Electronic Throttle Control

by

Mohd Hafizi Bin Mohamad

A project dissertation submitted in partial fulfilment of

the requirements for the Degree

Bachelor of Engineering (Hons)

(Electrical and Electronic Engineering)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2011

CERTIFICATION OF APPROVAL

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Approved by,

____

(Assoc. Prof. Dr Mohd Noh Bin Karsiti)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2011

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.

MOHD HAFIZI BIN MOHAMAD

ABSTRACT

Electronic Throttle Control (ETC) has been widely used in most of the automobiles around the world. ETC is also known as Drive-By-Wire (DBW). Since most of us demand for a car which is fuel efficient and meets gas emission, car manufacturer had been finding ways to built them. The invention of Electronic Throttle Control was a good way towards reducing the fuel consumption and exhaust emission. The objective of this project is to build a functional ETC system and study its control element in the process. The main focus of this project is to control the opening of the "butterfly" valve. To accomplish this target, a remote control servomotor will be attached to the Electronic Throttle Body (ETB). The servomotor then will be control remotely by using PIC microcontroller. Gearing set and spring is use to help the servomotor achieve high torque and low speed condition and to maintain the position of the butterfly valve opening. At the end of the project, the working ETC prototype will be built. A lot of time, energy and money have been contributed to make sure this project is achievable.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank to Allah for helping me and giving me strength and courage in completing this Final Year Project (FYP). Without HIM, I will not be able to complete this course.

I am also profoundly grateful to my supervisor, Assoc. Prof. Dr. Mohd Noh Bin Karsiti who has guided and assisted me in completing this FYP. Without your supervision, I am just like a ship without the captain.

My greatest appreciation also goes to all my family especially to my father, Mohamad Bin Ismail, my mother Azizah bte Mahmud and my sister Nor Hafizah Bte Mohamad who have always prays for me. You all are always stood by my side.

I would also like to take opportunity to express my deepest gratitude to all my friends who have share their knowledge especially Mohd Fakhrul Amin Bin Abd Razak, a loyal friend who always help me in programming and do circuit design and Hadi Aiman Bin Hamidon, a charming person who always support me in whatever I do.

Last but not least, many thanks to the others whose name was not mention in this page. Without you, I am no one. Thank you very much.

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LIST OF ABBREVIATIONS

ETC	Electronic Throttle Control
DBW	Drive-By-Wire
TPS	Throttle Positioning Sensor
ECU	Electronic Control Unit
DC	Direct Current
ETB	Electronic Throttle Body
PIC	Programmable Integrated Circuit
ADC	Analogue-to-Digital-Converter

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Electronic Throttle Control (ETC) is an automobile technology which serve the mechanical link between the accelerator pedal and the throttle. ETC is also called as Drive-By-Wire (DBW) system. An ETC-equipped vehicle operate with an ETC inside rather than the mechanical linkage cable. An ETC is consisting with Electronic Throttle Body (ETB), butterfly valve and Throttle Positioning Sensor (TPS). ETC is a technology that replaces the conventional cable connection between a vehicle's accelerator pedal and the engine's throttle body [12].

In a Drive-By-Wire car, a microcontroller determines the correct throttle plate position. If the driver needs sudden acceleration and steps on the accelerator pedal, the sensor on the pedal transmits the driver's pressure on the pedal to the microcontroller, which calculates and relays the correct throttle position to the motor, which moves the butterfly opening accordingly. Electronic control of the butterfly opening offers improved fuel economy and emissions by maintaining optimal throttle condition at all times, which sometimes human driver cannot.

One of the parts of ETC is TPS. Most automobiles that already use ETC is equip with Throttle Positioning Sensor (TPS) to provide input to traction control, antilock brakes, fuel injection, and other systems, but use a Bowden cable to directly connect the pedal with the throttle. Instead, the signal sent from the TPS will be use by the Electronic Control Unit (ECU) to determines the required throttle position by calculations from data measured by other sensors such as an accelerator pedal position sensor, engine speed sensor, vehicle speed sensor and then positions the throttle via an actuator driven by a small, high-torque direct current (DC) motor. The electric motor within ETC is then driven to the required position via a closed-loop control algorithm within the ECU [13].

Since this project deals with throttle bodies, it is important to know about throttle bodies and how they work. The idea of this project is to control a throttle electronically; therefore it is important to know about engine and motors and how they actually work. RC servo was chosen due to its close-loop control system where feedback from the output can be used for error detection. Programmed to a programming integrated circuit (PIC), the servomotor should control the "butterfly" opening of the throttle precisely.

1.2 Problem statement

For the current technology, the ETC have make easier to integrate features such as cruise control, stability control, traction control and other that require torque management to the vehicle, since the throttle can be moved irrespective of the position of the driver's accelerator pedal [6]. There is an idea that has been suggested that ETC or DBW system might allow a car to become completely separate from its control [6]. From the idea, it is mean that future car might theoretically be controlled by any number of different control system such as joystick, steering wheels, push button or even voice command [6].

One of the most technologies that use ETC is Hybrid car [6]. This is the best example of DBW system that has ETC, brake control and transmission control. Further application of the DBW concept, in Europe and Japan automatic parking assist is also available; the car can control the steering to guide itself backwards into a parking space [6].

Since most of us demand for a car which is fuel efficient and meets gas emission, car manufacturer had been finding ways to built them. The invention of Electronic Throttle Control was a good way towards reducing the fuel consumption and exhaust emission. A car could waste more energy depending on the driver's lifestyle. Since it is difficult to change a driver's habit in driving, Electronic Throttle Control is one of the best ways to reduce the fuel consumption and also the exhaust emission. By controlling the opening of the throttle or the "butterfly", this can maximize the percentage of the combustion in the engine. Since the throttle communicates with the Electronic Control Unit, the angle of the "butterfly" opening is the important thing that needs to be taken for better efficiency and response.

1.3 Objectives

The main objective of this project is to build a functional ETC system and study its control element in the process. To accomplish this objective, a working prototype of ETC must be built.

1.4 Scope of study

The scope of the project study is limited to the study of identifying and combining the servomotor to the Electronic Throttle Body by using the cheaper and commercial available servomotor. The electronic circuit also needs to be built to control the servomotor. The suitable instrument, ETC and gearing set also needs to be find. This project also needs to study about the TPS. At the end of this project a working prototype that showcases its abilities is expected.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory

Getting started with a project, it is important to do a lot of research to understand about the project for. This project started by researching on the weakness of the mechanical driven throttle and what have been done to solve this problem. Knowing the objectives of this project, the throttle body of the engine was studied carefully.

Since ETC has been around, research was also done on it including the DC servomotor chosen. Due to this, understanding how the servomotor works and how to control them is important. This is important to determine type motor that need to be used for this project. For controlling the servomotor, a control board will be design to control the motor which control the opening of the "butterfly" valve.

Many researches have been done by the previous individual or group about the ETC. From mathematical approach until the actual design of ETC. One of the researches by using mathematical approach is done by Paul G. Griffiths [7]. His research is about controlling the ETC by using Embedded Software Control Design.

Nowadays, ETC is not only used for cars but also used for motorcycles. One of the example of motorcycle that use ETC or DBW system is YAMAHA R1 [8]. This feature is called YCC-T (Yamaha Chip-Controlled Throttle). The YCC-T is using to controls the throttle-valve opening for instantly responsive and smooth power.

