UNIVERSITI
TEKNOLOGI
PETRONAS

Electromagnetic Windshield Wiper: Conceptual Study and Analysis

by

Muhammad Syahmi Bin Ahmad

13747

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical)

MAY 2014

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Electromagnetic Windshield Wiper: Conceptual Study and Analysis

By

Muhammad Syahmi Bin Ahmad
13747

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfilment of the requirement for the
BACHELOR OF ENGINNERING (Hons)
(MECHANICAL)

Approved by,

____

AP IR. DR. MASRI BAHAROM
Main Supervisor,
Head of Mechanical Engineering Department
Universiti Teknologi PETRONAS

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD SYAHMI BIN AHMAD

ABSTRACT

The torque produced by conventional motor used to power conventional wipers may not be enough to move the wipers across the windshield especially during heavy rain. Higher torque is also needed to clear away snow during winter season. Electromagnetic windshield wiper is an invention that is focusing on replacing the motor as the source of forces / power by using electromagnetic principles. The prototype will make use of rocker- rocker mechanism. The proposed design is very novel because the design mechanism replaces electrical motor with electromagnet, thus reducing the amount of force required while producing higher amount of power. The wipers can be installed on both commercial and passenger vehicles. However, for this paper, it is concentrating on the production of prototype for experimental procedures only. Extensive studies, design modelling, circuit simulation, prototype fabrication and further experiment to analyse the effect of the electromagnetism towards the wiper are conducted throughout the project period.

ACKNOWLEDGEMENT

In completion of this 8 month period of Final Year Project [FYP] entitled Electromagnetic Windshield Wiper: Conceptual Study and Analysis, I would like to express my deepest gratitude to all parties that are involved in this project either directly or indirectly in the process of completion of this project. Throughout the project progression, I have learned a lot of new things and gain many experiences that will be valuable for my future career path.

First and foremost, I would like to thank my project supervisor, AP Ir Dr Masri Baharom who becomes my mentor and the most important people that teach and guide me throughout the project period. I am really appreciated for his help and information sharing in order for me to perform well and finish the project as per planned during the early part of the semester.

I would also like to express my gratitude to technicians and friends from Mechanical and Electrical Department, Universiti Teknologi PETRONAS, especially to Mr Jani, Mr Saiful, Mr Mohammad Shafiq, Mr Khairul Hanif, and Mr Fauzan Ghazali for their strong support and willingness to share their knowledge and expertise in helping me during the stages of prototype development and fabrication.

Last but not least, thanks to my family and friends for their support and encouragement throughout this 8 month period. I really hope that I could apply all of the skills and knowledge that I have gained throughout the project period for my future career.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION and NOMENCLATURE

PM	Permanent Magnet

CHAPTER 1

INTRODUCTION

1. Introduction

This chapter comprises all basics information regarding the project, which include the background of study, the problem statement, the objectives, and lastly the scope of study used for completion of the project**.**

1.1. Background of Study

For the past decade, a windshield wiper had play major roles in assisting the drivers to have a clear and unobstructed view while driving especially in bad weather. The wiper had undergone several modifications since its early manual design inception in 1903. The improvement of the design includes the introduction of vacuum–powered wiper, gear plus motor and linkages design wiper, an intermittent wipers, and the latest technology available on the market is rain-sensing wiper. With the advancement in technology, continuous effort has been made to improvise the design throughout the years.

In this paper, research and studies are focusing on the introduction of a new design of car windshield wiper, which use electromagnets as the main source of power instead of electrical motor as in conventional wiper nowadays. Motor and gear reduction principles are removed entirely from the system. The schematic drawing designs of the proposed wiper mechanism is as shown in Figure 1.1.

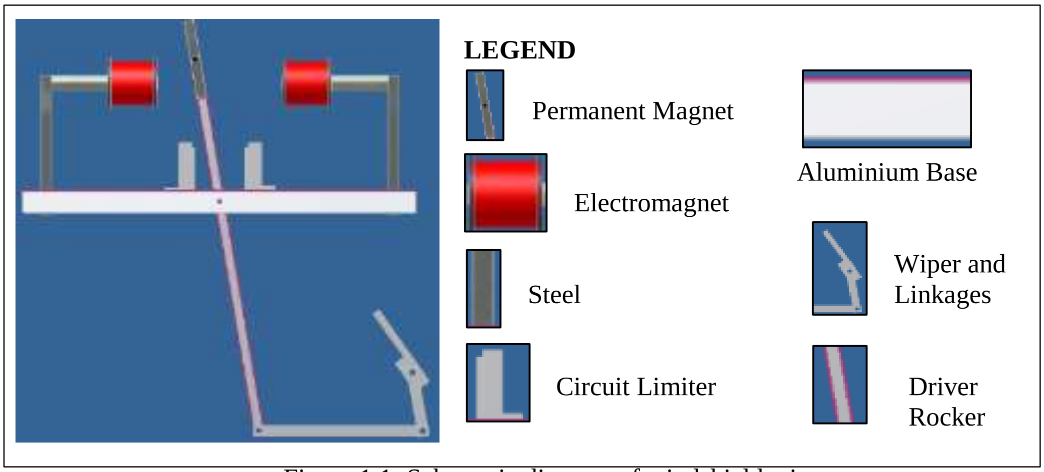


Figure 1.1: Schematic diagram of windshield wiper

The prototype make uses of rocker-rocker mechanism. A permanent magnet (PM) is attached to a driver rocker (middle rod), performing circular arc motion between two electromagnets. The electromagnet on both sides are made up of insulated copper wire winding. In order to amplify the effect of magnetic field produced, the ferrous materials (iron/zinc), is slotted in the middle of the winding to provide as on core for the electromagnet. Both copper winding cylinders are then connected with a 12 Volts battery power supply.

For the prototype, the author had used two different sets of power supply, for ease of differentiating the system. 12 Volts battery was used to produce the aforementioned electromagnet. Meanwhile, a 9 Volts battery is used to power up the small electrical component for use of alternating the current flow supply in order to change the electromagnet polarity such as relay, resistor, and switches.

Once the circuit is turned on, the PM driver rocker in the middle move to the right due to the attraction of different magnetic poles. It move closely to the right until it touched the dip limit switches which in turn trigger the relay to indicate that it has reached its destination. The relay then change the flow of the current supply to the left electromagnet and change the polarity of the right electromagnet. This sequence of process will in turn repel the middle PM to move to the left side of the electromagnet.

The other end of the driver rocker is connected to the other rocker via a connecting rod. The end of the other rocker is attached with the wiper. The repeated rocking motion of the driver rocker will cause the windshield rocker to move back and forth respectively. Small amount of PM driver rocker curve motion trigger big motion of the wiper across the windshield. The linkages are made up of light material such as aluminium. For this study, a rocker–rocker mechanism was applied, (both rocker will and can move up to 180°in rotation).

1.2. Problem Statements

Current amount of torque and speed produced by motor used in conventional wipers are not enough (can be added) to move the wiper across the windshield especially during heavy rain. Higher torque is also needed to clear away the snow during winter season.

1.3. Project Significance

The proposed wiper design can be installed on both commercial and passenger vehicles. Almost all of the current wiper designs in the world use an electrical motor and crank rocker mechanisms. Thus, the project end outcome is to come out with a new design of windshield wiper mechanism that provide as an option to the design that are currently available in the market.

1.4. Objective of Study

There are several objectives that need to be fulfilled by the end of the project.

i) To perform conceptual studies for the proposed design of the wiper.

ii) To study and investigate the experimental data of the prototype.

1.5. Scope Of Study

The scopes and the boundaries of this study are as follows**:**

i) Gather and review the study that been done previously.

ii) Perform simulation and fabrication of the prototype.

iii) Conduct experiment to test the prototype based on the following parameters:

   a. Test of the functionality of the driver rocker design as to prove the working mechanism
   b. Check on the speed of the driving rocker in regards to the magnetic force and distance
   c. Tested for experimental purposes, not being installed to the real car.

CHAPTER 2

LITERATURE REVIEW

2. Introduction

This chapter comprises discussion about windshield car wiper, electromagnetics, crank rocker mechanism, and RS Latching circuits.

2.1. The Car Wipers

Figure 2.1: Car Wiper

Figure 2.1 shows the conventional car wipers used nowadays. It is a part of the fundamental things that all cars should have. It is instrumental in ensuring the drivers to have a clear and non-obstructed view of the road.

2.1.1. Car Wiper Inventions

Before the invention of the automatic windshield wipers, the driver needs to work a crank in on his or her own in order to move the wiper back and forth. The history began when a person name Mary Anderson from USA patented her window cleaning devices design in 1903 [1]. On her trip to New York, she realise that the drivers were having difficulties while driving in the rainy and stormy condition. In her design, she was focused on meeting the following objectives:

(i) improvement of the devices by introducing swinging arm handle and

(ii) providing a device that are capable to be controlled from the inside which can operates on the outside surfaces of glasses to get rid of snow, rain, sleet and others. [2].

However, her design had never been put into production. Nevertheless, the concepts of her manual window cleaning devices had been made as a reference of car windshield wipers in early 1900's car models. Since then, the windshield wipers have undergone several steps of modification to the design. Improvement to the system includes change of power supply from engine vacuum to electric motors. Additional features such as intermittent wipers, windshield washer, rain sensor wipers and many more complement the wipers design that we currently have today.

Another innovative wiper features called 'auto park wiper" have been installed to Nissan Altima model in 2013 [3]. It is important especially in cold climates with ice or snow. From Nissan studies, it said that the driver tend to shut off the car while the wipers are still in motion. With the introduction of this new feature, it ensures that the wiper complete full cycle first and rest at bottom of the windshield, preventing it from stop at the middle and freeze due to the bad weather condition.

The latest conceptual studies are proposed by McLaren, whereby they are currently investigating the use of "ultrasonic force field / sound waves" to fully replace the usage of windshield wipers in automobiles industry [4]. It is a good idea, particularly in eliminating the weight of the motor used for wiper power source and decreasing the drag that was experienced by the car, due to the movement of wiper arm and blade.

2.1.2. Type of Car Wipers

The very first windows cleaning wiper was operated by moving a lever back and forth manually by a set of lever inside the car. In contrast, most of the cars today are using an electrical motor operated car wipers technology. The drivers can also control the speed of the wiper according to the weather.

Types of wipers that have been used by the car manufacturers to suit with the drivers view are shown in the Figure 2.2. Single arm wiper may provide better coverage in general, but are more complicated than the standard widely used two blade systems (Tandem system) [5].

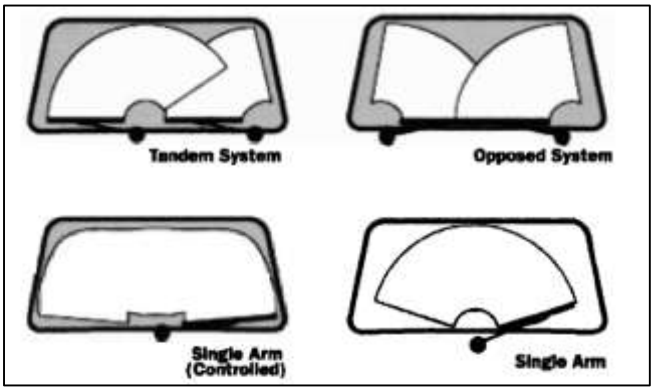


Figure 2.2: Wiper Blade Schemes

2.1.3. The Working Principles Of Car Wipers

The conventional wipers today basically consist of the combinations of two (2) mechanical technologies:

(i) A combination of electric motor and worm gear reduction that provides power to the wipers.

(ii) A neat linkage that converts the rotational output of the motor into the back-and-forth motion of the wipers.

