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JUDUL: DESIGN AND DEVELOPMENT OF DIGITAL PID CONTROLLER TO CONTROL SPEED OF PERMANENT MAGNET DC MOTOR FOR PCB DRILLING OPERATION

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(HURUF BESAR)

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76300 SUNGAI UDANG,
MELAKA.

DR WAN AZHAR BIN WAN YUSOFF
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Signature

: 

Name of Supervisor : DR WAN AZHAR BIN WAN YUSOFF

Date : 21 November 2007

DESIGN AND DEVELOPMENT OF DIGITAL PID CONTROLLER TO CONTROL
SPEED OF PERMANENT MAGNET DC MOTOR FOR PCB DRILLING
OPERATION


MUHAMMAD ALTAF BIN A JALIL

A report submitted in partial fulfillment of the
requirement for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
Universiti Malaysia Pahang

NOVEMBER 2007

I declare that this thesis entitled "*Design and Development of Digital PID Controller to Control Speed of Permanent Magnet DC Motor for Drilling Operation of PCB*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : MUHAMMAD ALTAF BIN A JALIL

Date : 22 November 2007

Keep moving forward.

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ABSTRACT

Every mechanical system in this world will always be affected by the environment that prevents it from working as wanted. Normally, there are always has differences between experiment result and actual result. Drilling operation is one example of a mechanical system that is always been effected by environment during actual process. During drilling operation, the speed of the motor that rotate the cutting tool will tend to be slower from the initial speed due to the friction causes when the cutting tool makes contact with the workpiece. The reduction of speed during drilling operation will decrease the performance of the drilling operation and make it less efficient. In order to solve this problem, a controller can be use to control the speed of the motor. Digital PID controller is one of the examples. Using Digital PID, it can eliminate steady-state error and improve transient response of the system response of the motor. The theory is, when the speed of the motor become decreasing during drilling operation, the Digital PID will detect the error and will tried to eliminate it. To eliminate the error, the Digital PID will increase the voltage supplied to the motor to maintain the speed of the motor. When the speed of the motor is maintained, the performance of the drilling operation can also be maintain and become more efficient.

ABSTRAK

Setiap sistem mekanikal di dalam dunia akan selalu terkesan dengan persekitaran yang akan menghalang sistem tersebut beroperasi seperti yang dikehendaki. Selalunya terdapat perbezaan di antara keputusan daripada eksperimen dengan keputusan yang sebenar. Salah satu contoh sistem mekanikal yang sering terkesan dengan persekitaran semasa operasi sebenar adalah proses menebuk lubang. Semasa operasi menebuk lubang, kelajuan motor yang memutarakan mata alat akan berkurangan disebabkan oleh geseran yang terhasil daripada pertemuan antara permukaan mata alat dengan bahan kerja. Pengurangan kelajuan ini akan menyebabkan proses menebuk lubang tersebut kurang efisien. Untuk mengatasi masalah ini, satu sistem kawalan boleh digunakan untuk megawal kelajuan motor tersebut. Salah satu contoh sistem kawalan yang boleh digunakan adalah PID Digital. Dengan menggunakan PID Digital, kesilapan tahap stabil dapat dihilangkan dan respons transisi untuk sistem motor tersebut dapat dipercepatkan. Secara teori, semasa proses menebuk lubang dijalankan, kelajuan motor akan berkurangan. PID Digital akan mengesan pengurangan ini dan akan menghilangkan perbezaan diantara kelajuan asal dengan kelajuan semasa. Untuk itu, PID Digital akan meningkatkan voltan yang dibekalkan kepada motor untuk memastikan kelajuan motor sentiasa setara dengan kelajuan asal. Apabila kelajuan motor berjaya di setarakan, mutu proses menebuk lubang juga akan dapat di setarakan dan efisiensi proses akan meningkat.

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LIST OF SYMBOLS

π	-	Pi
Φ	-	Magnetization characterization
ω	-	Rotational Speed
ω_m	-	Motor Rotational Speed
ω_n	-	Natural Frequency
ω_0	-	No-Load Rotational Speed
a	-	Transfer Function Constant
AVP	-	Average unit power of workpiece material
D	-	Diameter
f	-	Frequency
F	-	Distance The Drill Penetrates Per Revolution
$G(s)$	-	System Transfer Function
I_a	-	Armature Current
K	-	Gain
K_p	-	Static Error Constant
MRR	-	Material Removal Rate
N	-	Rotation per Minute
P	-	Power
PI	-	Proportional Interval Controller
PD	-	Proportional Derivatives Controller
PID	-	Proportional Interval Derivatives Controller
R_a	-	Armature Resistance
T	-	Torque
T	-	Overall Pulse Length
T_v	-	Time Constant
T_1	-	On-Pulse Length
T_s	-	Settling Time
V	-	Velocity
V	-	Voltage
z_0	-	Zeros for Compensator

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Drilling machines is the most common machine use to make a hole and it is widely use in the industry [5]. Drilling machines comes in a lot of type depending on its usage. The types of the drilling machines are Drill Press type, Bench-Type are Radial Drill. The Drill Press type is the common type. Bench type is for drilling small diameter holes and Radial Drill use to drill large diameter of holes [5].

The drilling machine performance is based on some criteria which are; how large of the work piece of the machine can handle, how many holes it can drill at one time and how accurate the holes can be drilled regarding its position and size.

Drilling machine comes in 9 parts (regarding the drill press type) which are fixed head, spindle, adjustable head, spindle, chuck, table, base, hand and column. The motor that rotate the drill is installed in the fixed head and it is the most important part in the drilling machines. It is because the motor will be effecting how fast the drill can rotate.

Electric motor comes in 2 type which are DC motor and AC motor. Different between DC motor and AC motor is the current use to rotate the motor. DC motor use direct current and AC motor use alternate current. The DC motor operates using an electromagnetic field that occurs when the wire coil inside the motor is given an electric current. The magnetic field of a permanent magnet in the DC motor will collide with the electromagnetic field to create a rotation for the motor. Basically, the rotation of the DC motor is based on the electrical current supplied to the motor. Zero volts mean zero speed and maximum volts means maximum speed.

To control the speed of the motor, Proportional Integral Derivatives (PID) controller can be use in the drilling machines control system. The PID controller is an active controller which eliminates steady-state error and improves the system transient response [6].

There are two types of controller; analog and digital [6]. Analog controller is simple and cheaper than digital controller. The digital control system use a computer to supervise and control the system which made the system more reliable in handling varies parameters and has immunity to noise [6].

In this project, an efficient and reliable PID will be design and build based on digital control system to control the speed of the DC motor in the drilling machine.

1.2 Project Problem Statement

The problem in this project is to control the speed of the DC motor. During the drilling process, when the drill is press onto the work piece to create holes, the speed of the motor tends to decrease slightly. This phenomenon occurs because there is friction force between the drill and the work piece due to the load given.

By the definition, friction is defined as the resistance to relative motion. Motion has connection with speed, so the higher the friction, the higher the resistance to the motion and decreasing in speed. The decreased of the speed will affect the speed the feed rate of the drilling process and there will be an error for the motor output. Normally user will calculate the speed needed for the drill machine theoretically before the drilling process [5]. Then, the drilling machine speed is set to a speed that larger than the calculated speed. This process required estimation by the user to get the exact speed for the drilling machine which is obviously impossible.

The problem for this project is that to correct the error of the speed of the motor cause by the friction forces during the drilling process.

1.3 Project Objectives

- i. To build a digital system PID controller for the DC motor speed control.
- ii. To make a C programming code for the digital PID
- iii. To use PCB as the test material for the drilling operation.

1.4 Project Scopes

First, this project will be focusing on building a digital PID controller as the controller in the control system. Even there are other more high performances controllers that can be use like fuzzy-logic, this project only based on designing a digital PID controller to correct the error for the drilling process.

The only parameter that will be study is only the speed of the motor before, during and after the drilling process. Any other parameter such as accuracy and position of the drill will not be discussed.