2.2 Electronic Throttle Body

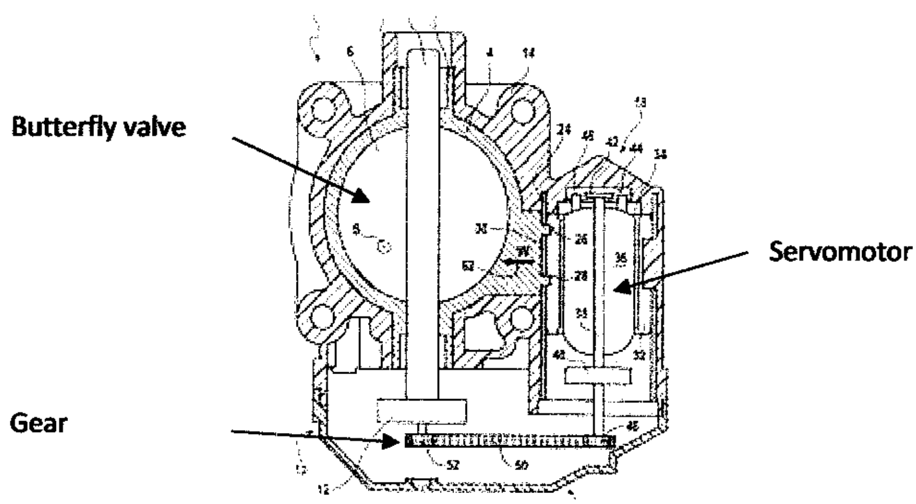

Figure 1 : Electronic Throttle Body

Electronic Throttle Body (ETB) is one of the parts of the Electronic Throttle Control (ETC). Basically, the butterfly valve opening is similar to the mechanically driven throttle body. The difference is the butterfly valve opening is control by a servomotor connecting by a set of gear and for the mechanically driven throttle; the butterfly valve opening is being control by the Bowden cable [1]. The ETC is connected to the ECU module that is control the butterfly opening angle depending on the driver control pressure at the throttle pedal.

When the driver presses the throttle pedal, the TPS will send a signal to the ETC module. The ETC module will correct the opening angle of the butterfly opening depending on the amount of pressure on the throttle pedal. The TPS will provide a feedback to the ETC module.

2.3 RC Servomotor

Remote Control (RC) servomotor is designed to receive a position command and move its motor shaft to the desired angle [2]. The servomotor are made from DC motor with potentiometer and servo controller chip built to them to determine the angle of its motor shaft and received commanded position and drive the commanded position in a feedback loop.

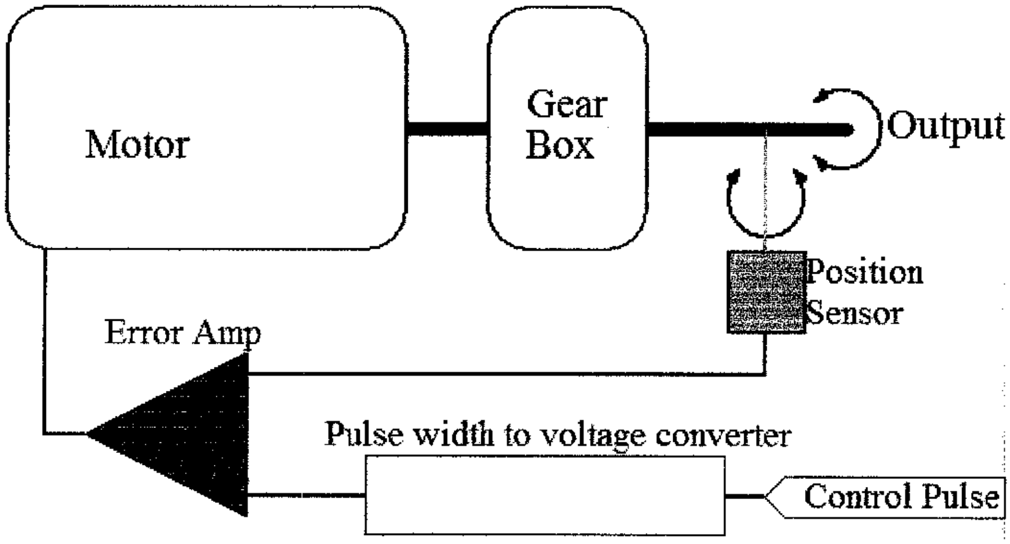

Figure 2 : RC Servo Motor Circuit Diagram

An RC servomotor has limited motion, where it can only rotate between -90 to +90 degree. To protect it from over rotating, it has mechanical stop device to ensure the motion is restricted.

There are three inputs for RC servomotor which is 5 Volt power supply, grounding and control signal cable. Usually, a 1.5ms pulse width would indicate 0 degree position of the motor shaft. A pulse width of 1ms indicates -90 degree and pulse width of 2ms would indicate +90 degree [3].

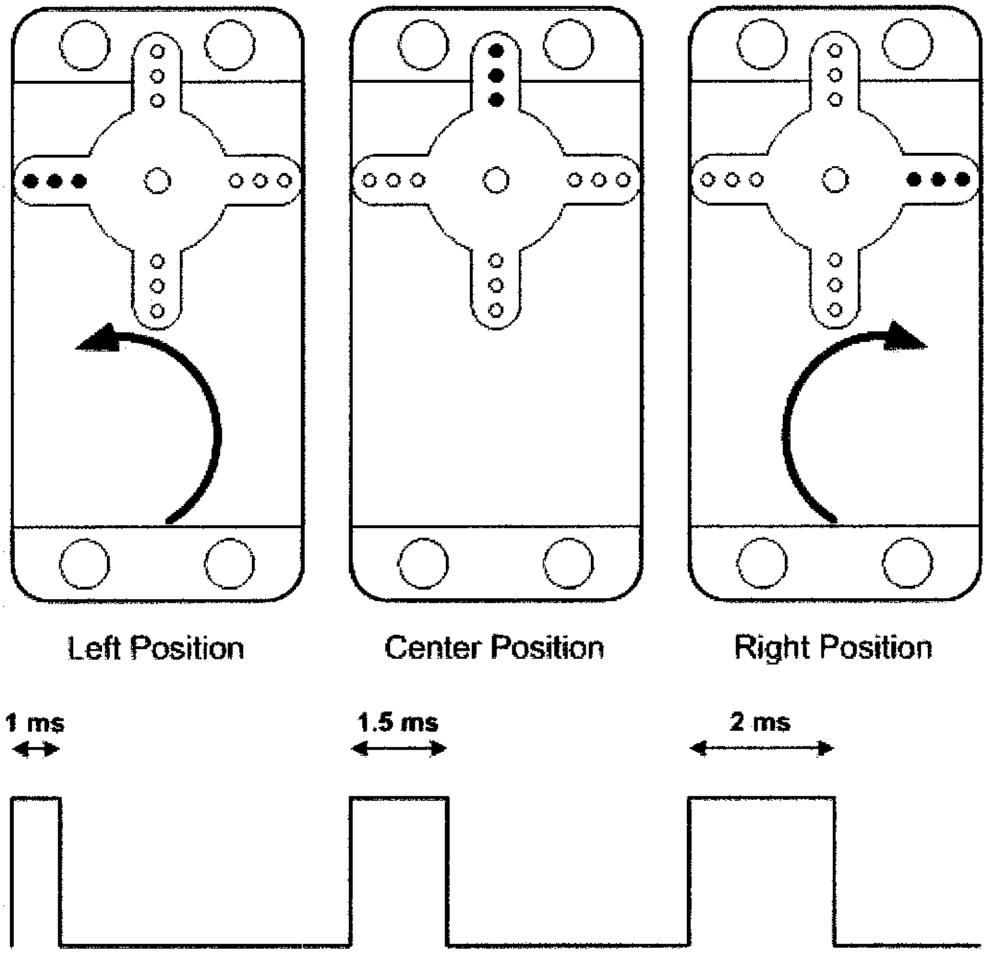

Figure 3 : RC Servo Motor Signal

2.4 Throttle Positioning Sensor

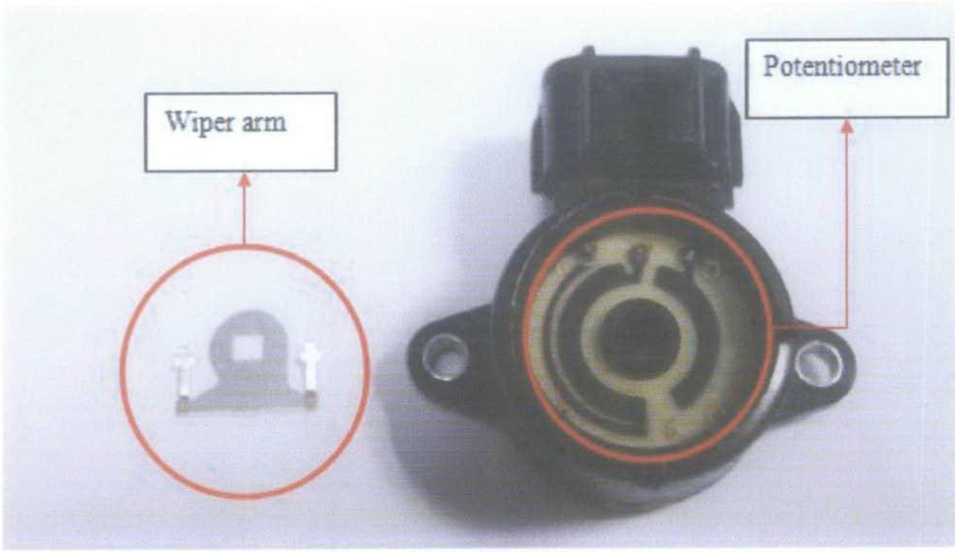

Figure 4 : Set of Throttle Positioning Sensor (TPS)

A throttle position sensor (TPS) is a sensor used to monitor the position/angle of the butterfly valve opening in the Electronic Throttle Body. The sensor is usually located on the butterfly shaft so that it can directly monitor the position of the butterfly valve opening [4].