2.1.3.1. Motor and Gear Reduction

In order to create a back and forth motion of the wiper blades quickly, a lot of forces need to be generated. A worm gear is used on the output of a small electric motor to produce the desired forces. The worm gear reduction can multiply the torque of the motor by about 50 times, while slowing the output speed of the electric motor by 50 times as well. The output of the gear reduction operates a linkage that moves the wipers back and forth. Inside the motor/gear assembly is an electronic circuit that senses when the wipers are in their down position. The circuit maintains power to the wipers until they are parked at the bottom of the windshield, and then cuts the power to the motor. This circuit also parks the wipers between wipes when they are on their intermittent setting [5].

2.1.3.2. Linkages

A short cam is attached to output shaft of the gear reduction. This cam spins around as the wiper motor turns. The cam is connected to a long rod; as the cam spins, it moves the rod back and forth. The long rod is connected to a short rod that actuates the wiper blade on the driver's side. Another long rod transmits the force from the driver-side to the passenger-side wiper blade [5]. Other type of linkages used are shown in Figure 2.4 and 2.5

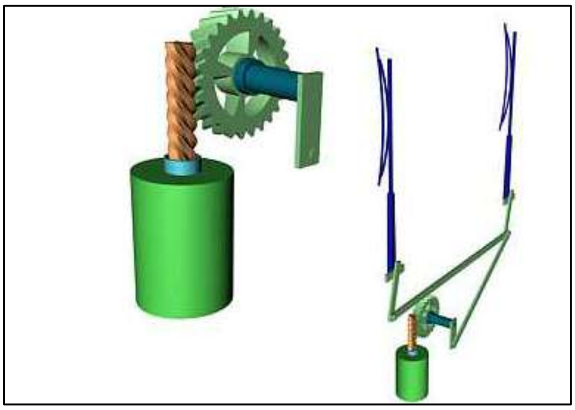


Figure 2.3: Car Wipers Working Mechanism

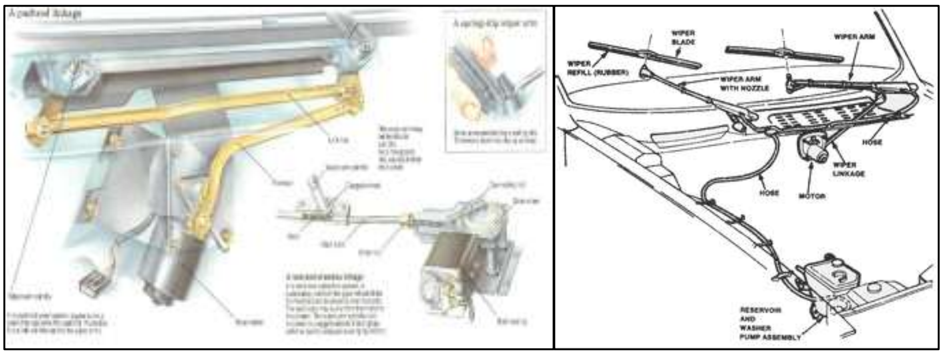


Figure 2.4: Car Wipers Linkage Mechanism

2.1.4. Wiper Blades Design

The wiper arms will drag a thin rubber strip layer across the windshield in order to remove the water. It is connected from six (6) to eight (8) places to ensure even distribution of pressure of wiper blades across the windshield glasses. The ability of the wiper blades to clean the windshield glass properly is due to several factors [6]:

(i) The slope and area of windshield

(ii) The amount of spring tension on the wiper arm

(iii) The number of pressure points or claws holding the blade

(iv) The material of the blade

2.2. Electromagnetism

General known idea is that magnets have a pair of poles, South Pole and North Pole. Like poles will repel each other whereas opposite poles are attracted.

Magnets are composed of atoms like any other matter. The atom is a combination of three (3) elements, proton, neutrons, and electrons. The former two are enclosed in the atom nucleus. Electrons on the other hand are in constant motion circling around the nucleus, and carry negative electrical charges with it. A magnetic field will produced whenever an electrical charge is in motion.

Magnets will attract ferromagnetic objects such as iron and nickel that are made up by small region called domains, which are behaving like magnets, (have two (2) dipoles). The domains are randomly arranged relative with each other when it is un-magnetized. However, when it is placed in close proximity to the magnet, the domains will be temporarily aligned. Hence, it will be attracted to the magnets due to the poles attraction.

In 1820, Hans Christian Oersted discovered that an electric current flowing through a wire caused a nearby compass to be deflected, an indication that the wire is generating magnetic field [7]. Straight segment of wire carrying an electric current will create circular magnetic field, whereby the intensity of the field is directly proportional to the amount of current carried. The right-hand rule is use to know the direction of magnetic field.

A long coil of wire consisting of multiple loops is referred to as solenoids. The magnetic field strength of a solenoid is the sum of the fields created by each individual loop, multiplied by the ampere of current that running through the wire. Placing a piece of iron in the centre of solenoids will create an electromagnet. The iron will increases the magnetic strength of the solenoid because the domains in the iron become aligned by the magnetic field crated by the current. Hence, resulting magnet field is basically are the sum of the current running through the circular wire plus the magnetic field created by the aligned domains in the iron. The iron used for electromagnets are soft iron core since it can quickly loses magnetism once the current supply is cut off. It can also regained magnetism easily once the current is turned on [8].

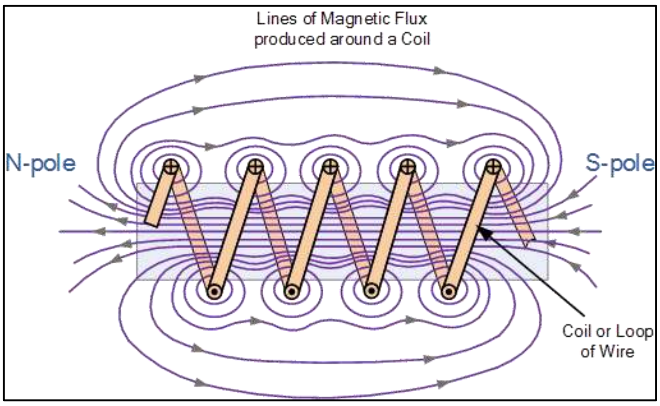


Figure 2.5: Electromagnet Line Force

Amount of flux available in any given magnetic circuit is directly proportional to the current flowing through it and the number of turns of wire within the coil. This relationship is called Magneto Motive Force, or m.m.f. (expressed in current). The more turns of wire in the coil, the greater will be the strength of the magnetic field. It can also be defined as:

Magneto Motive Force (m.m.f) = I (Current) x N (no of coil/ turn) (2.1)

Modern electromagnetism can be based on a set of four (4) fundamental relations known as the Maxwell's Equation which is shown on Table 2.1 [9]. The first and third equations are valid for static and dynamic fields. Faraday's Law explains on the production of an electric current in a closed loop by the magnetic fields, and this can only achievable if the magnetic flux linking the surface area of the loop changes with time (time varying magnetic fields give rise to an electric field. Ampere's Law is the converse to Faradays Law, whereby a time-varying electric field will give rise to a magnetic field.

Table 2.1: Maxwell's Equation

Reference	Differential Form	Integral Form	
Gauss's law	$\nabla \cdot \mathbf{D} = \rho_v$	$\oint_S \mathbf{D} \cdot d\mathbf{s} = Q$	(6.1)
Faraday's law	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\oint_C \mathbf{E} \cdot d\mathbf{l} = -\int_S \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{s}$	(6.2)*
No magnetic charges (Gauss's law for magnetism)	$\nabla \cdot \mathbf{B} = 0$	$\oint_S \mathbf{B} \cdot d\mathbf{s} = 0$	(6.3)
Ampère's law	$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$	$\oint_C \mathbf{H} \cdot d\mathbf{l} = \int_S \left(\mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}\right) \cdot d\mathbf{s}$	(6.4)

*For a stationary surface S.

2.2.1. Magnetic Strength Of Electromagnet

Magnetic fields are developed according to the pre-set current flow direction. If the current is flowing in the same direction (the same side of the coil) the field between the two conductors is weak. Likewise, when the current is flowing in opposite directions the field between them becomes intensified and the conductors are repelled.

The intensity of this field around the conductor is proportional to the distance from the power supply source. The strongest point is being next to the conductor and getting weaker progressively as the distance further away from the conductor. Current flow and distance are two main factors to calculate field intensity in single straight conductor. The formula to calculate the "Magnetic Field Strength or sometimes called "Magnetising Force" is as follows.

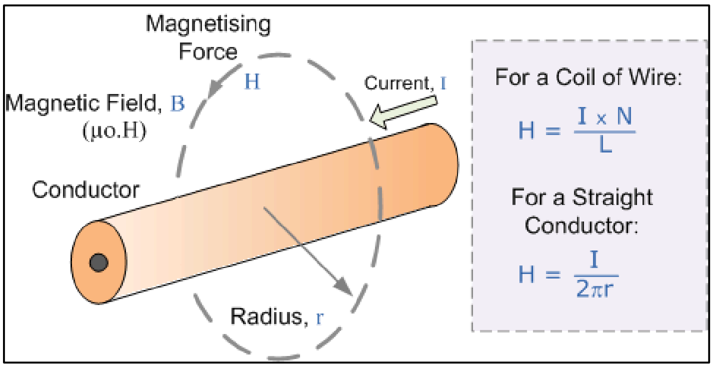


Figure 2.6: Magnetic Field Force

Whereby:

H - Strength of the magnetic field in ampere-turns/metre, At/m

N - Number of turns of the coil

I - Current flowing through the coil in amps, A

L - Length of the coil in metres, m

The magnetic field strength of the electromagnet depends upon the type of core material used. If the material is non-magnetic, for example wood, it can be regarded as free space as they have very low values of permeability. If however, the core material is made from a ferromagnetic material such as iron, nickel, cobalt or any mixture of their alloys, a considerable difference in the flux density around the coil will be observed.

Ferromagnetic materials can be magnetised / demagnetized easily and are usually made from soft iron, steel or various nickel alloys. The introduction of this type of material into a magnetic circuit has the effect of concentrating the magnetic flux making it more concentrated, denser, and amplified the magnetic field created by the current in the coil. The degree of intensity of the magnetic field is called Magnetic Permeability.

If the magnetic material has a high permeability then the flux lines can easily be created and pass through the central core. Permeability (μ) also can be understood as a measure of ease by which the core can be magnetised. The numerical constant given for the permeability of a vacuum is given as: $\boldsymbol{\mu_o = 4.\pi.10^{-7}}$ **H/m** with the relative permeability of free space (a vacuum) generally given a value of one. Different material have their own specific values of permeability.

Materials that have a permeability slightly less than that of free space (a vacuum) and have a weak, negative susceptibility to magnetic fields are said to be Diamagnetic in nature such as: water, copper, silver and gold. Those materials with a permeability slightly greater than that of free space and themselves are only slightly attracted by a magnetic field are said to be Paramagnetic in nature such as: gases and magnesium [10].