DC motor comes in a large variety of type depending on its usage such as; Series DC motor, Separately Excited DC motor and Permanent Magnet DC motor. Permanent Magnet DC motor is the type of DC motor that will be use in this project.

There are two types of control system that can be use which is digital system and analog system. In this project, the type of control structure that will be implements is the digital control system type structure.

In the system structure, there are two type of structure form which is open-loop system and closed-loop system. A closed-loop system will be use for this project.

In the control system, the feedback control type come in two which are; sampled data feedback system and phase locked feedback system. In this project a phase locked feedback system will be apply for the feedback control type.

The sensor is a device to detect any changes between the input and output of the system. Sensor can be a tachometer or encoder. The sensor that will be use in this project is encoder.

The material use for drilling in this project is PCB. This Project only focus on to study how to control speed of the DC motor when use to drill the PCB. Also the use of the PCB is because this project focus is for light drilling process.

CHAPTER 2

LITERATURE REVIEW

2.1 Drilling Machines

In fabricating process, Holemaking is one of the important processes to make a hole. Holes are use to put a fastener for joining, or to insert shaft [5]. Drilling is the most common process to make holes [5]. There are a lot of drilling machine type use in industry based on its usage and capabilities. The most common type is the Drill Press type [5]. Other than that is the Bench-Type use for light drilling to drill small diameter holes and Radial Drill use to drill large diameter holes. The drilling machines are design to have an adjustable drill speed to suit various kinds of drill and workpiece [5].

There are a lot of type of drill use in drilling processes which are Twist, Straight-Flute, Spade, Gun Drill, Drill with Bozel Carbide Tip and Drill with Indexable Carbide Insert. The Drill also has a high length to diameter ratio which made it easier to drill deeper holes [5]. Other than drilling, a drilling machines also capable to do other process such as Tapping, Reaming and Small Diameter Boring [5]. For the drilling process, the workpiece is located on an adjustable table fix with a holder or vise to secure it. The drill is lower manually by hand or automatically by using press feed. Drilling a workpiece manually need a higher operator skill.

During Holemaking process, problem occur when the tip of the drill make a contact with the workpiece surface. When the tip collides with the surface, the speed of the drill tends to decrease slightly lower than it initial speed. This phenomenon happens because the effect of friction force that gives a resistance to the drill. In the definition of resistance stated that friction is defined as the resistance to relative motion [5]. This shows that friction give effect on the motion of the drill which the drill speed. When the speed of the drill reduces, it will affect the drilling process because the speed plays an important role in determining the feed rate of the drill. In calculating the Material Removal Rate (MRR) for drilling process, given by equation 2.1 :

$$MRR = \frac{\pi D^2}{4} (F)(N) \quad [2.1]$$

D = diameter of the drill

F = distance the drill penetrates per revolution

N = rotational speed where $N = V / \pi D$

So, it is clear that speed give impact on the material removal rate for the drilling. Reduce of the speed mean reducing its MRR too. When the MRR reduces, it will affect the performance of the drilling process and make it less efficient and less power. This effect can be seen by the power of the drilling machine given by equation 2.2:

$$P = MRR \times AVP \quad [2.2]$$

P = Power

MRR = Material Removal Rate

AVP = average unit power of workpiece material

Other than that, speed also affects the Torque on the drill. In calculating torque for the drilling process, power and rotational speed is the main criteria in determining the torque of the drill. From the equation of torque for rotational speed in the equation 2.3:

$$T = \frac{P}{\omega} \quad [2.3]$$

ω = rotational speed of the drill.

P = Power

T = Torque

From equation 2.1, 2.2, and 2.3, it can be concluded that the criteria in determining the performance of the drilling process required the MRR, speed, Torque, diameter of drill, and distance of the drill penetrates per revolution.

In this project, the criteria that will be manipulated to improve the performance of the drilling process are speed. The workpiece to be drill will be PCB using a light drilling process.

2.2 DC Motor

In a traditional drilling process, an electrical motor is use to rotate the drill to make a hole at the workpiece. An electrical motor is a device that converts electrical energy into mechanical energy [7]. During the operation of an electrical motor, the electrical energy will be converted into a rotary mechanical energy.

There are two types of electrical motor which are DC motor and AC motor. Basically DC motor is an electrical motor that use direct current to operate while AC motor use alternating current to operate. The basic principle for the motor is the same for both type of motor. It works when an electromagnet from the coil in the motor collide with the field magnet in the motor. As remember about the magnet law that when both same pole are facing, the magnet will be rejecting each other. In the motor, the situation is just the same, the electromagnetic field that occur when the coil in the motor is given an electrical current collide with the field magnet in the motor, both magnet will be pushing each other and create a torque for the motor to rotate.

In a DC motor, there are two main parts that keep the motor running which are the stator and rotor. Stator is always being the field magnet that is fixed in the motor [7] and rotor is movable parts that create torque while the motor operate. Normally a rotor can be in a cylindrical or disc-shaped. The other part is the commutator. A commutator is a rotary switch that reverses the current supplied to the motor at each cycle [3] to make sure that the motor is rotating at a same direction during the operation.

There are a lot of types of DC motor which include Permanent Magnet DC motor, Separately Excited DC motor, Series DC motor. These all types are use in different application based on each motor characteristic.

Permanent magnet DC motor as like its name is a DC motor that uses a permanent magnet as the stator. A suitable permanent magnet is installed in the motor as a field excitation. The type of permanent magnet can be ferrites or rare earth depended on the motor application. A ferrites permanent magnet normally is low in cost but come in a bulky size and low retentivity. A rare earth permanent magnet has high retentivity which allows large reduction but it also very expensive.

By the use of the permanent magnet in the DC motor, it can eliminate field copper loss that needed for field supply. The permanent magnet DC motor is more efficient, reliable, sturdy and compact because the field fluxes remain constant for all loads. It is also more linear to speed torque character. The disadvantage of permanent magnet DC motor is that its speed can't be controlled when above the base speed. The application of permanent magnet DC motor is at drilling machine, forklift truck and wheel chair.

A DC Separately Excited motor has a constant field current which the flux assumes to be constant.

$$T = KI_a$$

$$E = K\omega_m$$

$$\omega_m = \left(\frac{V}{K}\right) - \left(\frac{R_a}{K}\right)I_a = \left(\frac{V}{K}\right) - \left(\frac{R_a}{K^2}\right)T \quad [2.4]$$

In the equation, the $\omega_m = (V/K) - (Ra/K^2) T$, state that the speed regulation is depends on armature circuit resistance.

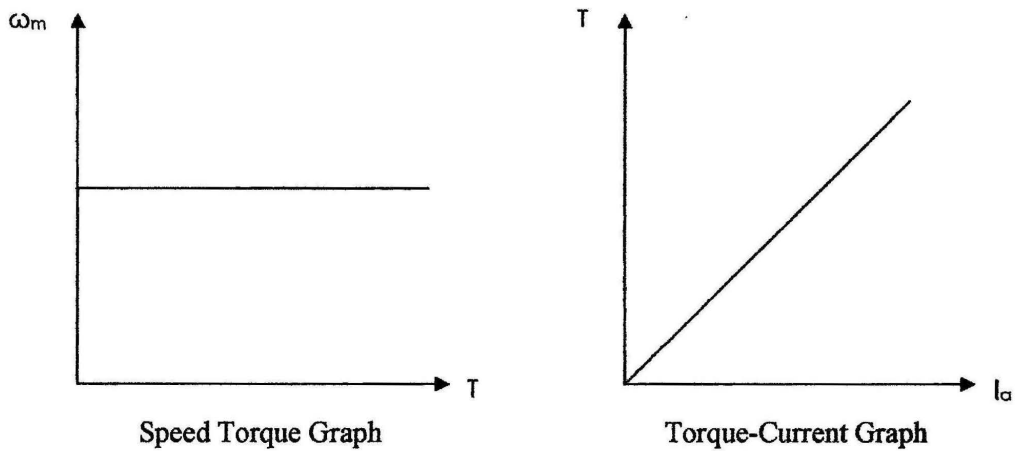


Figure 2.1: Characteristic of a DC Separately Excited Motor

The Figure 2.1 shows the behavior of the DC Separately Excited motor when it operates. The no-load ω_0 is determined by armature voltage and field excitation since we cannot determine it from the graph. The most application of the DC Separately Excited motor is that in an application that need a good speed regulation and adjustable speed.

