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

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

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**i**

I declare that this report entitled “**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.

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Date : 18.5.2018

**To my beloved mom and dad.**

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## 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 mengukur 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.

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## **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  $Ti_3SiC_2$ . 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  $Ti_3SiC_2$ . 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  $Ti_3SiC_2$  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. Ti<sub>3</sub>SiC<sub>2</sub> 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,

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

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] :

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

Where,

CF = cost function

$f_{1i}$  = force

$f_{1N}$  = nominal contact force

$v$  = travelling speed

$\Delta t$  = 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]:

$$c = \sqrt{\frac{T}{\rho S}} \quad (2.3)$$

Where,

$C$  = Critical speed

$T$  = Tension

$\rho$  = 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.

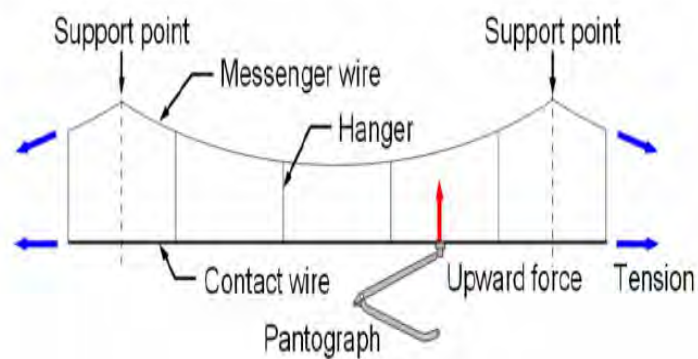


Figure 2.1: structure of contact wire system [10]

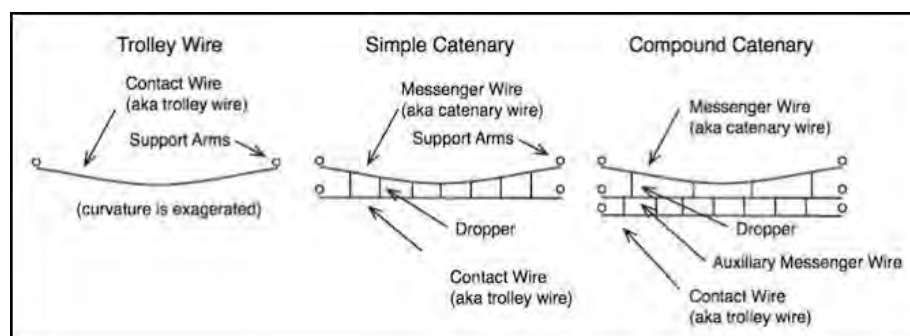


Figure 2.2: Catenary [10]

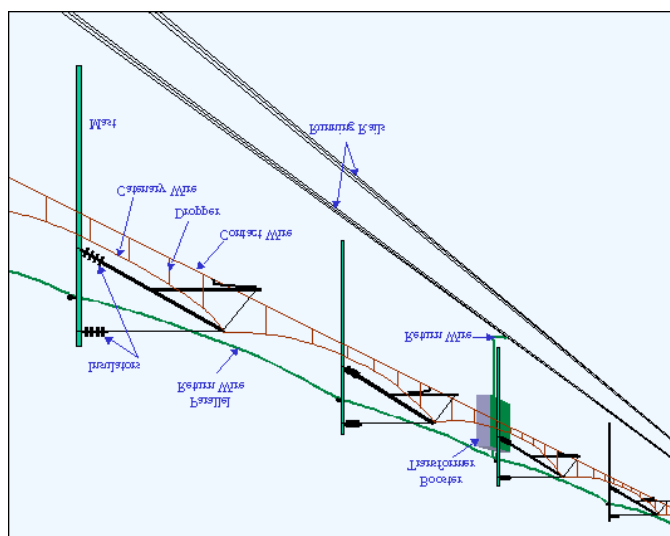


Figure 2.3: Transmission line [17].

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