2.3. Crank Rocker Mechanism

The mechanism also known as four bar linkages. From Grasshof's Theorem, it can be said that the motion of the linkages are depending on the ratio of the link of length dimensions [11]. The one that have a full rotation about fixed axis are called crank. Another link that are oscillated (swing) or moving between two limiting angels are called rocker. Basic four bar mechanism is shown in the Figure 2.4

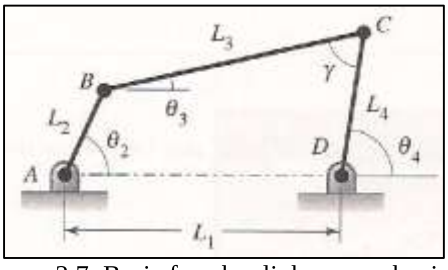


Figure 2.7: Basic four-bar linkage mechanism

Simple analysis need to be made before constructing the mechanism. It includes the determination of interior joint angles ($\theta_3, \theta_{4,}$ and γ) for known links, at certain crank angle (θ_2), throw angle, time ratio, Q and imbalance angle, β. The formula to determine the stated criteria are shown below. Other sample of four bar mechanism is shown in Figure 2.8.

$$BD = \sqrt{L_1^2 + L_2^2 - 2(L_1)(L_2)\cos\theta_2} \qquad (2.2)$$

$$\gamma = cos^{-1}[\frac{(L_3)^2+(L_4)^2-(BD)^2}{2\,(L_3)(L_4)}] \qquad (2.3)$$

$$\theta_3 = 2\,tan^{-1}\left[\frac{-L_2 sin\theta_2 + L_4\sin\gamma}{L_1 + L_3 - L_2\cos\theta_2 - L_4\cos\gamma}\right] \qquad (2.4)$$

$$\theta_4 = 2\,tan^{-1}[\frac{L_2 sin\theta_2 - L_3\sin\gamma}{L_2 cos\theta_2 + L_4 - L_1 - L_3\cos\gamma}] \qquad (2.5)$$

$$Q = \frac{Time\ of\ slower\ stroke}{Time\ of\ quicker\ stroke} \geq 1 \qquad (2.6)$$

$$\beta = 180°\,\frac{(Q-1)}{(Q+1)} \qquad (2.7)$$

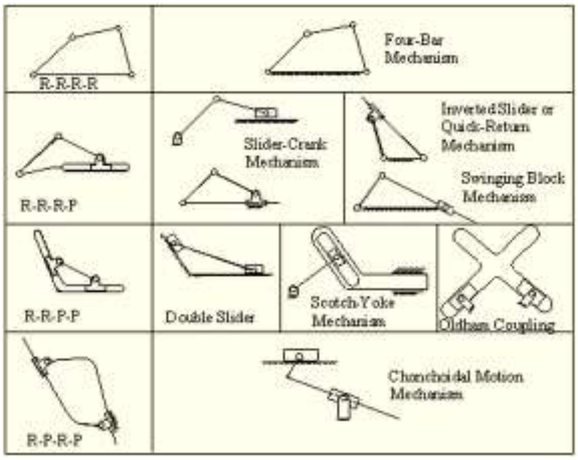


Figure 2.8: Four-bar mechanism alternative

2.4. S-R Latching (JK-Flip-Flop)

One of the most basic sequential logic circuit. “SR stands for Set-Reset. The reset input resets the flip-flop back to its original state with an output Q that will be either at a logic level “1″ or logic “0″ depending upon this set/reset condition. It is basically a one-bit memory on bi-stable that has two (2) inputs;

(i) one input will “SET” the device (output =1), labelled **S**

(ii) another input that will “RESET” the device (output = 0), labelled R

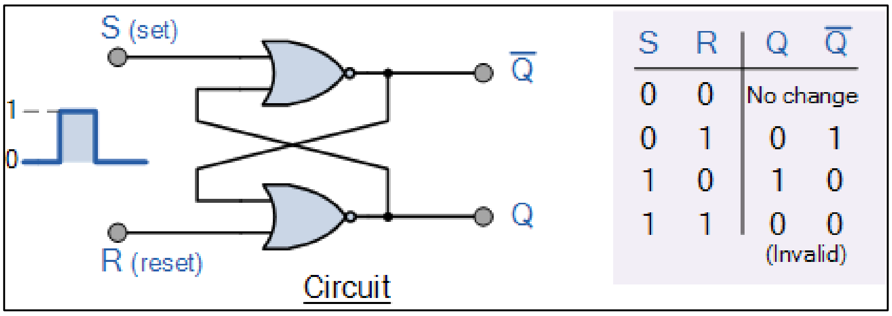


Figure 2.9: NOR Gate SR Flip-Flop Truth Table

The term “Flip-flop” relates to the actual operation of the device, as it can be “flipped” into one logic Set state or “flopped” back into the opposing logic Reset state. It is crucial in the setup of equipment which have 2 different input and one output. It can delay the process until the switch is pushed again, while maintaining the same properties of the circuit in the meantime. It can either be done using NOR gate and NAND Gate [13].

CHAPTER 3

RESEARCH METHODOLOGY AND PROJECT WORK

3. Introduction

This chapter explains on the methodology that was used prior to project completion. The methodology used for the studies are as shown in Figure 3.1. Project timeline (Gantt chart) and key milestones (red in colour) for the study are shown in Figure 3.2.

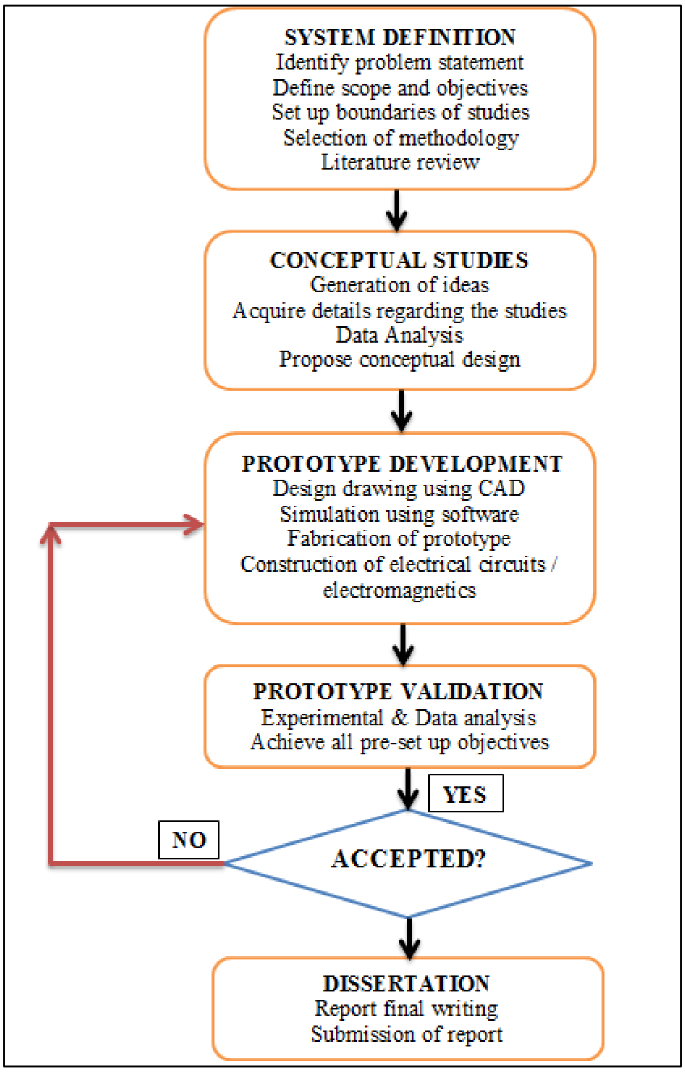


Figure 3.1: Methodologies Chart

This chapter comprises of four (4) main portions, the design drawing using computer aided design software (CAD), simulation of the prototype design for electromagnets and circuit designs, the fabrication of prototype, and experimental analysis to validate the functionality and conformance of the usage of prototype.

Electromagnetic windshield wiper: Conceptual study and analysis

NO	TASK	JANUARY			FEBRUARY				MARCH				APRIL			SEMESTER BREAK 2014	MAY		JUNE				JULY					AUGUST		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.0	TOPICS SELECTION																													
	SELECTION OF TOPICS																													
	- Project Title Submission to FYP Coordinator	√																												
	- Topic Assigned: Electromagnetive Windshield Wiper Conceptual Study & Analysis	√	√	√																										
2.0	SYSTEM DEFINITION																													
	SYSTEM DEFINITION																													
	-Identifying problem statement				√	√	√																							
	-Define scope and objectives				√	√	√																							
	-Set up boundaries of studies & selection of methodology				√	√	√																							
	-Completion of literature review & extended proposal				√	√	√																							
	-Submission of Extended Proposal on 23rd February 2014																													
3.0	CONCEPTUAL STUDIES																													
	CONCEPTUAL STUDIES																													
	- Slides Preparation for Proposal Defense																													
	- Oral Presentation to supervisor & examiners																													
	- Generation of ideas / acquire details regarding studies								√	√	√	√																		
	- Data Analysis / Conceptual studies								√	√	√	√																		
	- Propose Conceptual Designs								√	√	√	√	√																	
4.0	PROTOTYPE DEVELOPMENT																													
	PROTOTYPE DEVELOPMENT																													
	- Detailed Conceptual Designs / CAD design drawing											√	√	√	√		√	√	√											
	- Software design simulations											√	√	√	√		√	√	√											
	- Submission of interim report on 20 April 2014																													
	- FYP I Assessment																													
	- Prototype Fabrication																			√	√	√	√	√	√					
	- Construction of electrical circuits / electromagnets																			√	√	√	√	√	√					
5.0	PROTOTYPE VALIDATION																													
	PROTOTYPE VALIDATION																													
	- Experimental Data / Analysis																							√	√	√	√	√		
	- Achieve all pre set-up objectives																							√	√	√	√	√		
	- Progress Report Preparation & Submission																													
	- Pre-SEDEX																													
	- ViVa																													
6.0	DISSERTATION																													
	DISSERTATION																													
	- Preparation of final report / Dissertation final writing																													
	- Submission of dissertation by the end of FYP II																													

Figure 3.2: Project Gantt Chart / Key Milestones

3.1. System Definition

The author came out and decided on the basis of study such as the problem statement, significance of the project, objectives and scopes of study as aforementioned in chapter 1. Further discussion with the project supervisor was conducted to conform to all the details before the project started. All other pre-requirements such as the project timeline and key-milestones was set up early to ensure the project progress run as per planned as the time went. The system definition is vital in ensuring the project is achieving the pre-set objectives and manage to overcome the stated problem by the time the project is completed.

3.2. Conceptual Studies

After getting the basic understanding on the project, the author started the process of generation of ideas. Several ideas were put into discussion with the supervisor to get the best possible design of the electromagnet. Some calculations regarding the rocker design was studied to get the best configuration on the mechanism of the wiper. Some of the ideas that are being mentioned are shown below.

3.2.1. Basic Wiper Concept

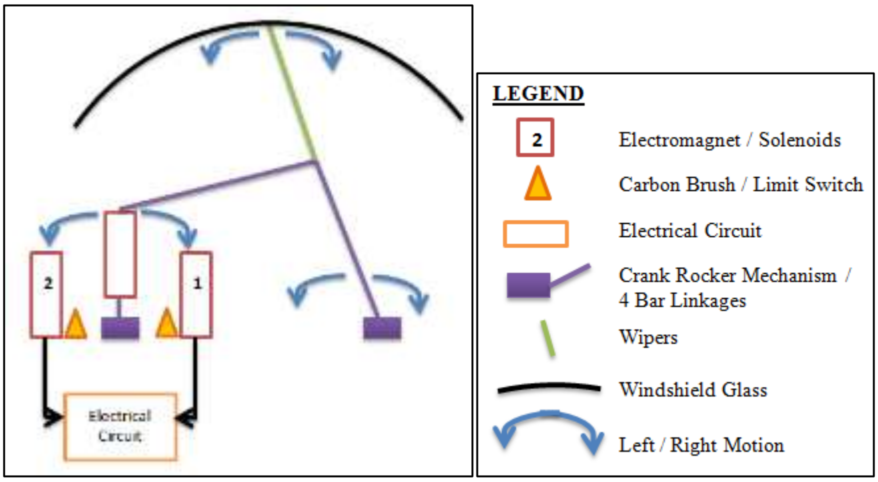


Figure 3.3: Basic Wiper Concept

Generally, this is the basic concept idea that has been proposed during the early part of the project. A PM are placed in between the electromagnet and connected to the linkages. Linkages will transfer the power generated by the electromagnet to move the wiper back and forth across the windshield.