The third type of DC motor is a Series DC motor. In this type of motor, the flux is a function of armature current where the unsaturated, region of magnetization characteristic Φ is assumed to be proportional to I_a .

$$\Phi = K_f I_a$$

$$\omega_m = \left(\frac{V}{(K_e K_f)^{1/2}} \right) \left(\frac{1}{(T)^{1/2}} \right) - \left(\frac{R_a}{K_e K_f} \right) \quad [2.5]$$

From the equation 2.5, the R_a value is the sum of armature and field winding resistance.

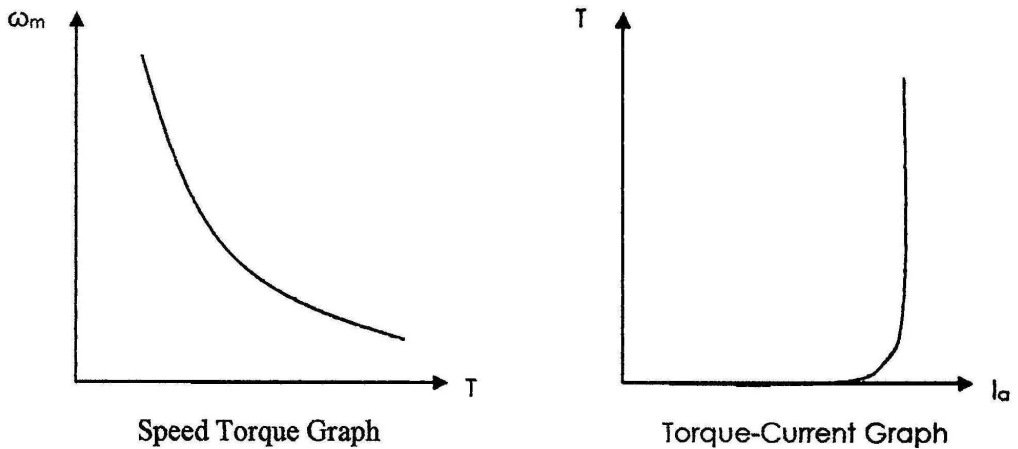


Figure 2.2: Characteristic of a Series DC Motor

Figure 2.2 represent the Series DC motor behavior while operates. During heavy overloads and starting, the power overloads and thermal overloading are limited to the reasonable value to avoid failure. The applications of Series DC motor are in the high starting torque application and heavy torque overload application.

2.3 Control System

A control system can be defined as a subsystem and processes assembled for the purpose of controlling the output of the processes [6]. A control system provides an output for a given input. There are some keywords need to be known to understand the control system thoroughly. When an input is given to the control system, the response will be stated in a graph as shown in the Figure 2.3.

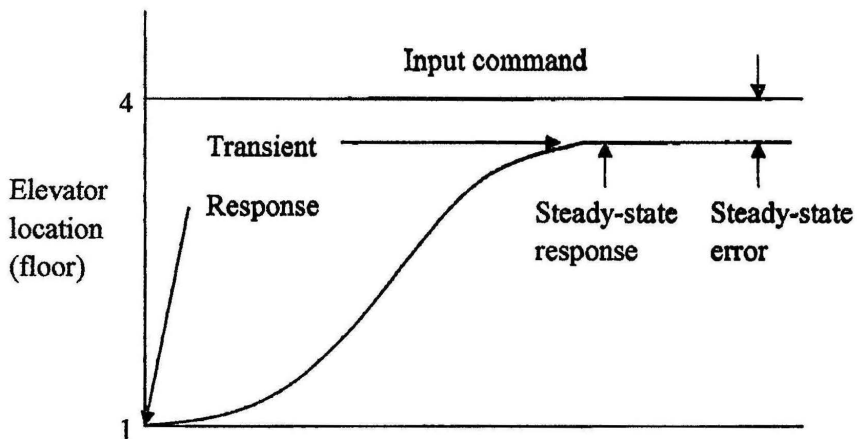


Figure 2.3: Elevator Response [6]

Figure 2.3 shows an example of an elevator response. Transient response can be defined as the elevated change of the output when the input is given to reach the desirable output. When the system had reached the state where the output had become constant, it is called steady-state response. The constant output when the system reaches the steady-state response sometime will have a different with the input. The difference between the constant output and the input is called steady-state error [6].

Control system can be divided into two types which are open-loop system and closed loop-system. An open-loop system is basically a linear system that cannot compensate with disturbances or to correct it. The open-loop system is with an input transducer that connect to the controller. The controller than is connected to the plant or processes to obtain an output called control variable. Sometimes an input can also be called references. The example of the open-loop system is shown in the Figure 2.4:

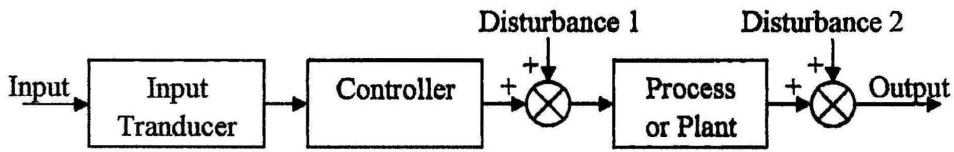


Figure 2.4: Open-Loop System [6]

From the figure 2.4, it can be concluded that an open-loop system is a linear system that depend on the input. If there are disturbance, the system will not react to it instead the system just adding the disturbances with the input and creating an output that are corrupted with the disturbances. Though the open-loop system is simple yet cheap, it cannot deal with any disturbances which make it not suitable for a system that required accurate output.

The other type of the control system is the closed-loop system. Everything is just the same with the open-loop system except that the closed-loop system has a feedback and an output transducer. The output transducer will measures the output response and convert it in the way that can be processes by the controller. The example of the closed-loop system is shown in the figure 2.5:

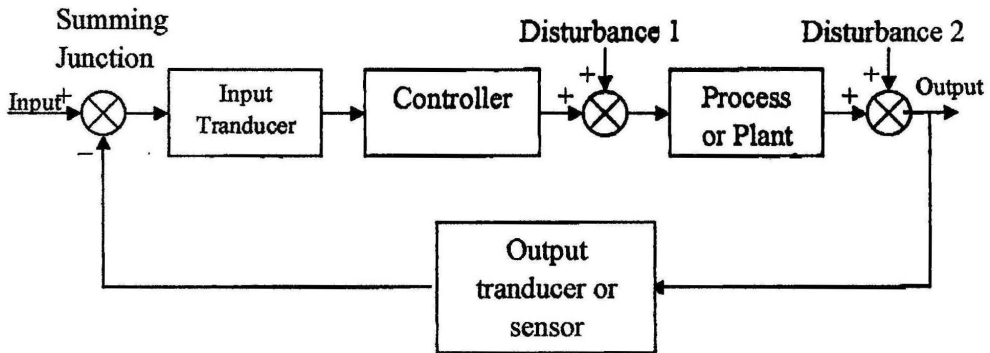


Figure 2.5: Closed-Loop System [6]

The difference between the open-loop and closed-loop system is that can be seen from the figure where the output is fed back to summing junction with the input. When both the output and input have a transducer that have a unity gain which amplifies the input to 1, the actuating signal will be the error of the system. The system will be run by the actuating signal if there are errors in the system, if not the system will be run by the input normally. The advantages of the closed-loop system are that it has greater accuracy with less sensitive with noise. The transient response and the steady-state error of the system can be controlled. The only disadvantages of the closed-loop system are only that it is more complex and expensive.