The sensor is usually a potentiometer, and therefore provides a variable resistance dependent upon the position of the butterfly valve opening and hence throttle position.

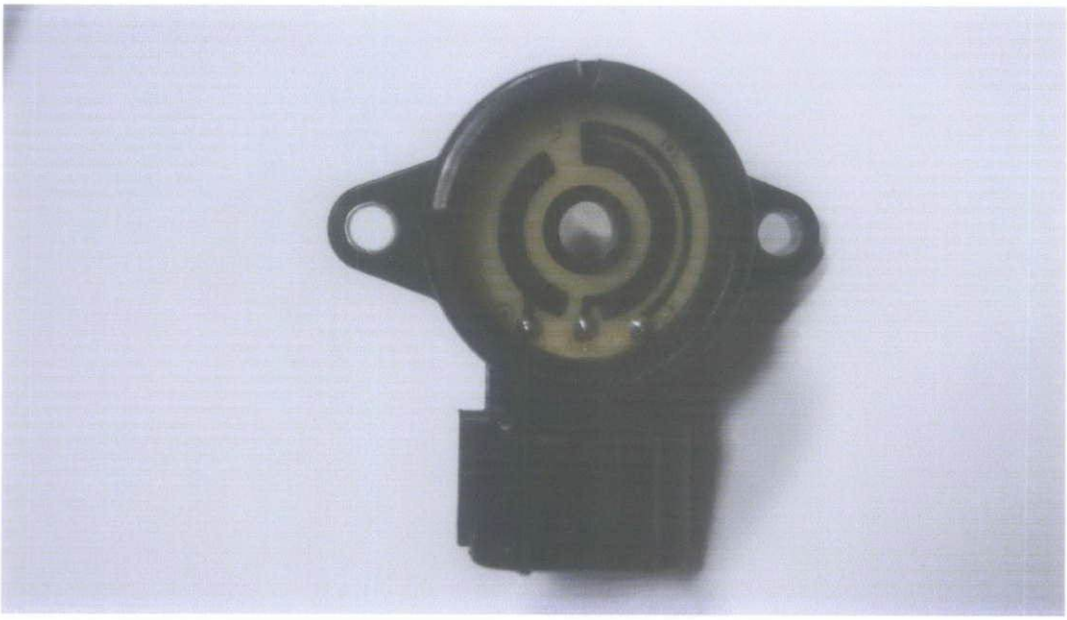

Figure 5 : Potentiometer in TPS Casing

The sensor signal from TPS is used by the electronic control unit (ECU) as an input to its control system. The fuel injection timing and ignition timing are corrected depending upon the butterfly valve opening angle, and also depending on the rate of change of that position.

Some ECU also can control the butterfly valve angle position by utilized the position sensor in a feedback loop to enable control.

TPS are accelerator pedal sensors, which often include a wide open throttle (WOT) sensor. The accelerator pedal sensors are used in "drive by wire" systems, and the most common use of a wide open throttle sensor is for the kick-down function on automatic transmissions.

The TPS is attached on the throttle body and converts the butterfly valve angle into an electrical signal. As the butterfly valve opens, the signal voltage increases. The ECU uses butterfly valve position information to know:

1) Engine state whether engine is idle, half open or fully open.
2) Switch off AC and emission control at wide open throttle (WOT).
3) Air to fuel ratio correction.
4) Power increase correction.
5) Fuel cut control.

The basic TPS required 3 wires. 5 volts are supplied to the TPS from the VC terminal of the ECU. The TPS voltage signal is supplied to the VTA terminal. A ground wire from the TPS to the E2 terminal of the ECU completes the circuit.

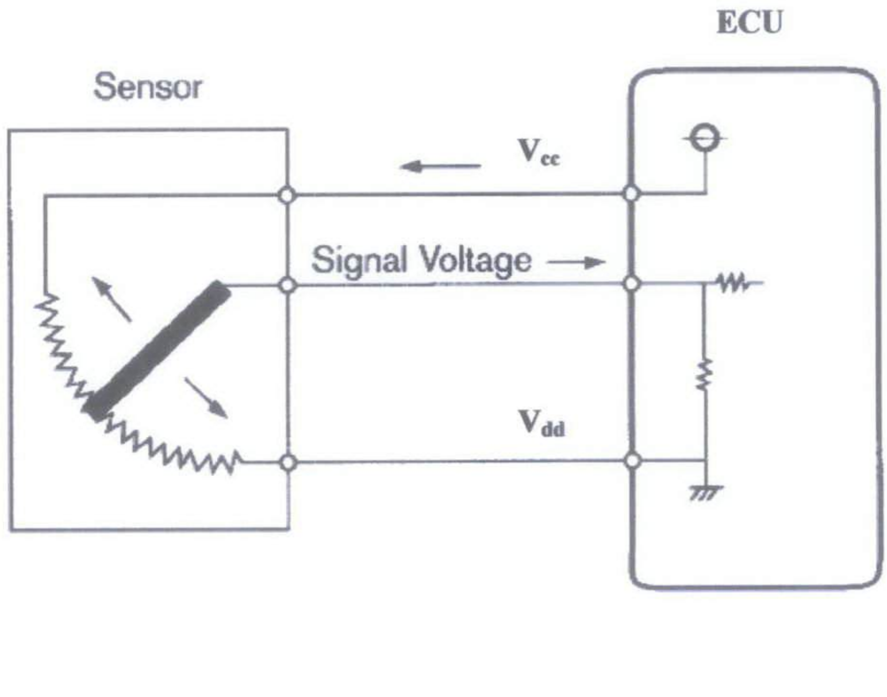

Figure 6 : TPS Circuit Diagram

At idle, voltage is approximately 0.6 – 0.9 volts on the signal wire. Form this voltage, the ECU knows that the throttle plate is closed. At wide open throttle, signal voltage is approximately 3.5 – 4.7 volts.

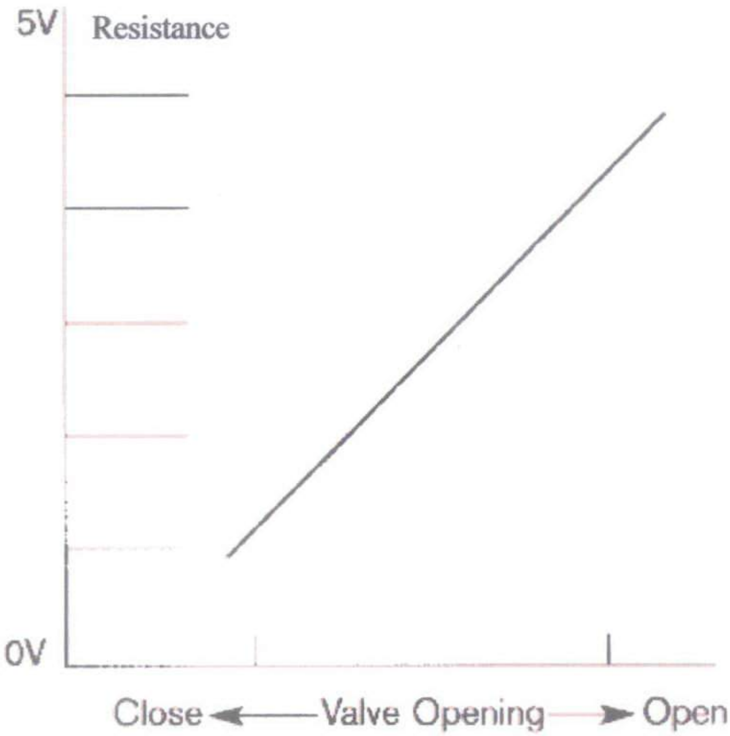

Figure 7 : Graph of Relation Between Resistance and Valve Opening

Inside the TPS is a resistor and a wiper arm. The arms are always contacting the resistor. At the point of contact, the available voltage is the signal voltage and this indicates throttle valve position. At idle, the resistance between the Vcc terminal and Vdd terminal is high, therefore, the available voltage is approximately 0.6 – 0.9 volts. As the contact arm moves closer the VC terminal (the 5 volts power voltage), resistance decrease and the voltage signal increases.

