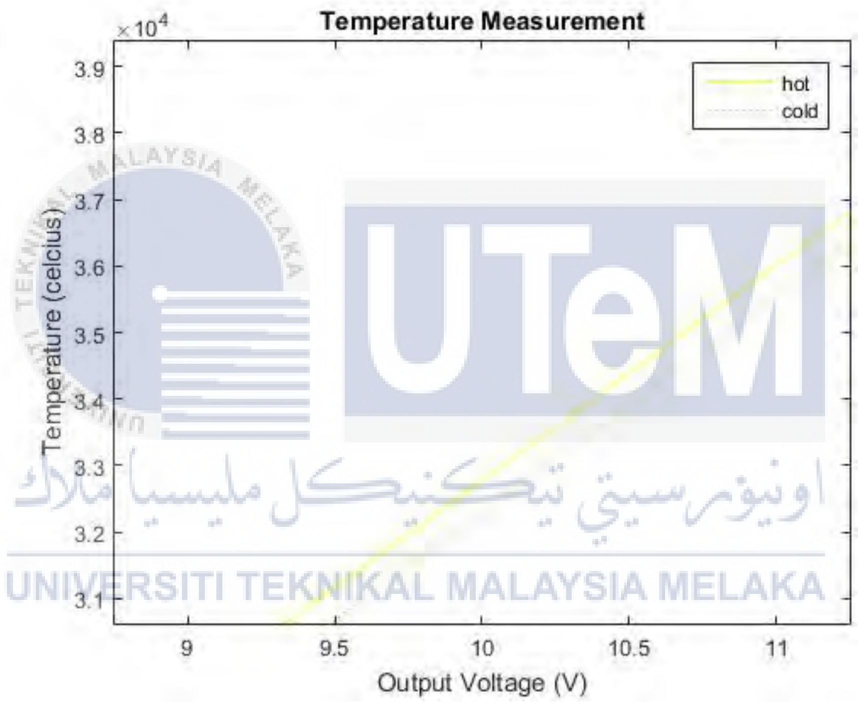


Figure 4.10: Temperature measurement.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Nowadays, people are racing in evolving a current technology as in increasing the speed of train. The speed of train can be increased by improving the pantograph attributes. By referring to the previous research, the chosen pantograph attributes were studied and analyzed for high speed train. The analyze attributes were friction force between two materials, maximum temperature at the catenary, critical speed for the catenary, and maximum pressure can be applied to the pantograph. All of the attributes were analyzed by using MatLab and SolidWorks software. Based on the result it shows that both CuMg and CuCd have their own advantage and disadvantage which are CuMg has low density and high friction coefficient and vice versa for CuCd. Both of the objectives of this study were achieved.

5.2 Future Work

This study and analysis can be improved by using a new material which is Titanium Silicon Carbide (Ti3SiC) to fulfill the requirement for high speed train system. Besides, the better system could be invented to reduce the creation of arc burning.

REFERENCES

[1] M. A. Abdullah, A. Ibrahim, Y. Michitsuji and M. Nagai, "Active Control Of High- Speed Railway Vehicle Pantograph Considering Vertical Body Vibration," *nternational Journal Of Mechanical Engineering And Technology(IJMET),* vol. 4, pp. 263-274, 2013.

[2] R. Garg, P. Mahajan, P. Kumar and a. V. Gupta, "Design and Study Of Active Controllers for Pantograph-Catenary System," pp. 1-6, 2014.

[3] M. T. Ko, M. Yokoyama, Y. Yamashita, S. Kobayashi and a. T. Usuda, "Contact Force Control Of an Active Pantograph For High Speed Trains," 2016.

[4] M. A. Abdullah, Multi-body dynamics analysis and controller design for active pantograph system of high speed railway vehicle, 2011.

[5] A. Bobillot, J.-P. Massat and J.-P. Mentel, "Design of pantograph-catenary systems by simulation," Research Department French Railways," 2011.

[6] S. Feng, S. Wei, Q. Bin, H. Yi-Qiang and a. L. Hua-Qiang, "Research Status and Development Trend Of Pantograph Contact Strip Materials," 2016.

[7] S. Frey, "Railway Electrification System Engineering," 2012, pp. 7-24.

[8] X. Ge, W. Liu, Z. Yang and Y. Wang, "The Study on Electrical Temperature Characteristic of High Speed Pantograph," Vols. 1-4, 2014.

[9] Z. Jing, L. Zhigang, S. Yan, L. Xioabing, D. Fuchuan, X. Zhao and L. Jinzeng, "study on Multidisciplinary Integrated of High-Speed Pantograph Based on Parameters Design Analysis and Optimal Controls," pp. 1-9, 2016

[10] "Lamifil - high quality copper and aluminium products," Lamifil, 2017. [Online]. Available: https://lamifil.be/global-markets/ . [Accessed 24 11 2017].

[11] "Researching the train of the future," DLR, [Online]. Available: http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10467/740_read-916/#/gallery/2043 . [Accessed 23 10 2017].

[12] "why use public transport," 20 july 2014. [Online]. Available: https://www.sustrans.org.uk/what-you-can-do/use-your-car-less/why-use-public-transport. [Accessed 28 9 2017].

[13] "Benefits of public transport," Public Transport Victoria, 2013. [Online]. Available: https://www.ptv.vic.gov.au/about-ptv/media-centre/student-media-enquiries/benefits-of-public-transport. [Accessed 28 9 2017].

[14] T. Dahlberg, "Catenary, Pantograph, and their Interaction," in *Vehicle Systems Dynamics*, 2007, pp. 591-593.

[15] T. Wu and M. Brennan, "Analytical study of pantograph-catenary system dynamics," *ISVR Technical Memorandum 819,* 1997.

[16] T. Usada, M. Aboshi and a. M. Ikeda, "Study of the Relationship between Vertical Acceleration of Carbody and Pantograph Contact Force," *The JSME Jointed Railway Technology Symposium,* pp. 271-274, 2000.

[17] "Sag in overhead transmission line and its calculation," 21 September 2016. [Online]. Available: https://electricalbaba.com/sag-in-overhead-transmission-line-and-its-calculation/. [Accessed 7 May 2018].

[18] J. P. M. P. Jorge Ambr, "Optimization of high-speed railway pantographs for improving pantograph-catenary contact," pp. 1-7, 2013.

[19] M. M. K. M.Amiri, "On the Thermodynamics of Friction and Wear," pp. 1-29, 2010.