A computer-controlled system, also known as digital control system is a system that use computer to control the system. The difference from the analog system is that the controller that built with analog component is being replaced with a computer. The advantages of the use of computer is that it can perform two works which as a supervisor to the system and to control the system [6].

The supervisory function helps in organizing task and control the parameter. While the control system can give a variable output with a variable input to the system which are the major advantage to the digital system [6]. The advantages of the digital system are that the design of the system can easily change and also it has immunity to noise. The example of the digital system is shown in the figure 2.6:

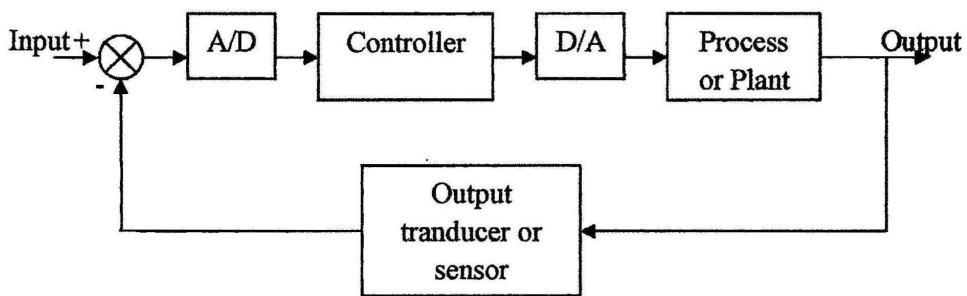


Figure 2.6: Computer-Controlled System

2.4 Control System Controller

When an input is given to a control system, sometimes it is hard to achieve the desirable output. The difference between the inputs with the desirable output is called steady-state error [6]. In designing a controller, some criteria need to be considered before choosing which controller than want to design. The main criteria that need to be focus are what improvement that wants to be made from the system. Two improvements that can be made to a control system are improving the transient response and steady-state error correction.

Improving transient response of the system will improve the system performance in settling time and percent overshoot. Steady-state error correction will make the system achieve the desired output that satisfied the user demand.

2.4.1 Type of Controller

There are six type of controller that can be implement which are PI, PD, PID, Lag, Lead and Lag-Lead controller [4]. To improve transient response, the controllers that can be use are PD or Lead controller. To improve the steady-state error, the controllers that can be use are PI or Lag controller. When both transient response and steady-state error want to be improves, the controller use are PID and Lag-Lead controller. PI, PD and PID are active type controller while Lag, Lead and Lag-Lead are passive type controller.

2.4.2 PID Controller

In this project, the controller that will be designed is PID controller. PID controller is a Proportional-plus-Integral-plus-Derivative controller [9]. As mentioned before, a PID controller is used to improve the transient response and to correct the steady-state error of a system [6]. The term proportional is referred to that the controller acts proportionally to error where the correction signal will be increase when the error increases [1]. Intergal means action by the controller that proportional to the integral of the error where the controller will keep summing the error over time as long as the error occur [1]. The derivatives part act as the predictor of the error behavior signal by corrective action based on the rate of change in the error signal [1]. The block diagram showing the PID controller is shown in figure 2.7.

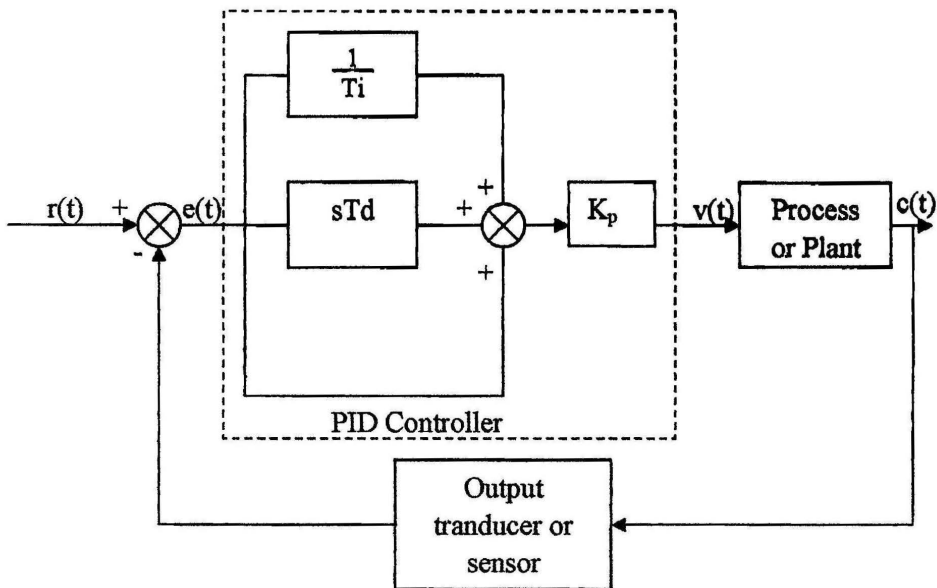


Figure 2.7: Plant with PID Controller [9]

2.5 Sensors

In the control system, sensor can be defined as device that measures the response of the system that helps the controller to make a correction action if the output is not following the user demand [2]. The example of sensors includes tachometer, thermocouples, and encoder. There are two types of sensor which is analog sensor and digital sensor. The example of analog sensor is tachometer and the example of digital sensor is encoder.

2.5.1 Tachometer

In this project, the sensor must be able to measure the DC motor speed. The analog sensor that can be use is tachometer. A tachometer is an electromechanical device that converts mechanical energy to electrical energy. Figure 2.8 shows how the Tachometer works. The output voltage is proportional to magnitude of the angular velocity of input shaft. A tachometer can be used as velocity indicator which provide shaft-speed readout, provide velocity feedback, as speed control and stabilization. The tachometer works by compared its output with reference voltage which represent the desired velocity to achieve. The accuracy of the tachometer is critically high, so the accuracy of speed control is depend on it.

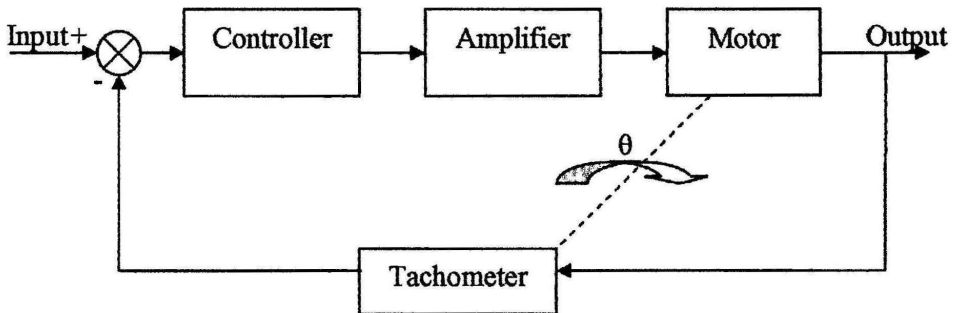


Figure 2.8: Tachometer Implementation in a Control System

2.5.2 Encoder

In a digital control system, the sensor that can be used is encoder. An encoder is a device that converts linear or rotary displacement into digitally coded or pulse signals. There are two types of encoder which are absolute encoder and incremental encoder. An absolute encoder is an encoder that the output is a digital signal. The output from the absolute encoder is a distinct digital code that indicative of each particular that have least significant increment of resolution. The absolute encoder can be use when the system are concern of data loss during power failure and also use to measure period of mechanical motion without the readout under power. Difference with absolute encoder, the incremental encoder provides a pulse for each increment of resolution but do not make distinctions between the increments. The incremental encoder advantages is that it is low cost, ease to operate and have versatility which available in linear or rotary type. Economic and control objective is the main criteria in choosing the encoder. The basic part of encoder is light source, rotary disc, stationary mask and sensor as shown in figure 2.9.