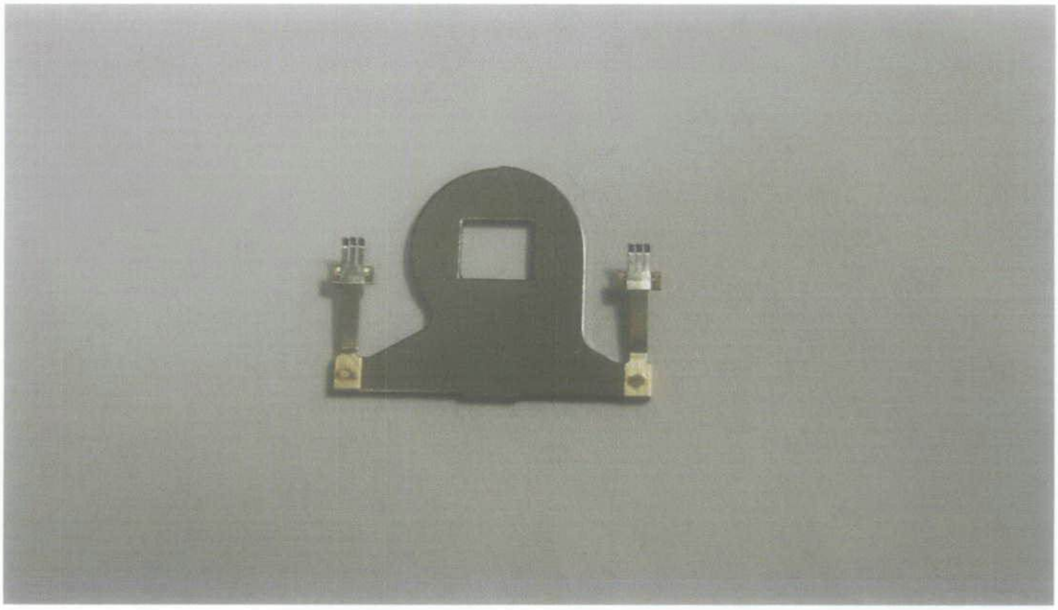

Figure 8 : Wiper Arm

2.5 Analogue to Digital Converter (ADC)

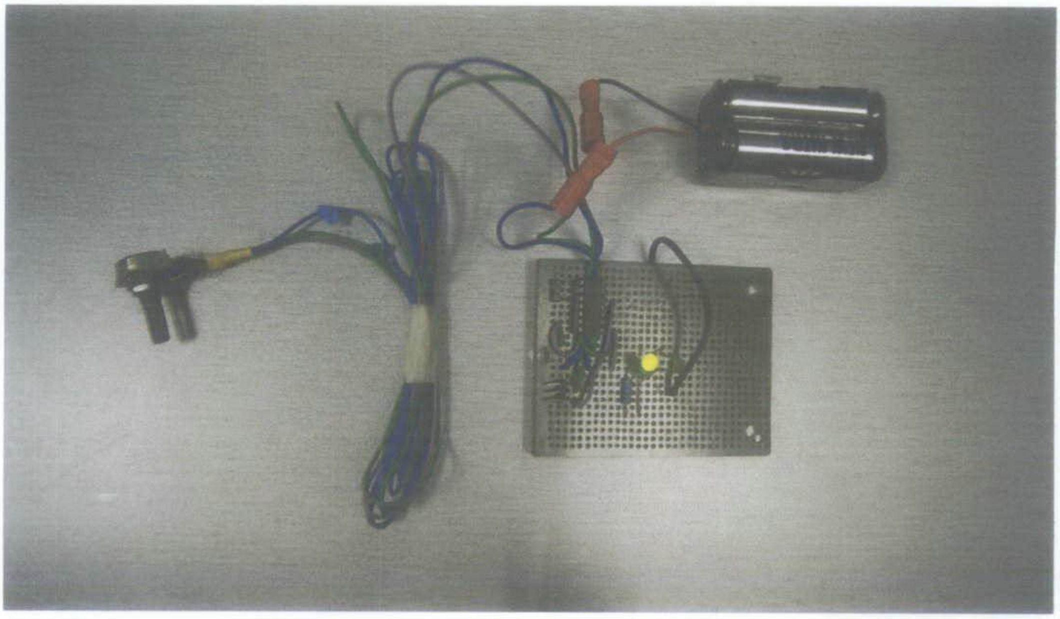

Figure 9 : ADC Circuit

An analogue-to-digital converter (ADC) is a device which converts a continuous quantity to a discrete time-digital representation. An ADC may also provide an isolated measurement. Typically, an ADC is an electronic device that converts an input analogue voltage or current to a digital number proportional to the magnitude of the voltage or current [5].

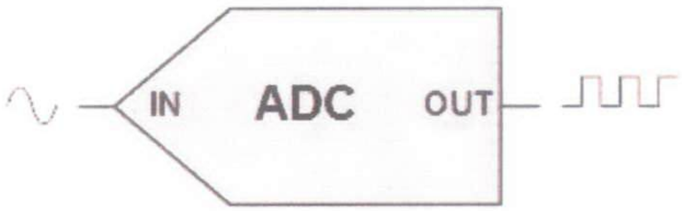

Figure 10 : ADC Signal Representation

2.6 Spring

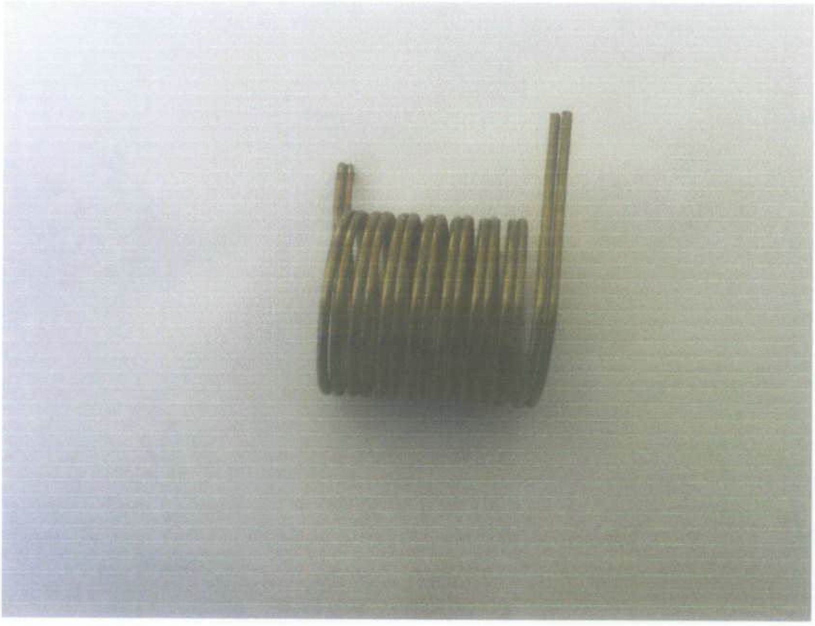

Figure 11 : Spring

Spring is an elastic object used to store mechanical energy [9]. Basically spring is made from hardened steel. The spring in figure 24 is come together with ETC unit. The function of the spring is spring provides a torque to close the throttle when the motor is off and to maintain the position of the throttle opening.