3.2.2. First Wiper Design

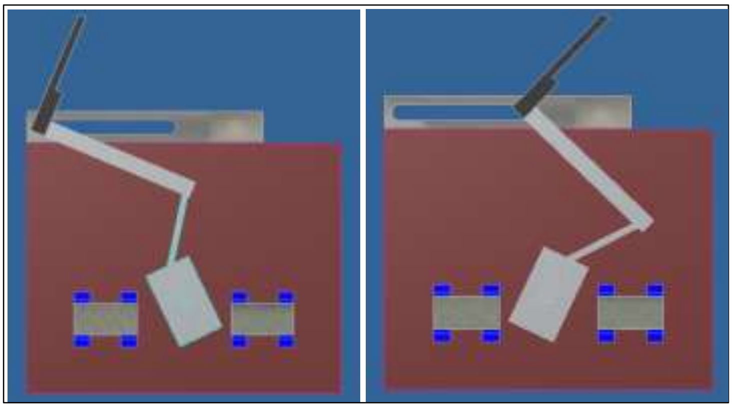


Figure 3.4: First Wiper Design

In this design, the magnet used has a hole in the middle for the ease of fabrication. Movement of the wiper is not smooth enough in the simulation due to miss-calculation in the design. In addition to that, the wiper should be moving in circular motion, not transverse as shown in the simulation. After discussion with the magnet developer, it was noted that the magnet with the hole in the middle did not have a stable amount of magnetic field across the magnet.

3.2.3. Second Wiper Design

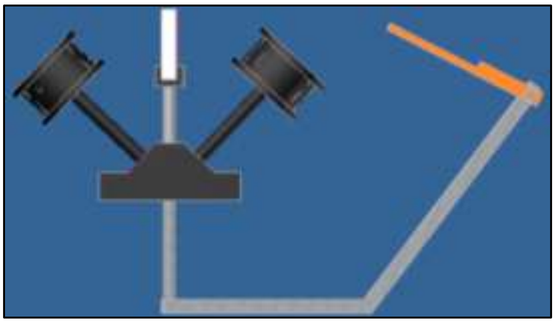


Figure 3.5: Second Wiper Design

In this design, the author decided to change previous magnet (the magnet with hole) with the bar magnet. The electromagnet is shown in the black colour, positioned on the left and right side of the PM. Once further study and simple test has been conducted, it is noted that the electromagnet will function at its best if positioned on the same level with the corresponding PM motion, means that it should not been placed at certain degree as shown in the above design.

3.2.4. Final Wiper Design

As explained in the early part of section 1.1

3.3. Prototype Development

There are several works that need to be completed once was design is finalized and are being explained further in detail in this section. All material specification of the component is also included.

3.3.1. Electrical Design Construction Simulation Test

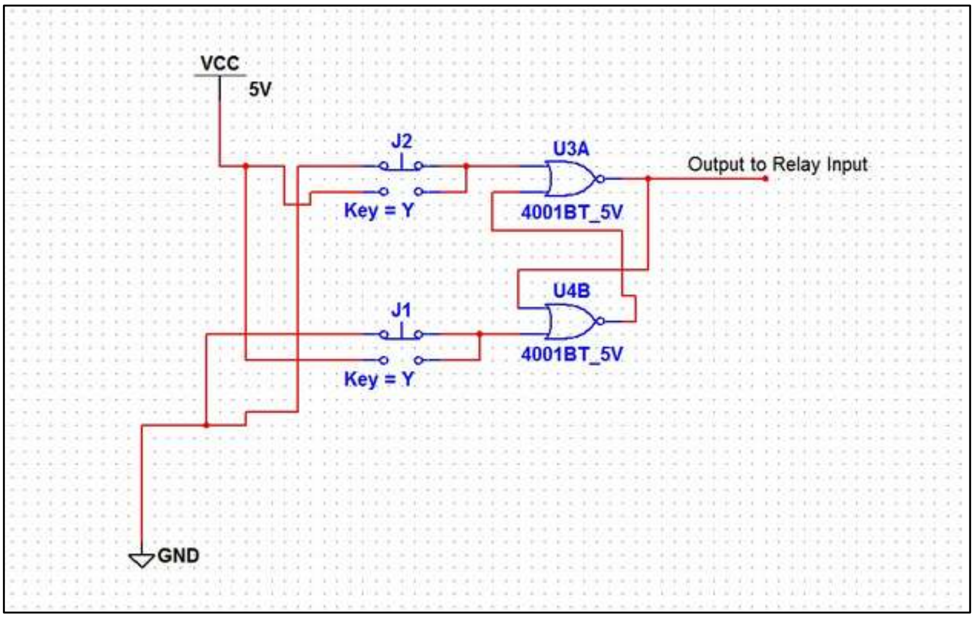


Figure 3.6: Circuit Simulation test via Multisim

As shown in the figure, the author had perform the simulation to check on the suitability of electrical component to be used in the stage of circuit construction via Multisim software. From the software, the waveform profile is captured to see the relationship of this dip switch via SR latching.

The relay will work based on the voltage and current difference principle inside the circuit. J2 and J1 are the corresponding dip switch that are located near to the left and right electromagnet as shown in Figure 1.1. It will act as set and reset switch (SR Latching). Set and reset switch means that the circuit remain on its definite function until another switch is being pushed. When J1 is pushed, it indicates that it is in “SET” and the current will flow in the U3A NOR Gate to the relay output. Once the other switch, J2, is pushed, it will flop back and change to "RESET" condition.

The waveform profile captured is as shown in Figure 3.7. It shows the correlation between input (SET or RESET) and the output in the form of straight line. Vertical line shows the phase changes (activation of S and R respectively). Noted that the output Q is unchanged if both set and reset are activated simultaneously. Phase change indicates that switches at both side of electromagnet are being pushed. It will then trigger the relay to change the other part of the circuit to alter the flow of current in the stated electromagnet, which in turn will change the electromagnet polarity.

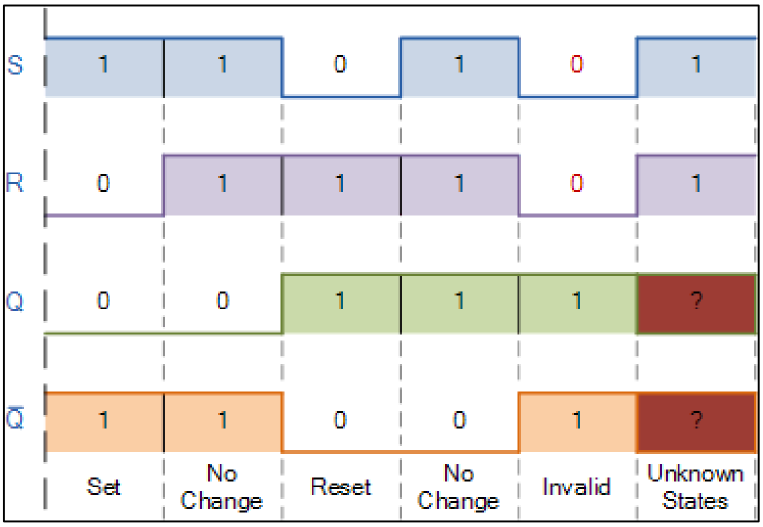


Figure 3.7: Waveform Profile

3.3.2. Circuit Testing Construction

The test for the circuit functionality is completed via helps from members and technicians assistance from Electrical & Electronic Department, Universiti Teknologi PETRONAS. The circuit was first created to test on the usage of dip switch via SR latching which had been discussed in the previous section. The circuit test is shown in the figure below.


Figure 3.8: Circuit Test on SR Latch Dip Switch

As the electromagnet was still in the development stages, the author had to test the circuit with the LED to check on its functionality. The dip switch is working as per requirement, whereby one of it is used to “turn on” the circuit while the other is used to “turn off” the circuit. The switch will not be affected even though it is pressed repeatedly. This is due to the circuit arrangement that had been set-up as shown earlier. The circuit will remain in its current configuration until another set of switch is pressed, which is perfect for this kind of application.

Once the circuit is completed with all the equipment (full set up – additional PM and electromagnet), it was then soldered in a more appropriate manner. All the circuit components are mounted and soldered on Vera board since it was safer to carry on bigger amount of current via solder lead rather than the breadboard.

Figure 3.9: Vera Board and solder lead

3.3.3. Circuit Part Completion

The circuit was then soldered as planned designed by Mr Shafiq. Listed are the components that are used for the electrical part for the whole wiper prototype system.

Table 3.1: Electrical Component Bill of Material

No.	Components	Quantity
1	JK Flip Flop (performed as RS Latch)	1
2	PNP Transistor	2
3	5V Relay	2
4	Resistor	2
5	Switch / Dip Switch	3
6	9V Battery	1
7	12V Battery	1
8	Voltage Regulator	1
9	Connecting Wire	As per used


Figure 3.10: Soldering Process

Concurrently, while soldering the circuit, it is advisable to check on the functionality of each component using an oscilloscope. An oscilloscope is a device that allows observation of constantly varying signal of voltages, usually as a two-dimensional plot of one or more signals as a function of time. It is a vital process to check whether the component will not be affected by the heat in the process of soldering. Checking on each component voltages, current, and other related electrical measures is completed as to gain conformity whether each of the component soldered can function as planned.


Figure 3.11: Checking Battery Voltage Value using an Oscilloscope

As for switches, the check on its effect on relay system was also done using the same instrument (oscilloscope) as shown in the figure below. The following figures show the process of identifying whether the switch attached near to the driving rocker and the relay soldered to the circuit managed to change the circuit flow of current. By doing that, it will change the polarity of the electromagnet, thus repelling the PM to the other side.

The first figure shows the circuit in normal configuration, at 0 Voltage, whereby it does not affected yet by the electromagnet (PM maintain unmoved).

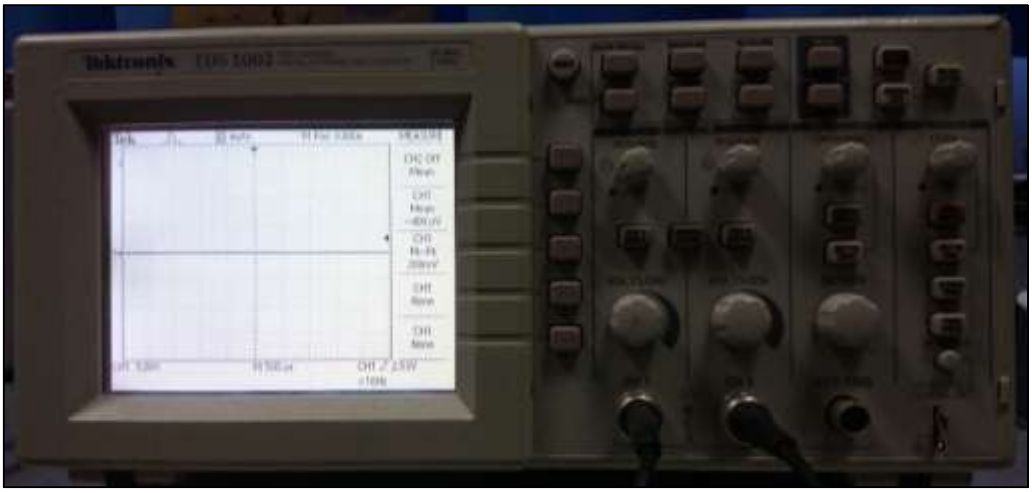


Figure 3.12: Normal Circuit Operation

In this second figure, it shows the voltage rises to 9V, meaning that the switch had been pressed and move to the other direction as opposed to the natural position. Rises in voltage shows the change of polarity of the magnet.