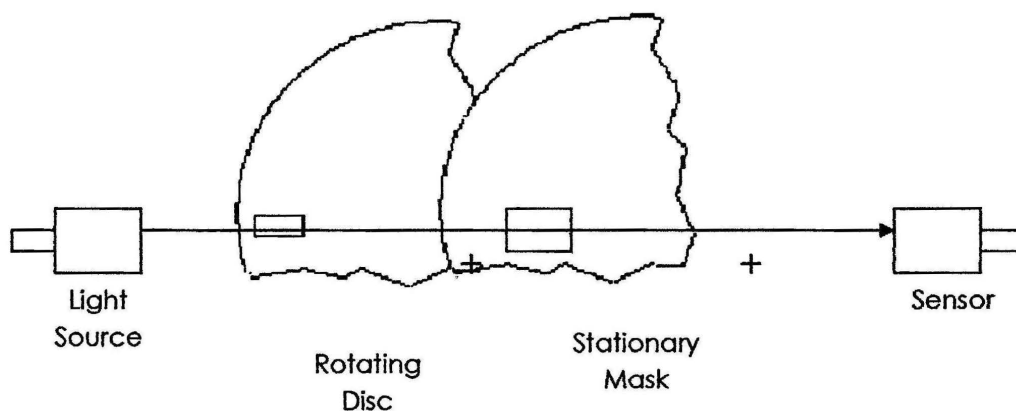


Figure 2.9: Encoder

2.6 Feedback Control Type

In a closed-loop control system type, the feedback control is use to create actuating signal where the signal from the output is summing with the input at the summing junction [6]. There are Sample Data system and Phase-Locked system in the feedback types. The use of this feedback type is depends on the system requirement.

2.6.1 Sampled-Data System

In a Sampled-Data System the sampling can happen in many reasons such as the sonar system in the submarine. The error can only been known when the sonar is return to the sensor. From the Figure 2.10, the signal $e(t)$ is sampled. The system is continuous except for single sampling operation [8]

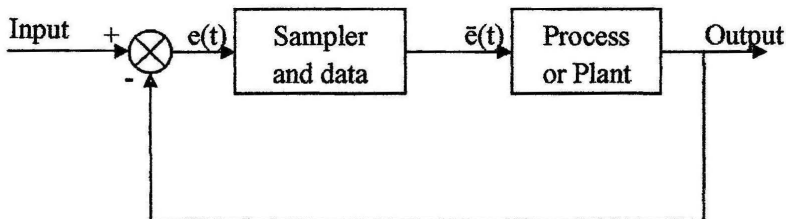


Figure 2.10: Sampled-Data Control System [8]

The disadvantage of the Sampled-data system is that there will be a data loss because the sampled-signal is not known at all instant [8]. To overcome this problem, the system is added with data hold to reconstruct the sampled signal into a form that closely resembles the signal before sampling [8].

2.6.2 Phase-Locked Control

For the Phase-locked control the reference signal are in pulse form [2]. Figure 2.11 shows the block diagram for the Phase Locked Control Type. The measurement of the rotation of the motor can be made using encoder which formed a feedback signal. The feedback signal is then supplied to the phase detector. The phase detector function as a detector of the phase difference that generated by the unwanted high-frequency components [2]. There is unwanted high-frequency that is removed using low pass filter and the resulting signal is supplied to drive amplifier [2]. The resulting signal will drive the motor or a desired speed or motion [2].

The meaning of the phase locked is that the phase output is locked onto the phase angle of the command signal. The advantage of the phase-locked system is that the speed error will be + 0.002 % or less.

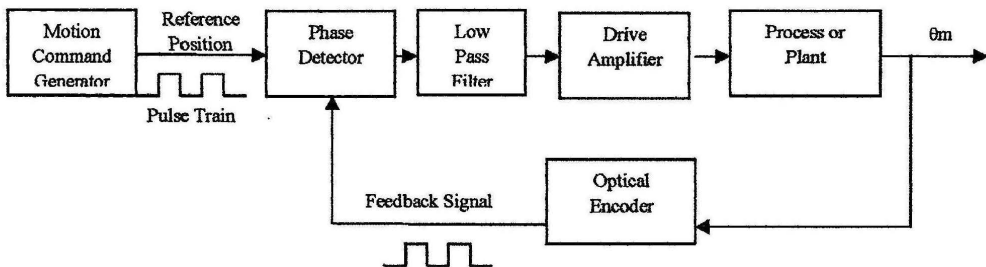


Figure 2.11: Phase-Locked Control Type

2.7 Driver Techniques

Driver is a primary hardware which generates necessary current to energize winding of the motor [2]. The drive is called drive amplifier and the typical driver for motor is servo amplifier. There are two types of driver which are:

1. Linear amplifier (continuous technique)
2. Pulse-Width-Modulation (PWM) amplifier

2.7.1 Continuous Driver

Linear amplifier is one of the examples of the continuous driver. It generates a voltage output that is proportional to the control input [2]. Due to the phenomenon, the driver is ineffective because a lot of energy is dissipated by heat. This happens because the power used by the motor is lower than the power supplied. So there will be energy loss by heat that will require cooling devices for the driver. The advantage of the linear driver is that it is cheaper and less complicated for a simple motor control system.

2.7.2 Pulse-Width Modulation (PWM)

From the linear driver problem, there are power dissipated which makes the driver inefficient to be use. To overcome this problem, a solid-state switch will be use to vary off time of a fixed voltage level in a constant period of pulse signal [2].

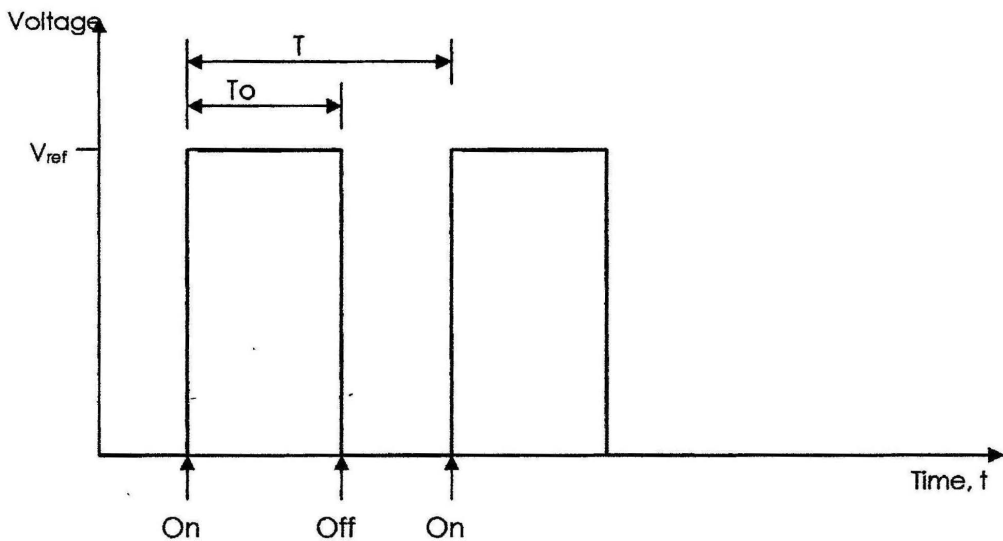


Figure 2.12: Duty Cycle of PWM Signal

From the Figure 2.12, the T is equal to the pulse period which is the interval between the successive on instant and the T_o is the on period where it is an interval between instant to the next off instant [2]. The equation that can be made based on the Figure 2.12 for the duty cycle is shown in equation 2.6:

$$DutyCycle = \frac{T_0}{T} \times 100\% \quad [2.6]$$

Noted that the V_{ref} and the period $1/T$ is kept fixed and the duty cycle and the T_0 is varied. From the equation also, it can be stated that average level of PWM signal is proportional to the duty cycle of the signal. In the PWM, the V_{ref} is “chopped” so that the voltage is varied. So the output level can be varied by changing the signal on-time period. To generate the PWM signal, software can be use by using straight liner from 0 to maximum level. The example of the PWM switch is thyristor [2].