2.7 Gear

Gear is a rotating machine part that has cut teeth, or cogs, which mesh with another toothed part in order to transmit torque [10]. The gear will provide the torque for the servomotor to open and closed the butterfly valve.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

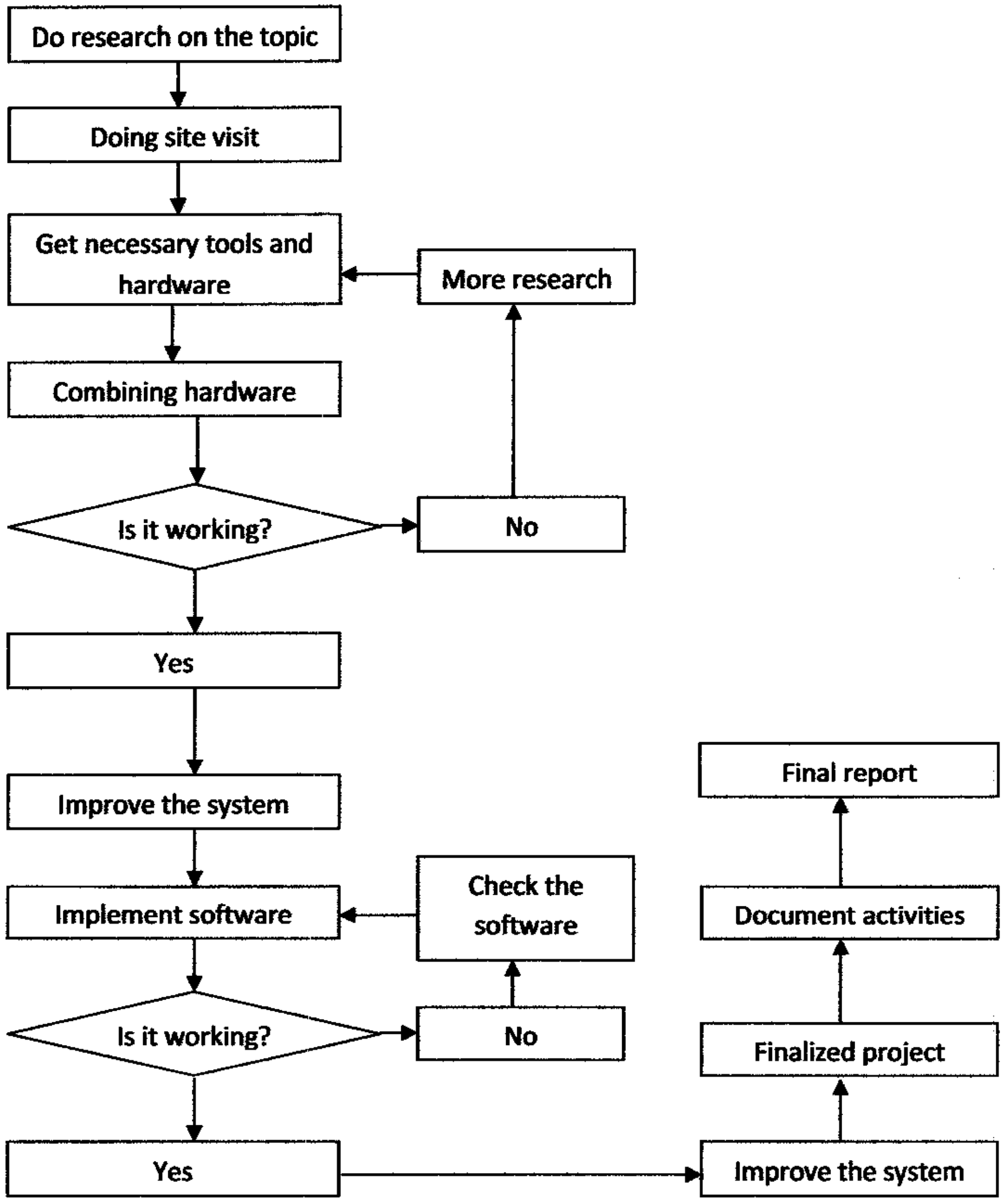

Figure 12 : Flowchart of the project phases

3.2 Project Activities

During this two semester, many research was conduct on what is ETC was all about. Knowing the purpose and problem faced, research was done especially which type of DC servomotor that is suitable for this project, what is TPS and what gearing set that can be used for this project. By the end of this semester, a complete ETC with servomotor attach to the ETB must be produce.

This system is developing in three steps which is understand the concept of ETC, designing the new prototype of ETC and testing the prototype after it has been complete. In understanding of the ETC, many researches have been done. By doing research, a lot of information can be gain. In designing the new prototype of ETC, the servomotor and the gearing set must be combining to the ETB. Research about TPS also needs to be done. Many challenges come when combining the servomotor and the gearing set to the ETB, and what is inside the TPS.

3.2.1 Choose the Right ETC

Because there is a lot of ETC used in the vehicle right now, it is hard to choose the ETC. To solve this problem, the ETC from the Perodua Viva is chosen. This is because it is already available at the University Technology of PETRONAS mechanical lab.

3.2.2 Choose the Right Servomotor

There are a lot of problem in finding the suitable servomotor. The final choice is to use the small size servomotor that has low torque and high speed condition. To solve this problem, gear is use to achieve high torque and low speed servomotor.

3.2.3 Attaching Servomotor and Gear to the ETC

Because there is no enough space at the ETB, attaching servomotor and gear to the ETB is quite complicated. Servomotor need to be fitted with the ETB otherwise the gearing set will not be functioning properly. At the end, the servomotor and the gear is properly attach to the ETB.

3.2.4 Dissemble the TPS

Because the TPS is small in size and also sensitive, it is hard to dissemble. The TPS need to be dissembling for further research and for that purpose; the TPS need to be broken. By doing that, all the part inside the TPS can be identified. To replace the broken TPS, another set of TPS has been bought.

3.2.5 Stepper motor

There is a potential to replace the servomotor with stepper motor in this project. This is because by using servomotor, the PWM will keep sending and receiving signal to/from servomotor to adjust its position. This action will make the servomotor unstable because it will keep adjusting. In addition, present of noise will make this scenario worst. To solve this problem, stepper motor can be used instead of using servomotor. This is because stepper motor rotation is direct relationship with the input supply and its work one way only. It will not keep adjusting the position because the rotation of the stepper motor is by referring to the input signal that is supply.

3.2.6 Microcontroller

Microcontroller is use to control the servomotor. Because the servomotor has PWM input signal, PIC 16F684 has been chosen because this microcontroller have ADC module so that it can control the servomotor rotation by sending PWM signal.

3.3 Tools and Equipment Used

3.3.1 Hardware Use for ETC

1. Electronic Throttle Control (ETC)

ETC contains Electronic Control Body, the "butterfly" and Throttle Positioning Sensor (TPS). The servomotor will be attached to the Electronic Control Body. The servomotor will control the opening of the "butterfly" by using gear. The Throttle Positioning Sensor will provide a feedback to the ETC module for error correction on the position of the "butterfly" opening.

2. Microcontroller

The microcontroller is basically a small computer in the form of an integrated chip that can be mounted on electronic boards. The microcontroller acts as the central control module for controlling the servomotor to opening the "butterfly".

3. Servomotor

A servomotor is an electromechanical device in which an electrical input determines the position of the armature of a motor. Servomotor is a Direct Current (DC) motor. The servomotor that this project needs to be use must have high torque and low speed features.

4. Gearing Set

The purpose of the gearing set is to help the servomotor to achieve high torque and low speed condition as well as to maintain the position of the servomotor while the servomotor controlling the "butterfly" valve.

3.3.2 Software Use for ETC

1. MPLAB IDE (C, assembly), PCWH (alternative).

   This software is used to program the microcontroller PIC.

2. PICKit2, WinPICProg(Alternative).

   This software is used to download the compiled program made in MPLAB into the PIC.

3. Microsoft Visual Studio 2009 Express Edition IDE (C).

   This software will create programs for the PC side of the project. Programming will be in C.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Electronic Throttle Control Design

Below is the result that is obtained from this project. The result will consist of four findings which is ETC, servomotor, gearing set, and Analogue to Digital Converter (ADC).