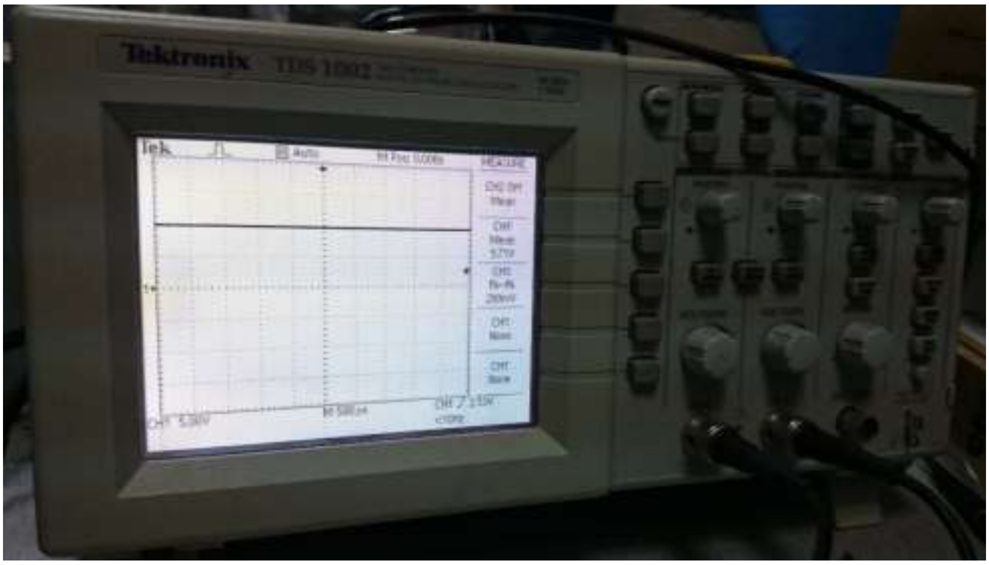


Figure 3.13: First time Switch Pressed, positive Voltage Value

As explained in the section 3.3.1, the circuit will remain in the configuration until another switch is pressed. Once the other switch is pressed, the circuit voltage changes, into negative value, which means that the current flow have been altered, and the electromagnet polarity had changed. The same process will re-occurr again and again until the main switch is turned off.

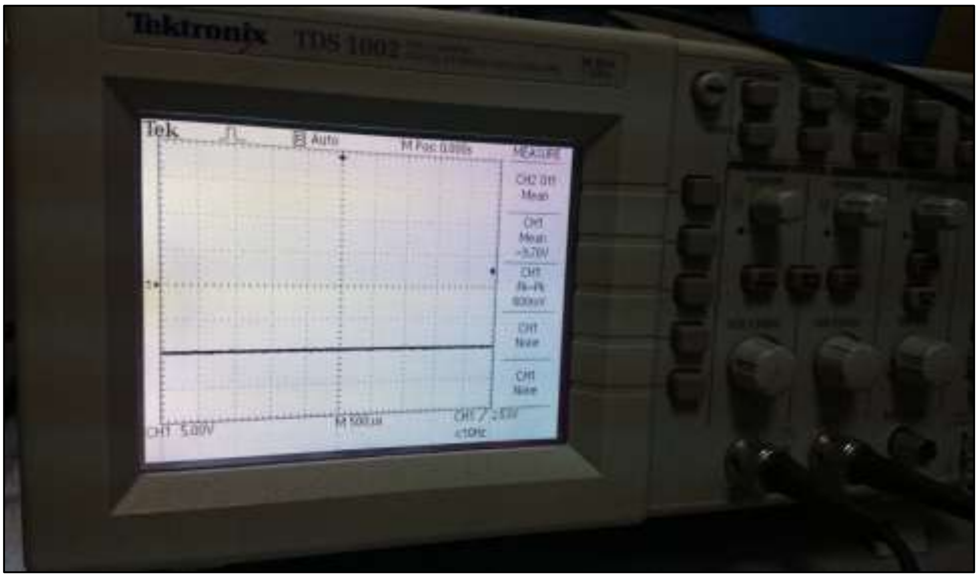


Figure 3.14: Second-time Switch Pressed, negative Voltage Value

For electrical part of this wiper, it can be divided into two sections, the circuit for relay changes, and for electromagnet construction. It uses two separable power sources, one of it is the 9V battery, while the other is 12V battery.

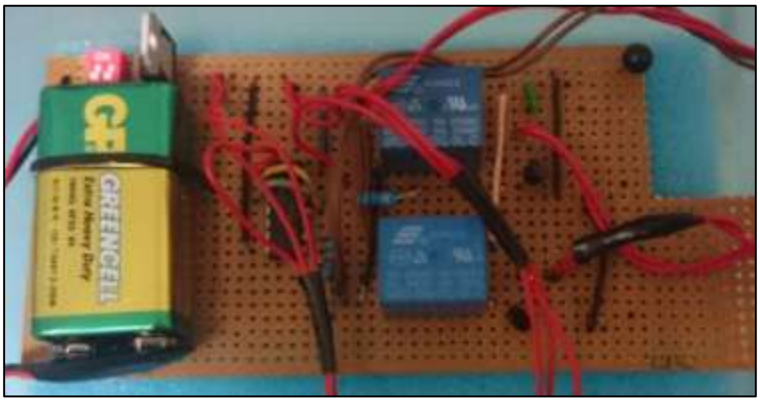


Figure 3.15: Complete Circuit

The circuit is explained in details here. The 9V battery works as power source to power up all the component inside the circuit. The red switch on top of it controls (turned ON or OFF) the whole circuit. The voltage regulator is needed as to lower down the voltage supplied by the battery to work in favour of the relay requirement, which is 5 Voltage. The relay change the current flow with the help of the switch that is attached near the driver rocker. As described earlier, the switch maintains the circuit configuration until another switch is pressed. The resistor in the circuit works as a buffer, to control relay operation with the dip switch attached near the driver rocker. All component inside the circuits are connected using a single core wire, as for easiness of soldering the component on the Vera board. The circuit is connected to two separate outputs, the dip switched mentioned earlier and also the 12 Volts battery used to produce the electromagnet. For the 12 Volts battery connection, multicore wire is used to avoid it from being over-burned by the increase amount of current flow and also due to its flexibility (more elastic and durable compared to single core)

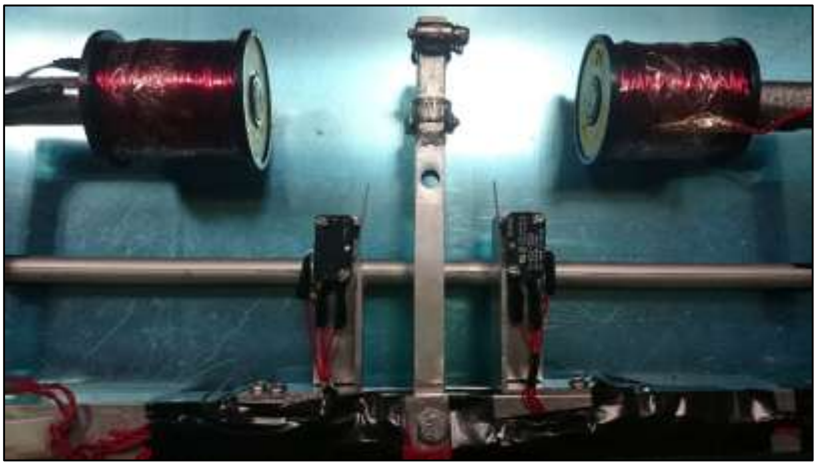


Figure 3.16: Dip Switch location near the driver rocker (PM)

3.3.4. Electromagnets

The insulated wire copper used for electromagnet are produced by RS Components. Its specification as given by the manufacturer are as follows.

Table 3.2: Insulated Copper Wire Specification (Electromagnets)

<table>
<tr><th colspan="3">SPECIFICATIONS</th></tr>
<tr><td>RS STOCK NO</td><td>357-766 (Soft Grade 2 Enamelled Copper Wire)</td><td rowspan="7">
BASEC Standards</td></tr>
<tr><td>DIAMETER</td><td>0.71 mm</td></tr>
<tr><td>LENGTH</td><td>142 m</td></tr>
<tr><td>MAXIMUM OPERATING TEMPERATURE</td><td>+155 °C</td></tr>
<tr><td>ENAMEL COATING</td><td>MIN outer Ø : 0.763 mm
MAX outer Ø: 0.789 mm</td></tr>
<tr><td>TOLERANCE</td><td>+/- 0.0007 mm on conductor</td></tr>
<tr><td>RESISTANCE</td><td>44.89 ohms / km</td></tr>
</table>

3.3.5. Permanent Magnet

For the permanent magnet, the author decided to use the one made from NdFeB Rare Earth material with a dimension of 5cm x 1cm x 1cm. As quoted from its manufacturer, One Magnet Malaysia, the material is the third generation of rare-earth permanent magnet that has high remanence, high coercive force, high-energy product and high performance/cost ratio. The magnet is suitable to be used in application for the development of high-performance, compact and light product [14]. Its specification are as listed below.

Table 3.3: Permanent Magnet Specification

NO	PROPERTIES				
	BrmT(KG)	bHc KA/m(KOe)	iHc KA/m(KOe)	(BH)max KJ/m3(MGOe)	Tw.C
N45	1320-1380 (13.2-13.8)	≥876 (≥11.0)	≥955 (≥12)	342-366 (43-46)	80

The PM has a magnetic force of approximately 5000 gauss which is equivalent to 0.5 tesla. This value differ significantly as compared to the specification in the first column that have 1320-1380 gauss. This is due to the smaller size of the PM, as the specification shows the maximum force it produced at its optimum size. The PM can be washed with water if needed, and will not bring any major health effect to its user. It is also needed to be maintained below its Critical temperature, 80°C, as to maintain its physical properties. The blue dot marks the North Pole of the magnet, (South Pole on the opposite side)

Figure 3.17: Permanent Magnet in comparison of size with 20 cent coin

3.3.6. Project Assemblies

Once all the aforementioned components have been completed and developed as planned, it will be assembled together as per drawing. The author used some machines to perform some working mechanical process in the lab based on the technical subjects previously learned in the earlier semesters. All machining equipment processes such as conventional lathe, threading, cutting, shaping, drilling, welding, and etc. are performed individually with the guidance and supervision from the assigned lab technicians. The process needed to be done as all the materials do not come at the desired sizing, thus a need to modify it according to the planned drawing data. The bill of material that has been used for the mechanical part of the project is as follows.

Table 3.4: Mechanical Component Material Bill of Material

No.	Components	Quantity
1	Iron bar 1 inch x 108 feet	1
2	Iron rod 1 inch x 7 feet	2
3	Iron cylinders 1 inch x 5 feet	2
4	Aluminium bar 2 inch x 18 feet	1
5	Aluminium rod 1 inch x 18 feet	1
6	5000 gauss NdFeB magnet	1
7	Screws, Nuts, and Washers	As per used

As all the process have been completed, the prototype has been mounted on the aluminium board for ease of handling and mobilizing. The following figure shows the image of driver rocker from front view. The rest of the wiper system is not included due to time constraint and difficulties in acquiring the material for the project assembly. In addition, the project scope is only to deliver and test on the validity of the driver rocker working mechanism only, as to prove that this concept can work in the near future.

Figure 3.18: Driver rocker Assembly

CHAPTER 4

CALCULATIONS, RESULTS, AND DISCUSSIONS

4. Introduction

This section comprises results obtained from physical test that had been performed using the prototype and some discussion related to the results taken.

4.1. Minimum force to move the Permanent Magnet

As mentioned in section 3.3.5, the PM has a magnetic force of 0.5 Tesla. To calculate the minimum force required to move the PM in the circular arc as mentioned earlier, the following equation is used. The current supplied from the 12 Volts battery is 2.4 Ampere

$$Minimum\ Force\ to\ move\ the\ PM$$
$$= No.of\ rotation\ x\ Current\ Supplied\ x\ Magnetic\ Force \tag{4.1}$$

From copper wire specification, it has a length of 142 m and resistance of 5 ohm with a diameter of the solenoid cylinder of 5 cm. In order to calculate the number of turns in the solenoid with respect to the solenoid cylinders, the corresponding equation is used.

Therefore,

$$\text{N} = \frac{\text{Total wire Length}}{\text{Circumference of solenoid cylinders}} \tag{4.2}$$

$$= \frac{142\ meter}{\pi\ x\ 0.05\ meter}$$

$$= 904 \text{ turns}$$

As a result, minimum force required to move the PM is

= 904 x 2.4 Ampere x 0.5 Tesla

= 170.4 Newton

If the amount of force generated from the electromagnet did not exceed that value, the PM in the driver rocker will not move and remain static.