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter will be about what are the steps and experiment that need to be worked on to complete this project and to achieve all the objectives. Several experiments had been set to make sure this project can be done correctly. The flow of the project will be start with the building of the Digital PID hardware since it is the most important part in this project. Next after building the hardware, this project will continue with completing a programming for the Digital PID to operate. After the hardware and C code had been done, the next process involves in calculating the mathematical model of the permanent magnet DC motor use in this project. By confirming that the mathematical model for the DC motor is correct, it will be continue with tuning the PID to eliminate the steady-state error and improve transient response of the DC motor. When everything is completed, the last part will be the testing of the Digital PID performance in controlling the speed of the motor when drilling the PCB. The Methodology flowchart is shown in Appendix A.

3.1 Building Digital PID Hardware Circuit

When building and designing the hardware of the Digital PID, the important things that need to be considered is the part in the hardware that suitable for the Digital PID. Some checklist need to be known to choose what are the functions needed for the Digital PID to make it works. The functions are:

- i. The hardware that will be use to process all the data.
- ii. Signal converter that need to be use. If any.
- iii. Type of driver use to amplify the signal to the DC motor.
- iv. Type of sensor that use to capture the digital pulse.

After knowing all the function needed by the Digital PID, a plan and design on what type of circuit and electronic part that suitable to build the Digital PID hardware.

3.2 Creating the Program for the Digital PID

The important thing in digital hardware is that it can be controlled by using computer. To make the hardware understand the command from user, a computer language must be created to program in the Digital PID hardware. This program will be use to told the hardware to do all the process needed such as collecting all data needed, process all the calculation and displaying all the result on the computer. The programming used is C programming.

3.3 Calculating the Mathematical Model for the DC Motor

After the hardware and the program for the Digital PID had been completed, the mathematical model of the plant which in this project is the DC motor need to be calculates. The mathematical model need to be find to know what are the behavior of the DC motor response when running in actual condition. Other than that, the result of response from the mathematical model can be compare with the response when the motor running by the controller to make sure that the hardware and the program really works. Here are the steps need to be done to get the mathematical model of the DC motor.

- i. Get the response of the motor while running by the Digital PID hardware without any compensated by the PID.
- ii. Get the value of the output when the steady state condition had been met.
- iii. Find the time constant of the response by getting the 63% from the steady state final value.
- iv. The time response then must be divided with 1 to get the value of the constant a .
- v. After getting the value of a , enter the value in the equation 3.1 below to get the mathematical model of the DC motor.

$$G(s) = \frac{a}{s + a} \quad [3.1]$$

- vi. Then, simulate the mathematical model in the MATLAB Simulink the response and compare it with the response get in the step I.

By having the right mathematical model of the DC motor, the actual performance of the DC motor can be known and the tuning process of the Digital PID can be much easier to be done.

3.4 Digital PID Tuning

For tuning the PID, the only part that needs to be altered is the C program for the Digital PID. But before any alteration can be made, there are some calculation needed to be completed to make sure any alteration make is right on track. The steps to do the calculation are as follow:

- i. Make a root locus using MATLAB for the mathematical model of the DC motor.
- ii. From the root locus, get the natural frequency and gain for the response.
- iii. Calculate the settling time by using the natural frequency in step II.
- iv. Calculate the new settling time with the desired transient performance (this part is to find the PD transfer function). From the new settling time, calculate the new natural frequency and poles position for the desired performance.
- v. The new poles will be not in the root locus in step I, so a new zero position need to be determine to achieve the design objective.
- vi. The value of the zero in step V must be enter in the equation 3.2 below to get the transfer function of the PD compensator

$$G(s) = K(s + Zc) \quad [3.2]$$

- vii. Create the root locus for the new transfer function of the DC motor that include the PD compensator transfer function using MATLAB.
- viii. Check if there still any steady error and the new gain, K.
- ix. Find the transfer function for the PI compensator. Enter the value of zero, Z_c for the PI compensator in the equation below (the value of the Z_c can be getting by taking the value that as close as possible to zero (0)).

$$G(s) = K\left(\frac{s + Z_c}{s}\right) \quad [3.3]$$

- x. Combine all the transfer function for the DC motor, PD compensator, and PI compensator and find the root locus for the new transfer function using MATLAB.
- xi. Get all the data from the root locus.
- xii. Simulate the transfer function to check the new performance of the compensated system.

After the entire step above is complete, the C program of the Digital PID must be adjusted by following the new compensated system.

3.5 Test the System Performance with Digital PID Compensated During Drilling the PCB

When all the hardware, C program and Digital PID tuning had been completed, the last step is to test whether the Digital PID is capable on controlling the speed of the motor while drilling the PCB. The steps to complete this experiment are:

- i. Run the motor without using any Digital PID adjustment in the C program.
- ii. Set the desired speed to run the DC motor.
- iii. Drill the PCB till the tool penetrates the workpiece.
- iv. Observe the behavior of the drilling process.
- v. Adjust the C program by adding the Digital PID tuning value.
- vi. Set the desired speed to run the DC motor same as speed in step II.
- vii. Repeat step III and step IV.
- viii. Compare both the result for drilling with compensator and without compensator.

By completing this experiment it can prove that when using Digital PID, the speed of the motor can be control during the drilling operation and the drilling process can be more efficient when control using Digital PID.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 Introduction

All the things about this chapter are the findings got from the experiment explained in the previous chapter. This chapter will show the result and data that can be use to achieve all the objective of this project. In this chapter, it will include the schematic diagram and what are the electronic part needed to build the hardware, the complete C program script and how it was planned and works for the Digital PID. Next result will be about the mathematical model for the permanent magnet DC motor and the PID tuning. Last this chapter will explain about the effect of the Digital PID in controlling the speed of the motor during drilling operation. Other than that, this chapter will discuss about all the result. All the data will be thoroughly discuss so that at last part of this project, it can be concluded and any recommendation to improve this project can be given.

4.1 Building the Digital PID Hardware

After completing the design and development of the Digital PID hardware, it happens to be four main parts that need to be built. Only by combining all this four parts can make the Digital PID hardware works. The four parts are:

- i. Programmable Integrated Circuit (PIC).
- ii. Digital-to-Analog Converter.
- iii. DC motor driver.
- iv. Encoder and light sensor.

The PIC use in this project is a PIC 16F877A model that use to process all data received and sent throughout the process. Since the data process by the PIC is only in digital, a Digital to Analog converter need to be use to convert the digital data from the PIC into analog signal to run the motor. The analog signal from the converter is weak, so a driver is needed to amplify the signal to make sure it is sufficient to run the motor. The encoder and the light sensor is use to create a digital pulse as a feedback signal to the PIC. The complete schematic diagram for the Digital PID hardware is shown in the Appendix B.

4.1.1 The Programmable Integrated Circuit (PIC)

The PIC is an electronic component that can be program and use to control, process, receive and send all data to make the Digital PID hardware works. In this project, the PIC that had been chooses PIC16F877A. This PIC consists of 4 set of port which are Port A, Port B, Port C and Port D. All this port can be the input or output based on the use of this project. The PIC itself have some advantages that can be use which are Real Time Clock Counter (RTCC) and use RS232 to send and receive data from the computer. The detail about the port use and connect is shown the Figure 4.1.