4.1.1 Electronic Throttle Control (ETC)

In this project, the ETC that been used is taken from Perodua Viva. The ETC taken contains Electronic Throttle Body (ETB), Throttle Positioning Sensor (TPS) and "butterfly" valve. The servomotor will be attached to the ETB and it will control the "butterfly" valve. The servomotor then will be control by the microcontroller.

Figure 13 : Electronic Throttle Body with the "butterfly" valve

4.1.2 Servomotor

The servomotor needs to meet a few requirements for this project which is needed to have high torque, low speed and small which is fit with the ETB size. There are a lot of servomotor that have high torque and low speed for example power window motor and wiper motor. This two motor cannot be used in this project because of their big size. For small size motor, the torque is very low and the speed is very high. It is also not suitable with this project. It takes some time to do some research in finding the best servomotor.

For this project, the servomotor that has been chosen is SANWA SX-01. After taken a few considerations, this is the best servomotor chosen.

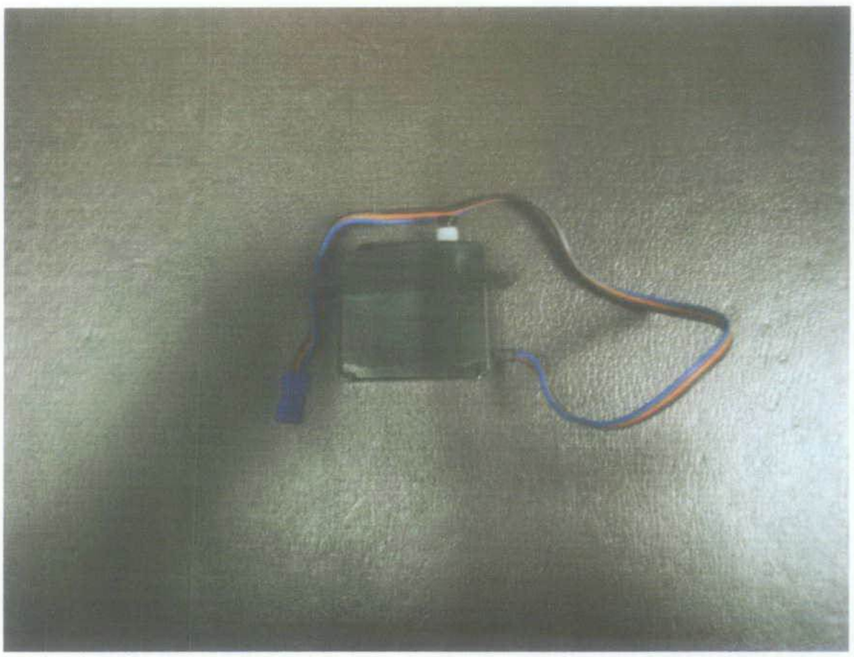

Figure 14 : Sanwa SX-01 servomotor

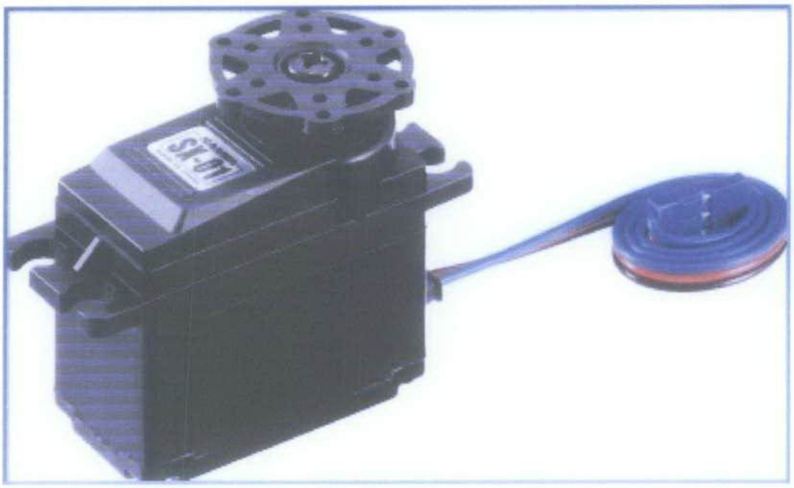

Figure 15 : Sanwa SX-01 servomotor

Table 1 : Sanwa SX-01 servomotor specification

Weight	45gram
Size	39x20x36mm
manipulating speed	0.13sec/40degree/6V
manipulating energy	3.5kg/cm 6V

4.1.3 Gearing Set

Because many of the small size servomotors have low torque and high speed, gear can help the servomotor to achieve high torque and low speed condition. Another purpose of the gear is to help the servomotor to maintain the position of the "butterfly" valve. For this project, gearing set from DVD writer is used to build the ETC prototype. This is because this gearing set is easier to get and meet the criteria needed for this project.

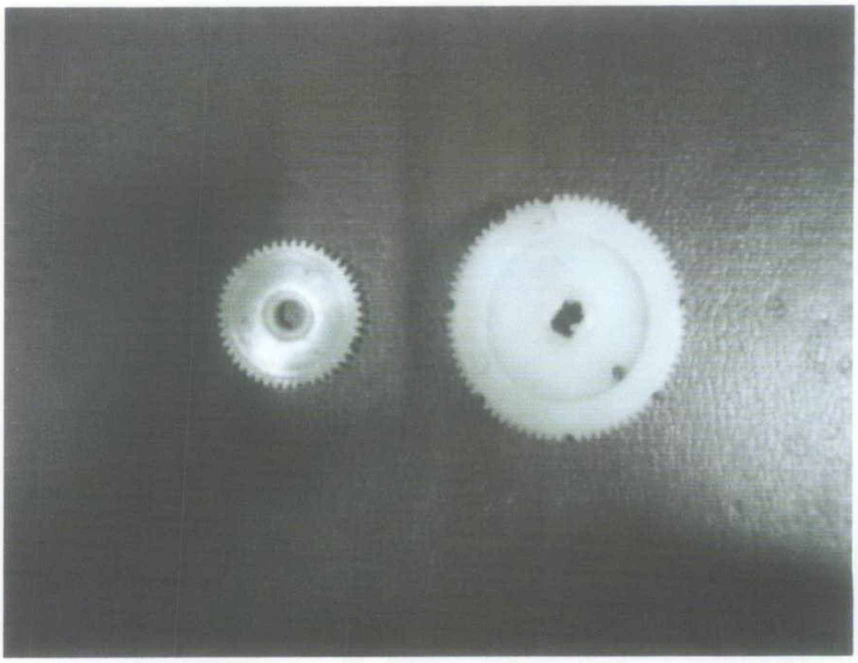

Figure 16 : Gearing Set

4.1.3.1 Gear Ratio

For this project, two spur gears are used. The larger gear (74 teeth) is attached to the butterfly valve opening shaft while the smaller gear (36 teeth) is attached to the servomotor. Therefore,

$$\text{Gear Ratio} = 36 : 74$$
$$= 1 : 2.06$$

The desired maximum opening for butterfly valve is 90 degree. Therefore, the range to drive the throttle gear is:

$$90/360 = X/74$$

$$X = 18.5 \text{ teeth}$$

The servomotor then will be operated to work with below calculated range:

$$18.5/36 = X/360$$

$$X = 185 \text{ degree}$$

Therefore, the servomotor should be operating at 0 degree << X << 185 degree. Because the servomotor rotation is limited to 180 degree only, the servomotor then will be operate at 0 degree <<X<<180 degree only.