4.2. Force produced by electromagnet variation

As mentioned in section 3.3.4, insulated wire is used for the production of electromagnet. The equation used to calculate magnetic force generated from the 12V voltage supply to make the electromagnet is as follows [15].

$$F = \frac{(N\ x\ I)^2\ x\ \ (4\pi\ x\ 10^{-7})\ x\ a}{(2\ x\ g^2)} \tag{4.3}$$

Whereby,

F = Force Generated in Newton

I = Current Supplied in ampere

g = Length of Gap between solenoid (wrapping wire) and metal in meter

a = Area in meter

N = Number of turns of the solenoid

Magnetic Constant / Permeability of Space = $4\pi\ x\ 10^{-7}\ T\ m/A$

This equation is applicable to the air core electromagnet, an electromagnet with hollow core inside the solenoid cylinders. In order to amplify the force produced, an iron core is inserted inside the hollow area. This action changes the value of permeability of space as iron is 200 times greater in permeability compared to natural condition (air core). The following figures shows the relative permeability effect of other material compared to the air core [16].

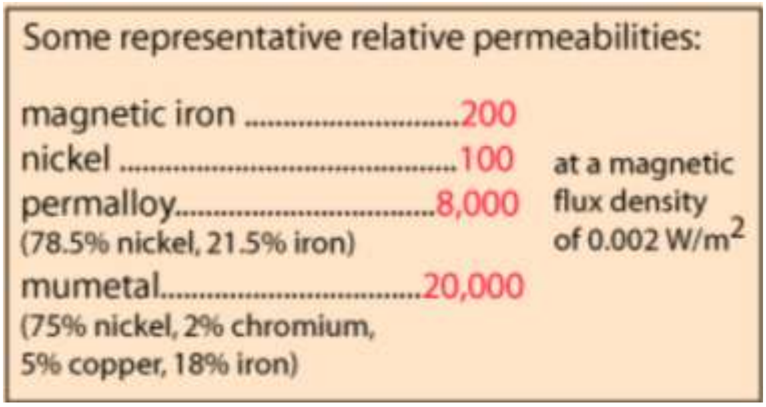


Figure 4.1: Relative permeability with respect to air

For experimental purposes, the author had decided to calculate the force generated from 3 different set up of electromagnet and test it whether it can move the PM or not. The electromagnetic set up are;

i) Air Core + Air Core (Both solenoid cylinder without core/hollow)

ii) Air Core + Iron Core (One is made hollow, the other one with inserted iron)

iii) Iron Core + Iron Core (Both are inserted with iron as core)

By using the equation 4.3, the force calculated by three different set up is tabulated.

Table 4.1: Force Generated by Electromagnet

TYPE OF CORE	FORCE (Newton)	NO OF ROTATION (n)	CURRENT (Ampere)	PERMEABILITY OF SPACE (with respect to air)	AREA OF ELECTROMAGNET (m2)	DISTANCE FROM METAL (meter)
air core	8.40	904	2.4	0.000001257	0.012	0.065
iron core	1680.54	904	2.4	0.0002514	0.012	0.065

As there are 2 sets of electromagnets developed in the system, it takes the total amount of force generated to the following value.

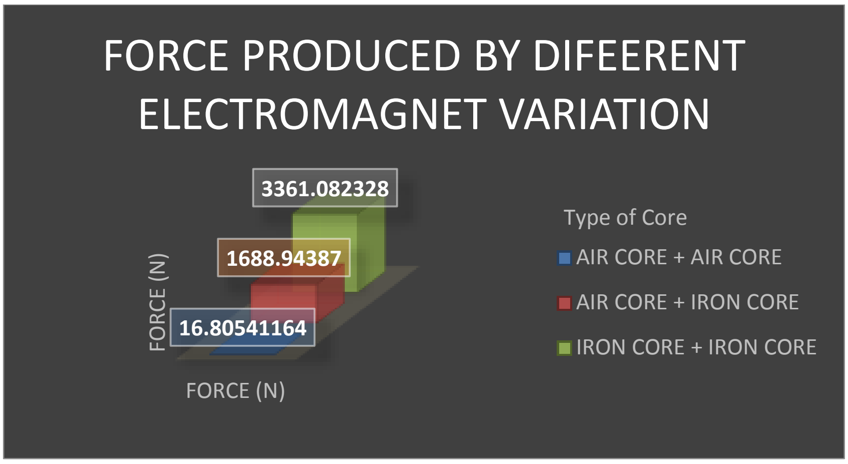


Figure 4.2: Force Generated by Different Electromagnetic Setup

As mentioned earlier, the minimum force to move the PM is 170.4 Newton. Therefore as a stipulated condition stated in the table 4.1, only core type two and 3 are capable of moving the PM in that circular arc motion. It is because the force generated by the electromagnet exceed the minimum value of force of the PM. As expected, the value of core type 3 produced greatest amount of force of 3361 Newton due to the additional iron core that are being inserted in that solenoid cylinders. To create more force, actions such as decreasing the distance of the electromagnet from the incoming metal, adding up number of winding turns of the electromagnet and changing the core to material that have greater permeability can be done. However, for this paper, the distance is fixed to be at 6.5 cm as the PM will hit the electromagnet if the distance is being put nearer thus restricting the free circular movement motion of PM.

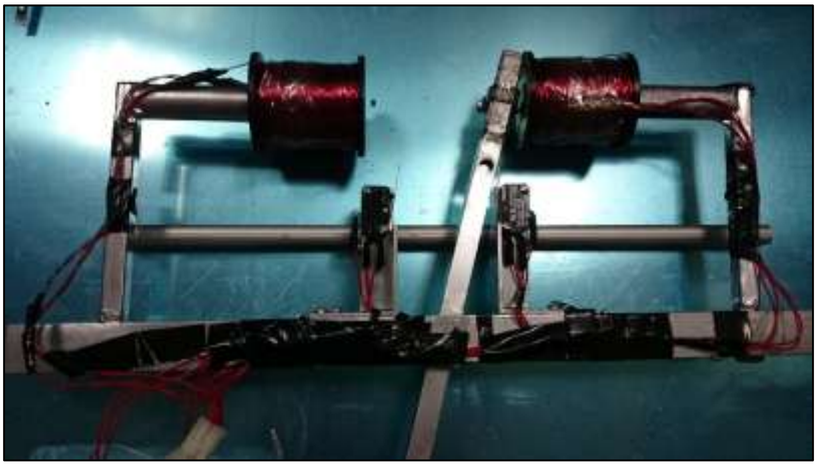


Figure 4.3: PM position with respect to electromagnet

4.3. Angular Speed of Driver Rocker

Further test was conducted to test on the angular speed of the driver rocker. For this test, the author decided to calculate on the speed of type 3 core (iron core + iron core). The movement of the driver rocker is captured using a high speed camera by setting it up to 1000 frame per seconds, whereby images and videos have been captured. As calculated, the rocker will make a 30° circular arc rotation between the electromagnets. Some of the images captured are shown below.

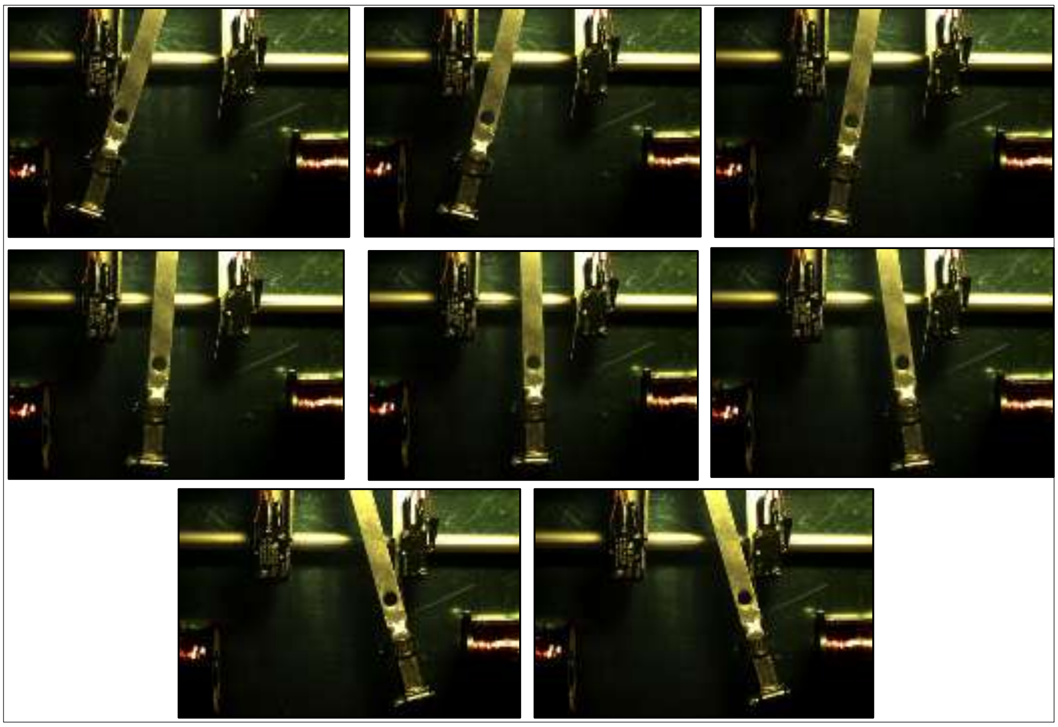


Figure 4.4: Images of PM performing one circular arc motion

To plot the angular velocity profile of the PM/driver rocker, the author had decided to take the images in 10 frames interval for ease of calculation. 1 frame represents 0.001 seconds. The driver rocker takes about 50-60 frames of images to complete one way of circular arc motion, which is approximately 0.05 second per cycle. The steps of calculating the angular speed of the PM/Driver Rocker are as follows;

i) Capture image of the moving driver rocker

ii) Import the image to CAED software, to calculate the degree (°) created

iii) Set left side of switch as reference point and motion to the right as positive. Motion to the left is referred as negative value

iv) The angle created between maximum left switch point and maximum right switch point is calculated, equivalent to (30°) circular arc rotation

v) Angle created is converted to radian and relative radian (with respect to 30° mentioned earlier)

vi) Time is calculated with respect to the frame images number

There are two (2) sets of data, the original data produced and its components are shown in the left side of the table. However, since the author had set up the left switch as a reference point, the data need to be recalibrated and shown on the right part of the table to be used for generation of the velocity profile.