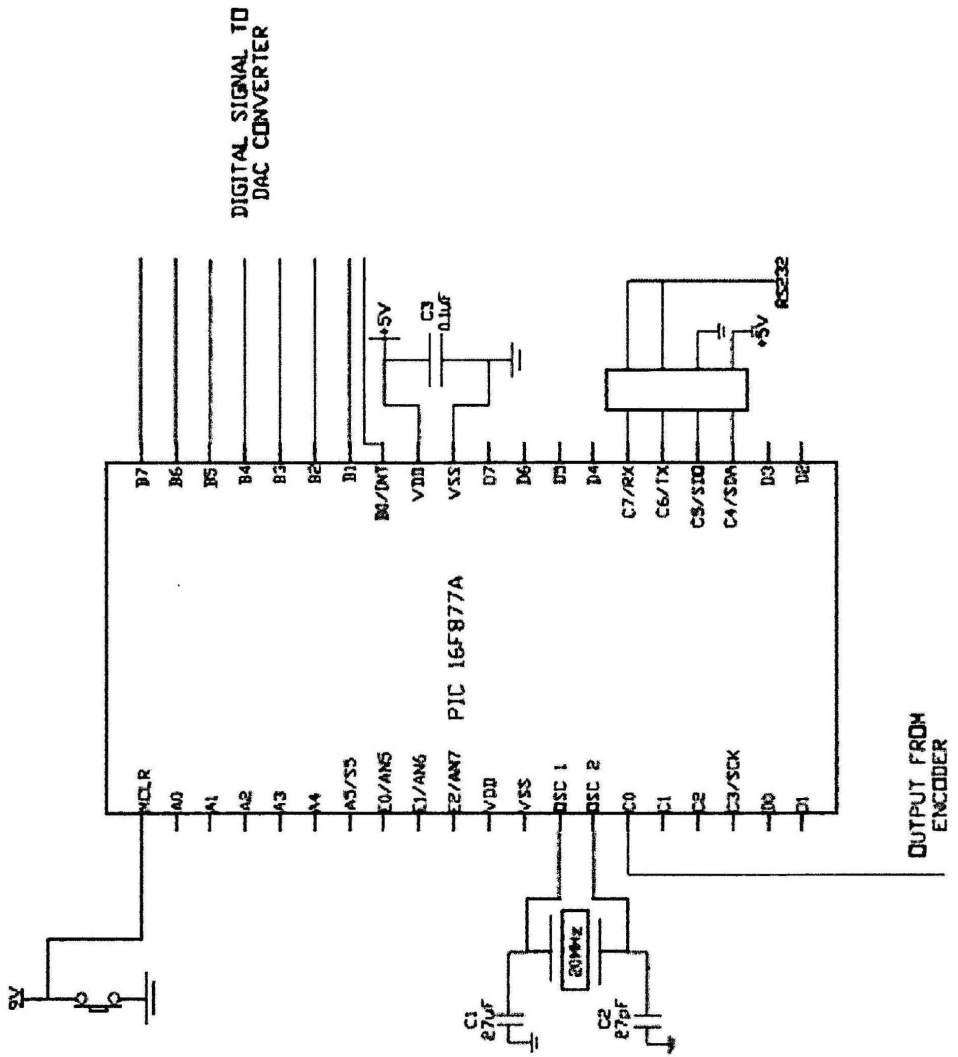


Figure 4.1: PIC16F877A Configuration for Digital PID

From the figure, shows that all port B is set to send digital output signal to Digital-to-Analog Converter meaning that the only output is from port B. All port B is use for the digital signal output because the digital signal output needs 8 ports to create a complete digital signal. In this project, port B was choose because only port B available to be use without crossing with other connection.

The data from encoder is sent to port C0. This port will read the digital data given to PIC for processing. It is connected with the encoder light sensor output that will transmit the digital pulse created by the encoder to the PIC.

Port named OSC 1 and OSC 2 given a 20MHz capacitor for clocking of the Real Time Clock Counter (RTCC). The RTCC is use to count the time for one complete pulse to get the frequency of the DC motor while running at the certain voltage.

While for connecting RS232 to the PIC, port C7, C6, C5, and C4 is use. The RS232 cable is use to transfer data from PIC to computer and receive the data from computer to the PIC.

The MCLR port is use for supplying 9 volts power to PIC and as an on-off switch button for program installation. V_{DD} and V_{SS} port also use to supply power to the PIC for 5 volts.

4.1.2 The Digital to Analog Converter (DAC)

Signal that sent by the PIC is in a digital signal, but the motor need an analog signal to rotate, so a digital to analog converter (DAC) is needed to convert the digital signal. In this project, the DAC use is DAC0808LCN model. This converter consist of 16 port and convert the digital signal (example: 10110110) to the analog signal which in voltage. The connections of the circuit are shown in the Figure 4.2.

From the figure, it shows that port 5 to 12 is use to receive the digital signal from the PIC. Port 5 will be set as Most Significant Bit and port 12 is set as Less Significant Bit.

Port 3 and Port 16 is given -15V as V_{ee} and Port 13 is given 15V as V_{cc} . These three ports is use to power the converter. Port 14 is given 10V V_{ref} as a control to avoid overload that may damage the DAC. Port 4 is use as the analog signal output and Port 2 and Port 15 is ground.

There is a problem after converting the digital signal to analog signal where the analog signal is in current form not in voltage. Operational amplifiers (op-amp) need to be connected to Port 4 to change the signal output to voltage. The op-amp that had been used is LM2907 and it is inverting type op-amp. By only connecting the DAC with the op-amp can change the signal from current to voltage and make the running of the motor possible.

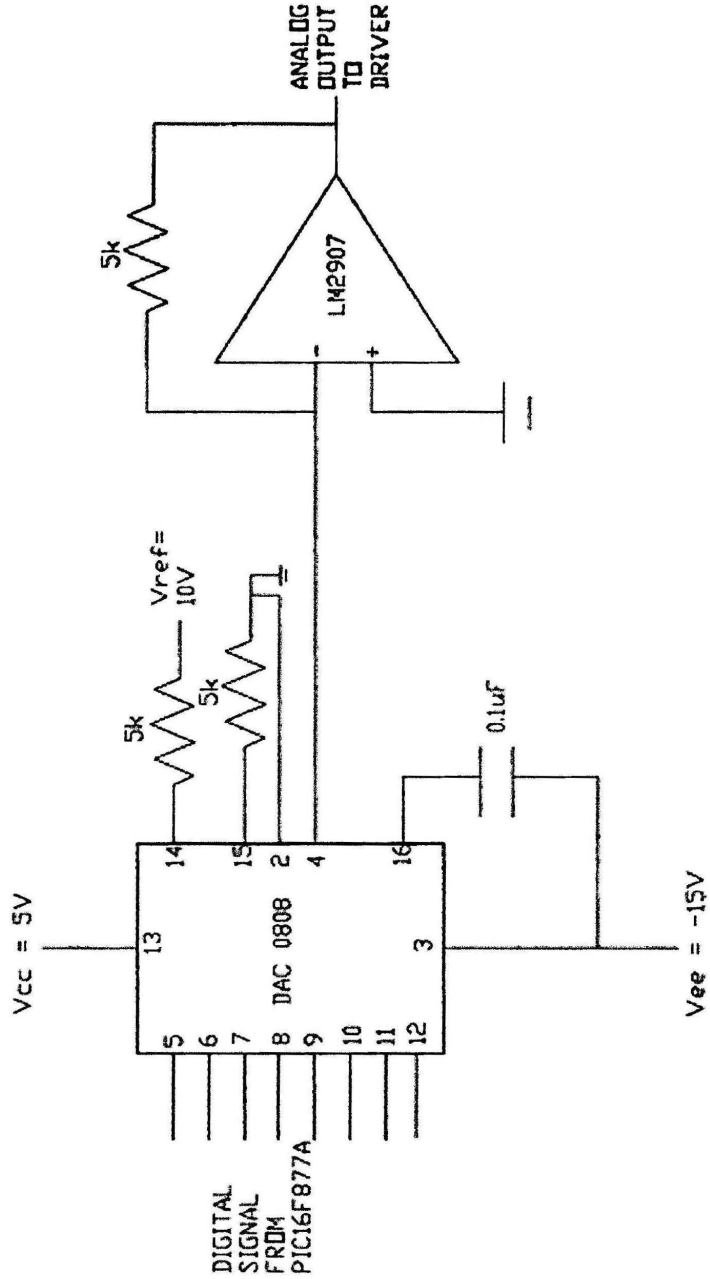


Figure 4.2: Digital to Analog Converter Connect with Inverting Operational Amplifier

4.1.3 DC Motor Driver

After the digital signal is converted to analog signal, the analog signal happens to be so weak. Even the output voltage is sufficient, but it is only a value, the signal is still weak and hard to rotate the motor. To settle this problem, a DC motor driver need to be use to amplify the signal and make it possible to run the motor. In this project, the DC motor driver type use is Multi-Directional Motor Driver and the circuit for this DC motor driver is shown in Figure 4.3. To make this circuit, the electronic components that need to be use are:

- i. Transistor TIP31 and TIP32.
- ii. Two diodes.
- iii. One capacitor $1\mu\text{F}$.