4.1.4 Analogue to Digital Converter (ADC)

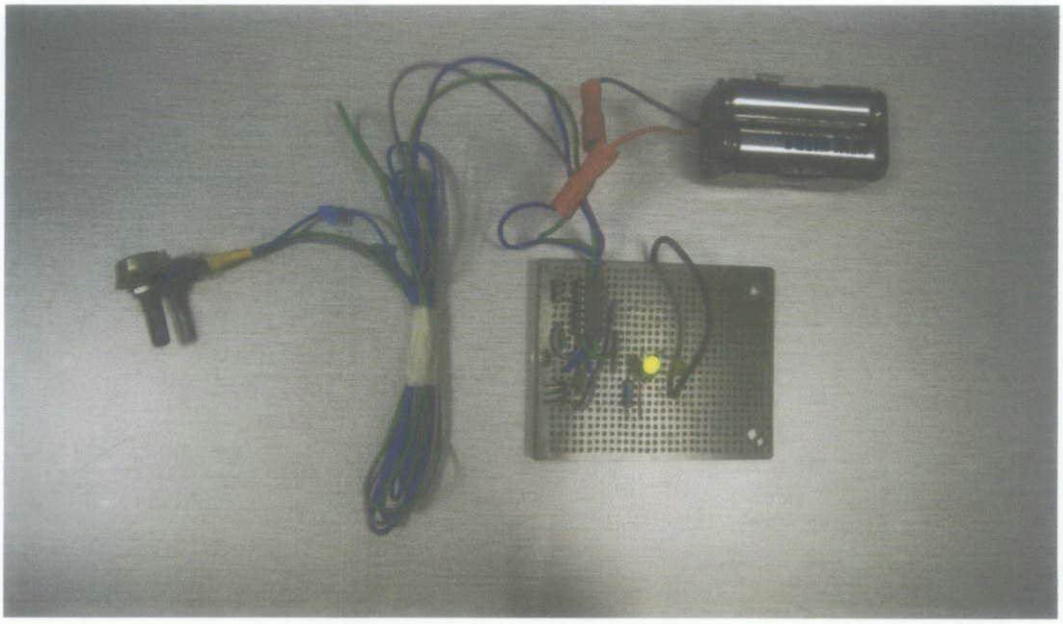

Figure 17 : ADC Circuit

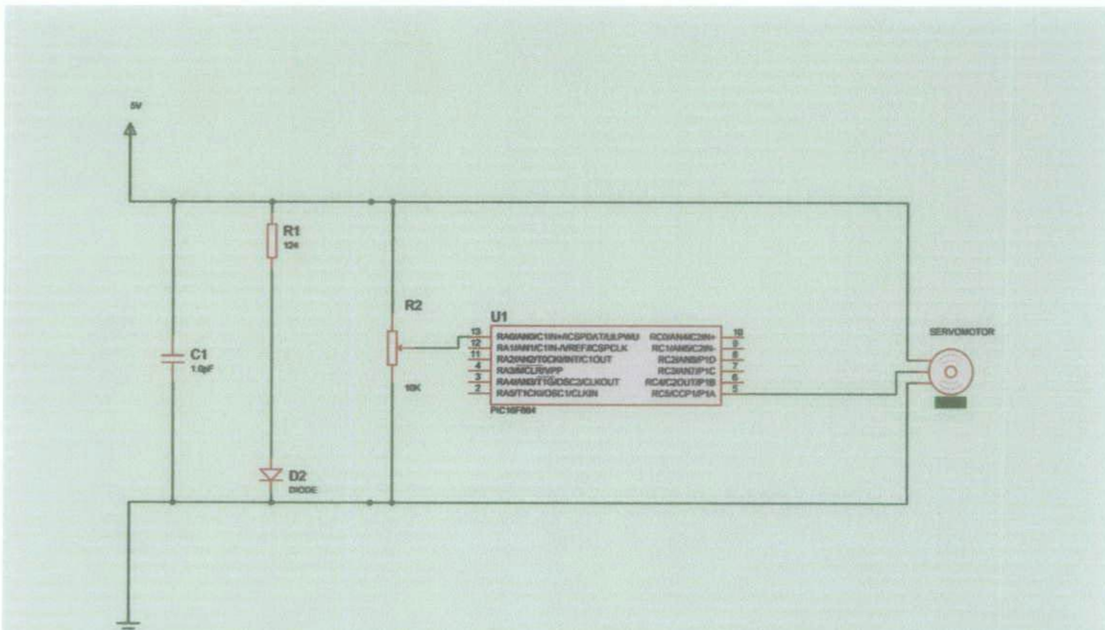

Figure 18 : ADC Circuit Diagram

For this project, PIC 16F684 is used for Analogue to Digital Converter. The ADC will read the value from the variable resistor which represented in analogue signal and convert the signal to digital signal. The converted signal then will be used to move the RC Servo Motor. Below is the program code for the ADC.

```
#include <16F684.h>

#fuses HS, XT, NOWDT, NOPROTECT,NOBROWNOUT, PUT,

#use delay (clock = 4000000)


int8 C0 = 0;

int8 C1 = 0;

int8 C2 = 0;


void setup (void)

{

      setup_adc_ports (0);

      setup_adc_(ADC_CLOCK_DIV_8);

      setup_adc_channel(0);

      setup_ccp1_(ccp_pwm);

      setup_timer_2(T_2_DIV_BY_16, 225, 1);

      output_low(PIN_A1);

      output_low(PIN_A4);

      output_low(PIN_A5);

}

void main()

{

int32 sum;

int16 value, pwm;

int no_acqs, t2_value;

set_tris_C(0x111);
```

Table 2.1 : ADC Source Code

```
setup();

while (TRUE)

        {

        value = Read_ADC();

        sum = sum + value;

        no_acqs ++;

        if (no_acqs > 127)

        {

                pwm = sum / 128;

                set_pwm1_duty (pwm + 256);

                sum = 0;

                no_acqs = 0;

        }
```

Table 2.2 : ADC Source Code

4.1.5 Spring

Spring act as a safety mechanism in this prototype. The spring provides a torque to close the throttle when the motor is off [7]. The equilibrium position of the spring in some electronic throttle bodies is set to a small positive angle and the throttle is used to control idle speed [7]. Another function of spring is to maintain the position of the throttle opening and act as a mechanical correction to reduce the noise comes from the servomotor.

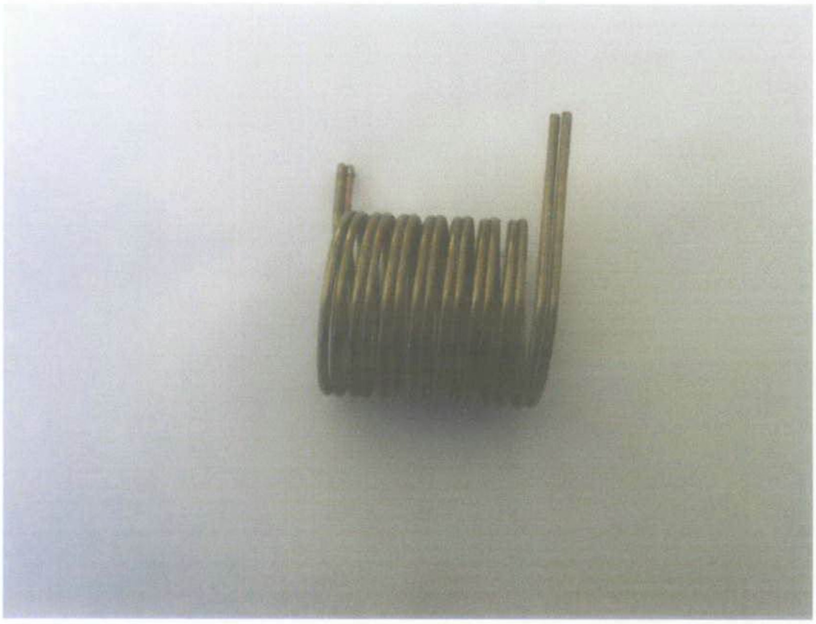

Figure 19 : Spring

4.2 Electronic Throttle Control Prototype

Figure 20 shown is the prototype of the ETC. It is consist of :

1) ETB; the main part of the ETC,
2) Servomotor; to control the butterfly valve opening,
3) Gearing set; to help servomotor achieve low speed and high torque and to maintain the position of the butterfly valve opening,
4) ADC circuit; to control the rotation of the servomotor,
5) Spring; to provide a torque to close the throttle when the motor is off, maintain the position of the throttle opening and act as a mechanical correction to reduce the noise comes from the servomotor.