Table 4.2: Permanent Magnet Driver Rocker Circular Arc Rotation Motion

PERMANENT MAGNET DRIVER ROCKER CIRCULAR ARC ROTATION MOTION							
Frame	Angle	Radian	Seconds		Theta	Relative Radian	Seconds
47	71.4	1.246327	0.001		0.0	0	0.001
57	74.3	1.296948	0.002		2.9	0.050621111	0.002
67	79.8	1.392953	0.003		8.4	0.146626667	0.003
77	86.5	1.509906	0.004		15.1	0.263578889	0.004
87	88.0	1.536089	0.005		16.6	0.289762222	0.005
97	93.3	1.628603	0.006		21.9	0.382276667	0.006
107	100.1	1.747301	0.007		28.7	0.500974444	0.007
110	101.4	1.769993	0.008		30.0	0.523666667	0.008
117	99.3	1.733337	0.009		-2.1	-0.036656667	0.009
127	97.5	1.701917	0.010		-3.9	-0.068076667	0.010
137	89.3	1.558781	0.011		-12.1	-0.211212222	0.011
147	86.5	1.509906	0.012		-14.9	-0.260087778	0.012
157	81.2	1.417391	0.013		-20.2	-0.352602222	0.013

167	74.7	1.30393	0.014		-26.7	-0.466063333	0.014
169	71.6	1.249818	0.015		-29.8	-0.520175556	0.015
177	74.6	1.302184	0.016		3.0	0.052366667	0.016
187	79.4	1.385971	0.017		7.8	0.136153333	0.017
197	82.1	1.433101	0.018		10.5	0.183283333	0.018
207	93.2	1.626858	0.019		21.6	0.37704	0.019
217	95.5	1.667006	0.020		23.9	0.417187778	0.020
227	100	1.745556	0.021		28.4	0.495737778	0.021
232	101.4	1.769993	0.022		29.8	0.520175556	0.022
237	100.2	1.749047	0.023		-1.2	-0.020946667	0.023
247	97.6	1.703662	0.024		-3.8	-0.066331111	0.024
257	94.3	1.646059	0.025		-7.1	-0.123934444	0.025
267	87.2	1.522124	0.026		-14.2	-0.247868889	0.026
277	80	1.396444	0.027		-21.4	-0.373548889	0.027
288	71.9	1.255054	0.028		-29.5	-0.514938889	0.028

As calculated, the corresponding angular velocity of the driver rocker at(30°) rotation = 0.523 radian and 63 frames to complete one cycle is

$$\omega = \frac{0.523\ radian}{0.063\ seconds} = 8.39 \text{ rad/s}$$

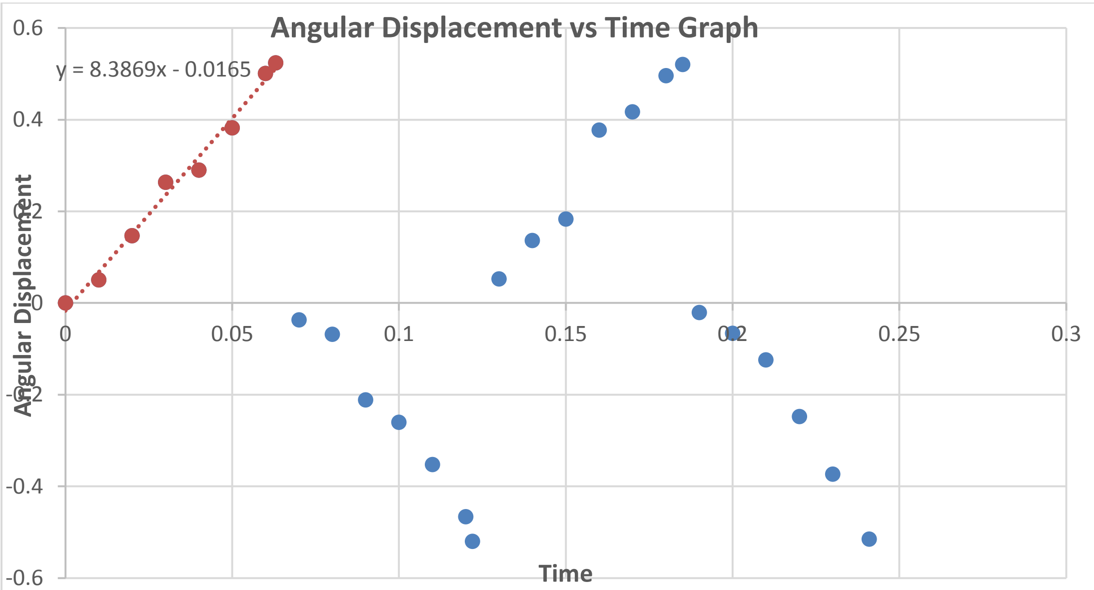


Figure 4.5: Angular velocity Profile

The angular speed of this design is comparable to the speed of the wiper produced by the electrical motor. The profile of the wiper shows positive (motion to right / forward motion) value and negative (motion to left value / reverse motion) in relation to time to complete the cycle. Noted that the pattern between the motions are quite similar, thus indicating that the angular velocity of the driver rocker is linear / same throughout the whole system.

4.4. Linkage Mechanism

The simulation is conducted in ADAMS 10.0 to evaluate the effect of the linkage position and length towards the angular velocity of the driving rocker. The simulation is conducted four (4) times at a ratio linkage length between the driver rockers to wiper rocker of;

i) 1:0.9 ratio

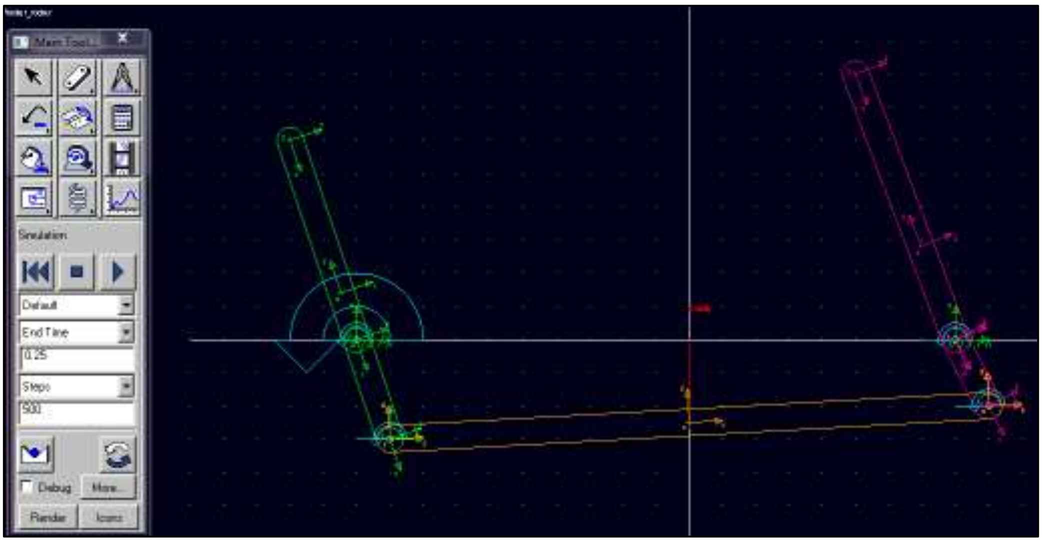


Figure 4.6: 1:0.9 ratio view

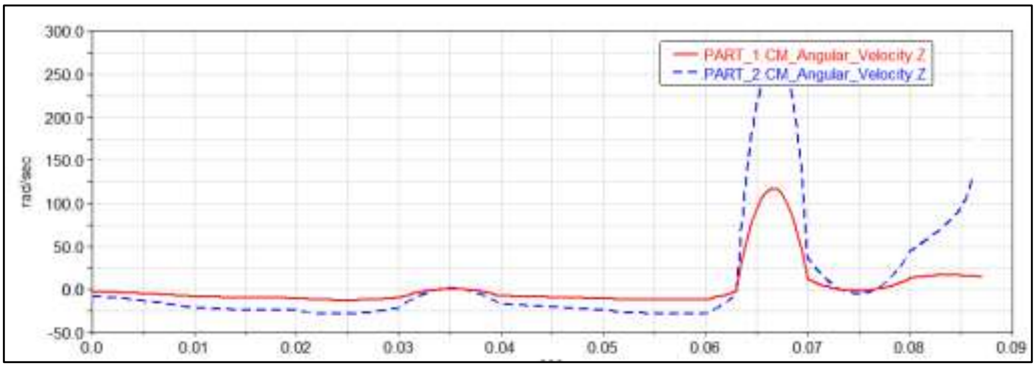


Figure 4.7: Angular Velocity Profile at 1:0.9 ratio

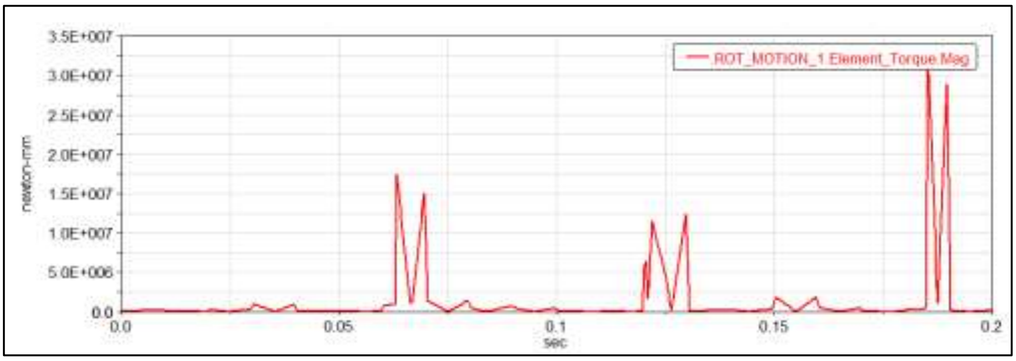


Figure 4.8: Torque magnitude at 1:0.9 ratio

At this ratio, the rotational arm of the driver rocker produced the highest torque which shows the value of torque up to $3.5\ x\ 10^{-7} Nmm$. In addition, there are changes in angular velocity between the driver rocker and the wiper rocker. In order to generate more power to the wiper, it is advisable to have a higher angular velocity. As shown in figure, the wiper rocker move two (2) times faster than the driver rocker. It is vital that this is maintained throughout the simulation, due to the necessity to move the wiper more quickly across the windshield especially in bad weather condition.

ii) 1:1 ratio (same length)

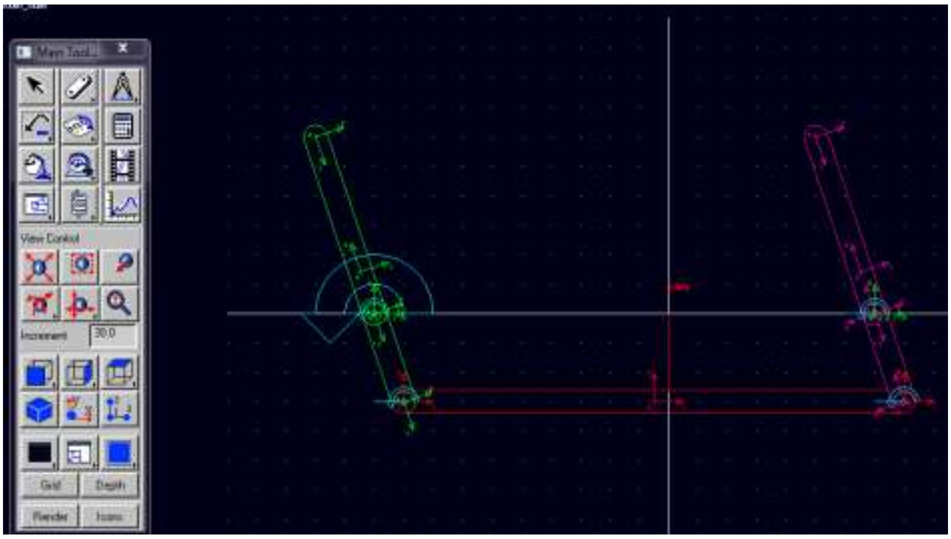


Figure 4.9: 1:1 ratio view

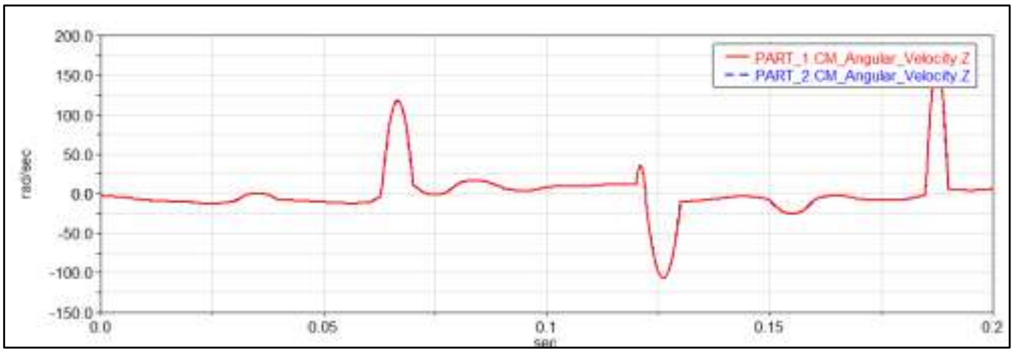


Figure 4.10: Angular Velocity Profile at 1:1 ratio

As shown in figure 4.10, the angular velocity of the driver rocker and the wiper rocker are equivalent to each other. This is happening due to the same length / mirror drawing in ADAMS, whereby both rockers share the same characteristic; same angle, same length, and jointed to each other via another linkage. Therefore, this is not the best configuration that is needed for the wiper design.

iii) 1:1.5 ratio

In this scenario, the length of the driver rocker is set to be 1.5 times longer than the pre-set up value of the driver rocker.