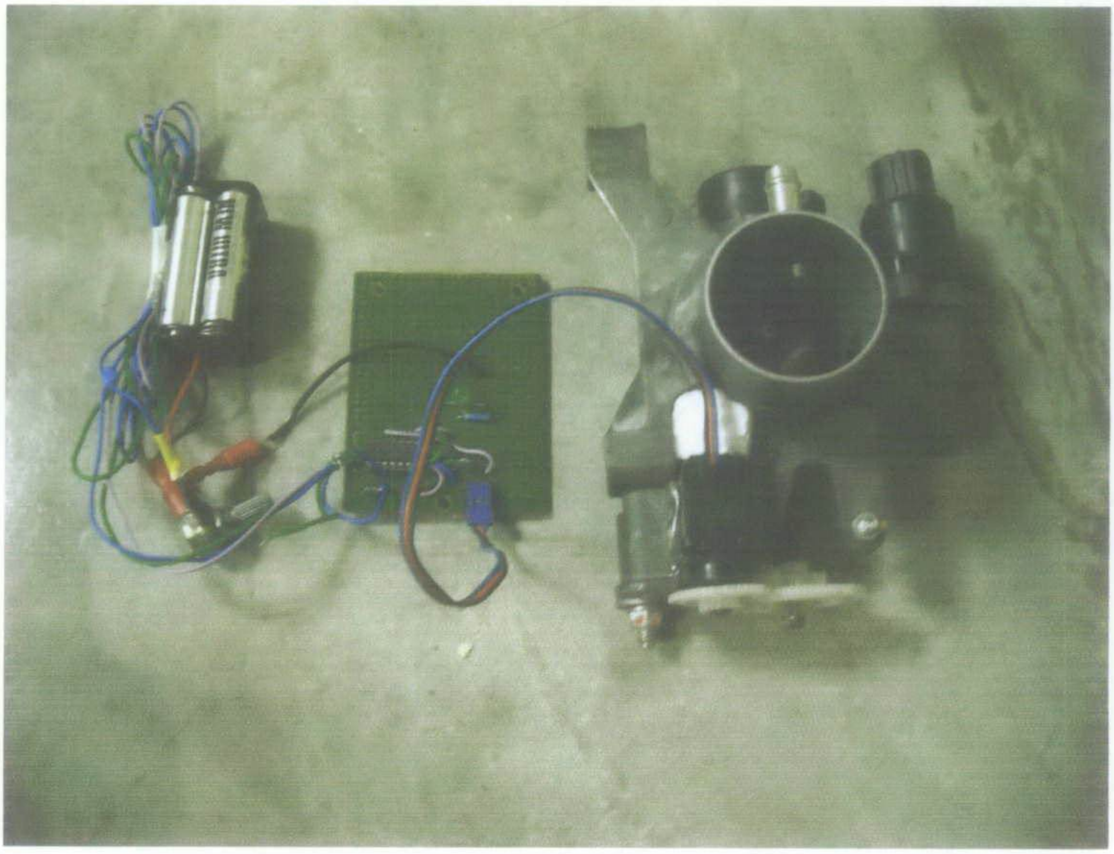

Figure 20 : ETC prototype

4.3 Discussion

There is some disturbance that will be encounter by the servomotor which is the vacuum effect when the surrounding air flows into the engine via the ETB. The maximum load that can be handling by the servomotor is 3.5kg/cm at 6.0v.

In terms of response, the very important part in this project is the response time of the motor. In order to achieve a fast response, higher duty cycle frequency must be supply to the servomotor. For servomotor, the maximum duty cycle that can be supply is 60 hertz [11]. If more than that, the servomotor will experience humping movement when rotating.

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

There are a lot of thing that need to be consider in designing the ETC. One of the most important things is to choose the best servomotor. The servomotor must meet the criterion which is needed to have low speed and high torque. Another important criterion for the servomotor is able to handle high load. Because the servomotor is not meet the criterion needed, gear is use when designing the ETC so that the servomotor can achieve high torque and low speed condition.

Another important thing that needs to be considered is the response of the servomotor. The servomotor must have fast response so that it can open and close the butterfly valve precisely. To achieve fast response, the microcontroller must be design carefully.

Overall, the prototype of ETC is successfully built. This prototype consist ETB, servomotor, ADC circuit and spring. Although much research has been done in preparation of this project, it is still apparent that there are many things that remain unclear; from devices that still need to be understood fully, to problems that crop up with every milestone achieved. In the end, this project is achievable.

While designing the ETC prototype, there are some limitations to this project. One of the limitation is the ETB does not have larger free space to attached the servomotor. The best way to solve this problem is by using smaller size of servomotor. Another limitation is the noise come from the potentiometer. This noise will make the servomotor rotation unstable.

5.2 Recommendations

For future recommendation, the TPS system needs to be research deeper. The ECU also need to research so that the TPS can work together with the ECU. After all this thing are done, the ETC prototype then will be assemble back to the Perodua Viva and test run need to be conducted to see the result of the ETC prototype that have been made.

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APPENDICES

APPENDIX A

GANTT CHART FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic															
2	Preliminary Research/Design Work															
3	Submission of Preliminary Report (Initial Proposal)				19/8											
4	Project Work															
5	Submission of Progress Report									22/9						
6	Seminar										29/9					
6	Project work continue															
7	Submission of Interim Report														2/11	
8	Oral Presentation															8/11

APPENDIX B

GANTT CHART FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work (ADC)															
2	Project Work (TPS)															
3	Project Work (Potentiometer Sensor)															
4	Project Work (Prototype)															
5	Submission of Progress Report															
6	Pre EDX															
6	EDX															
7	Submission of Technical Report															
8	Oral Presentation															

PIC16F684

MICROCHIP

14-Pin Flash-Based, 8-Bit CMOS Microcontrollers with nanoWatt Technology

High-Performance RISC CPU:

- Only 35 instructions to learn:
  - All single-cycle instructions except branches
- Operating speed:
  - DC – 20 MHz oscillator/clock input
  - DC – 200 ns instruction cycle
- Interrupt capability
- 8-level deep hardware stack
- Direct, Indirect and Relative Addressing modes

Special Microcontroller Features:

- Precision Internal Oscillator:
  - Factory calibrated to ±1%, typical
  - Software selectable frequency range of 8 MHz to 125 kHz
  - Software tunable
  - Two-Speed Start-up mode
  - Crystal fail detect for critical applications
  - Clock mode switching during operation for power savings
- Software Selectable 31 kHz Internal Oscillator
- Power-Saving Sleep mode
- Wide operating voltage range (2.0V-5.5V)
- Industrial and Extended Temperature range
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Brown-out Reset (BOR) with software control option
- Enhanced low-current Watchdog Timer (WDT) with on-chip oscillator (software selectable nominal 268 seconds with full prescaler) with software enable
- Multiplexed Master Clear with pull-up/input pin
- Programmable code protection
- High Endurance Flash/EEPROM cell:
  - 100,000 write Flash endurance
  - 1,000,000 write EEPROM endurance
  - Flash/Data EEPROM retention: > 40 years

Low-Power Features:

- Standby Current:
  - 50 nA @ 2.0V, typical
- Operating Current:
  - 11 µA @ 32 kHz, 2.0V, typical
  - 220 µA @ 4 MHz, 2.0V, typical
- Watchdog Timer Current:
  - 1 µA @ 2.0V, typical

Peripheral Features:

- 12 I/O pins with individual direction control:
  - High current source/sink for direct LED drive
  - Interrupt-on-change pin
  - Individually programmable weak pull-ups
  - Ultra Low-Power Wake-Up (ULPWU)
- Analog Comparator module with:
  - Two analog comparators
  - Programmable on-chip voltage reference (CVREF) module (% of VDD)
  - Comparator inputs and outputs externally accessible
- A/D Converter:
  - 10-bit resolution and 8 channels
- Timer0: 8-bit timer/counter with 8-bit programmable prescaler
- Enhanced Timer1:
  - 16-bit timer/counter with prescaler
  - External Timer1 Gate (count enable)
  - Option to use OSC1 and OSC2 in LP mode as Timer1 oscillator if INTOSC mode selected
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Enhanced Capture, Compare, PWM module:
  - 16-bit Capture, max resolution 12.5 ns
  - Compare, max resolution 200 ns
  - 10-bit PWM with 1, 2 or 4 output channels, programmable "dead time", max frequency 20 kHz
- In-Circuit Serial Programming™ (ICSP™) via two pins

Device	Program Memory	Data Memory		I/O	10-bit A/D (ch)	Comparators	Timers 8/16-bit
	Flash (words)	SRAM (bytes)	EEPROM (bytes)				
PIC16F684	2048	128	256	12	8	2	2/1