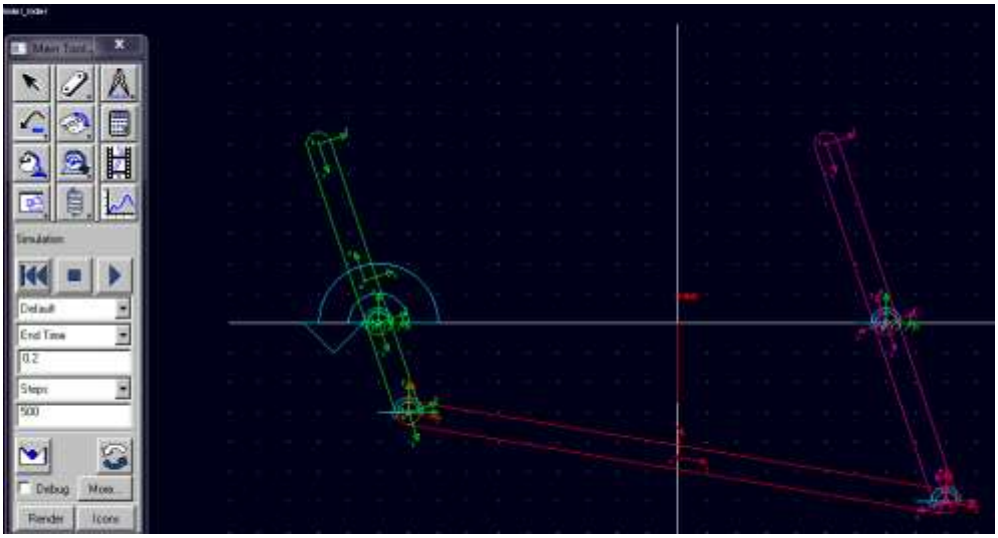


Figure 4.11: 1:1.5 ratio view

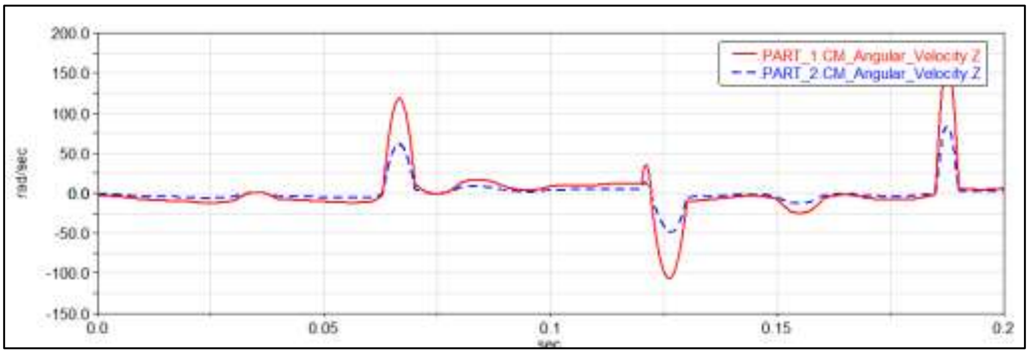
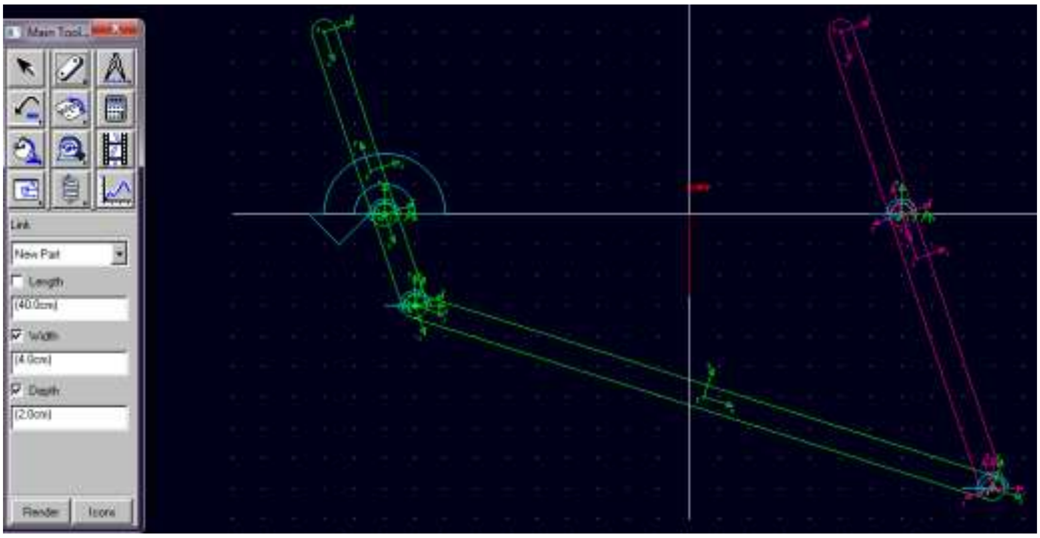


Figure 4.12: Angular Velocity Profile at 1:1.5 ratio

As shown in figure 4.12, the angular velocity of the driver rocker and the wiper rocker is not similar as compared to the second scenario. Angular velocity of the wiper rocker is slightly smaller than the driver rocker especially at the crest. The crest and amplitude of the velocity signals motion change of the wiper rocker from forward motion to reverse motion. The angular velocity of the driver rocker is approximately 125 radian/seconds, nearly doubles the velocity as compared to the much slower rocker that moves at only 65 radian/seconds.

iv) 1:2 ratio

In this scenario, the wiper rocker length is set to be double the length of the driver rocker.



‘Figure 4.13: 1:2 ratio view

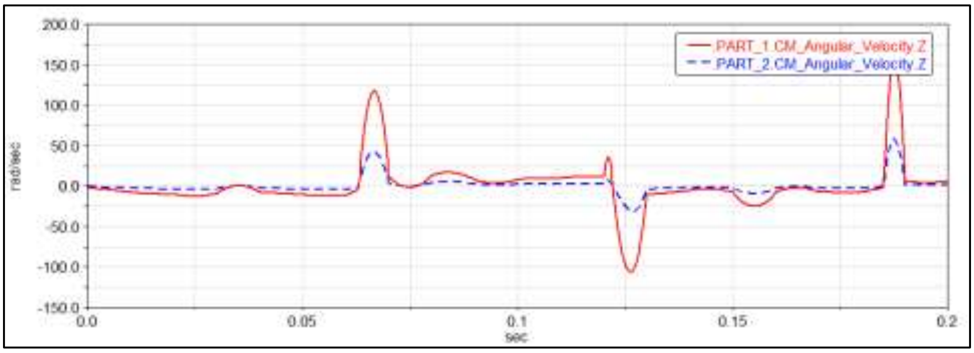


Figure 4.14: Angular Velocity Profile at 1:2 ratio

In figure 4.14, the angular velocity profile produced a pattern that looks quite similar to the previously mentioned scenario whereby the wiper rocker is much slower compared to the driver rocker. It only moves at the motion of 45 radian/seconds.

As to compare all the data gathered, the angular velocity of the driver rocker is maintained throughout the entire simulation for ease of comparison purposes. It can be concluded that the configuration of linkages was affected both torque and the angular velocity of driver rocker. If the situation required the wiper to be moving at a higher speed and lower torque, it is advisable to have a shorter wiper rocker length. In contrast, for a slow speed wiper, longer wiper rocker length is needed. Linkages configuration can be changed according to the wiper’s function.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In this project, a windshield wiper prototype was fabricated and predicted to be able to generate maximum torque value of 35 Nm which is considerably higher as compared to the electrical motor used in the current wiper designs that can produce only 6-12 Nm. The wiper rocker was found to be able to move two (2) times faster than the driver rocker at a speed of 250 rad/s, which is high enough to move the wiper across the windshield. In order to generate more power to the wiper, higher angular velocity can be applied to the input. In order to amplify the force generated by the electromagnet, iron core is used or can be replaced with other high permeability material if there is a need of a greater amount of force to move the driver rocker at a higher speed.

This paper is only focuses on confirming the concept, which is to develop the designs of the wiper and test the prototype with certain experiment for validation purposes. The objectives are therefore fully achieved by the end of the project period. As the prototype produced can only be working at one speed (cannot vary the speed of the driver rocker), further additional electrical component that can control the current supplied and set up needed to be designed in order to make the prototype to be more perfect. Replacing power sources from motor to electromagnetic is one of innovative designs that can be further investigated and developed in the near future. Thus, it is hope that this project will trigger further generation of ideas improvement.

REFERENCES

[1] III, J. F. (2010). *Mary Anderson. Encyclopedia of Alabama*, [Online]. Available: http://www.encyclopediaofalabama.org/face/Article.jsp?id=h-2553

[2] Anderson, M, Window-cleaning device. Patent 7 43 801, United States Patent Office, 1903

[3] NissanNews.com |USA. (2012, May) *Details Matter: 2013 Nissan Altima Windshield Wiper Innovation*. [Online] Available : http://nissannews.com/en-US/nissan/usa/releases/details-matter-2013-nissan-altima-windshield-wiper-innovation

[4] Joseph N. (2013, December) McLaren working to replace windshield wipers with sound waves. [Online] Available: http://www.autoblog.com/2013/12/17/mclaren-ultrasonic-windshield-wiper-technology-report/

[5] Nice, Karim. (2001,March) "*How Windshield Wipers Work*". [Online] Available: http://auto.howstuffworks.com/wiper.htm on 16 February 2014.

[6] Sulaiman M.F. *Product Development Using QFD Methodology - A Case Study of Car Wiper*, Degree dissertation, Faculty of Manufacturing Engineering, National Technical University College Of Malaysia, 2005

[7] Alimuddin K., "Magnetism" in Basics of Electromagnetism: Almol Publications Pvt. Ltd, 2008, pp 84 -92

[8] Proctor, R.R, Electromagnet design. Patent 5 955 935, United States Patent Office, 1999

[9] Fawwaz T.U, “Maxwell’s Equations for Time-Varying Fields” in Fundamentals of Applied Electromagnetics Fifth Edition: Pearson Prentice Hall, 2007, pp 255-270

[10] n.a (April 2014) *The Electromagnet*. [Online] Available: http://www.electronics-tutorials.ws/electromagnetism/electromagnets.html

[11] n.a (n.d) *Four Bar Mechanism*. [Online] Available: http://ocw.metu.edu.tr/pluginfile.php/6885/mod_resource/content/1/ch7/7-1.htm

[12] Myszka. D. H. “Mechanism Design” in Machines & Mechanism Applied Kinematic Analysis Fourth Edition: Pearson Prentice Hall, 2012, pp 109-119

[13] n.a (2014, April) *Sequential Logic Circuit : SR Flip-Flop.* [Online] Available: http://www.electronics-tutorials.ws/sequential/seq_1.html

[14] Wong, K.F (2008) Products: NdFeB Rare Earth Magnet [Online] Available: http://www.onemagnet.com.my/pro_ndfeb.html

[15] Jason, L. (2013, July) How to Calculate Solenoid Coil Electromagnetic Force [Online] Available: http://www.byronacademy.org/knowledge-center/view/calculatiing-emf-in-solenoid/

[16] n.a (n.d) Relative Permeability [Online] Available: http://hyperphysics.phy-astr.gsu.edu/hbase/solids/ferro.html#c5