All the components are connected as shown in the Figure 4.3 and a 12V power supply is use to power the motor driver. This power supply also need to be same as the maximum voltage of the DC motor driver to avoid overload to the motor while the digital PID running in full signal.

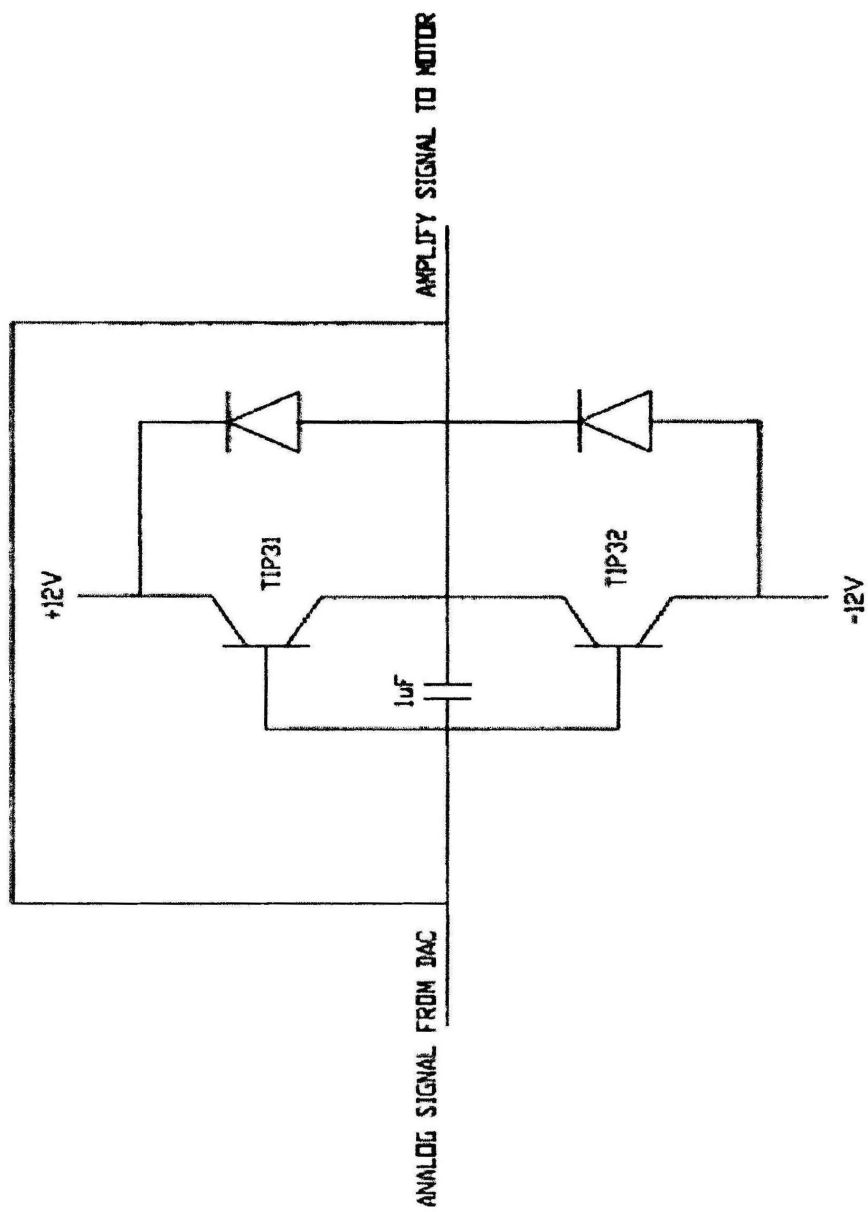


Figure 4.3: Multi-Directional DC Motor Driver

4.1.4 The Encoder and the Light Sensor

In the PID hardware, the encoder and the light sensor is use to create a pulse signal from the movement of the DC motor. In this project, the encoder used in this project is made with 1.5mm sheet metal. To make the encoder to be in round shape and creating 30 uniform rectangular holes around the face of the encoder, a Turret Punch Machine was used. The machine will use punching method to create the encoder into the desired shape. The encoder was installed at the tip of the DC motor and the encoder side is placed between the light output and the sensor of the light sensor. The theory is that, when the DC motor rotate, the holes at the encoder will create an on-off situation that will be detected by the light sensor and a signal pulse will be created that represent the behavior of the DC motor speed. The connection for the encoder and the light sensor is shown in the Figure 4.4.

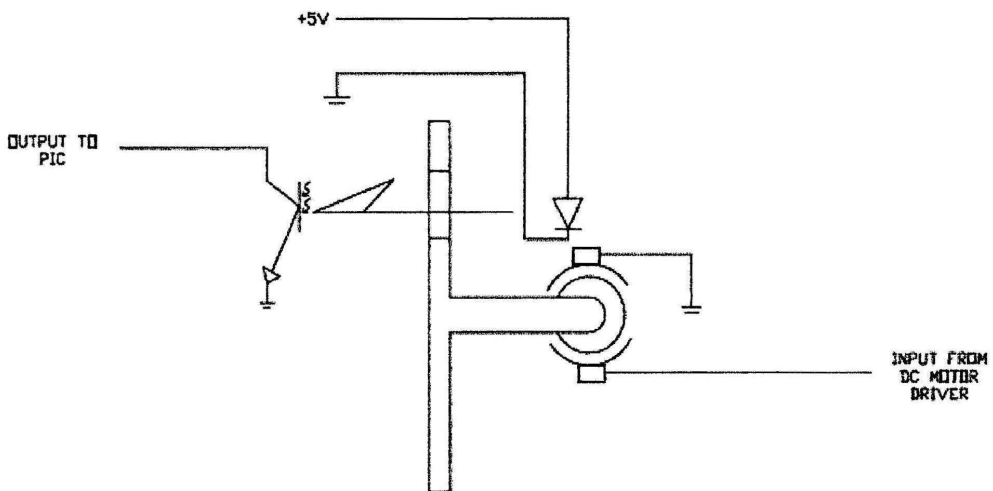


Figure 4.4: Encoder and Light Sensor

4.2 The Digital PID C Program

When the Digital PID hardware circuit is completed, it come to the making of the Digital PID software that will be installed in the PIC 16F877A by using PCW compiler software. The flow of the program is shown in the Figure 4.9.

The most important part in the C program is the Real Time Clock Counter (RTCC) part. The RTCC is use to count the time needed to complete one single pulse. The time recorded will be use to calculate the frequency of the motor that will be use to compare with the frequency references that already set earlier in the program. To calculate the frequency, the math.h application needs to be included in the start of the program. There is a problem when use the RTCC to count the pulse time. The problem occur when counting the pulse at the first time where the number recorded will not be the same if the counting is repeated second time. In order to get more exact value, the RTCC will count the single pulse time for 3 times and get the average for the last two counts recorded since the two last counts is more appropriate (this is done by inspection in the SLOW, where the last two count have slightly same value and can be assumed stable to get the exact value of time).

When the C program had been running successfully, it will be transfer to the PIC 16F877A by using RS232 cable. To transfer it, the CDM program will be use. To transfer the program, first open the CDM program. Then browse the C program file (the file type is HEX file). Before clicking the start button, the switch for the PIC needs to be held off. After the downloading start, release the button before the countdown finish. The program will be installed in the PIC is the step is done correctly. The complete C program of the Digital PID is included in the Appendix C and any further detail can be refers to the complete C program for more understanding and explanation.

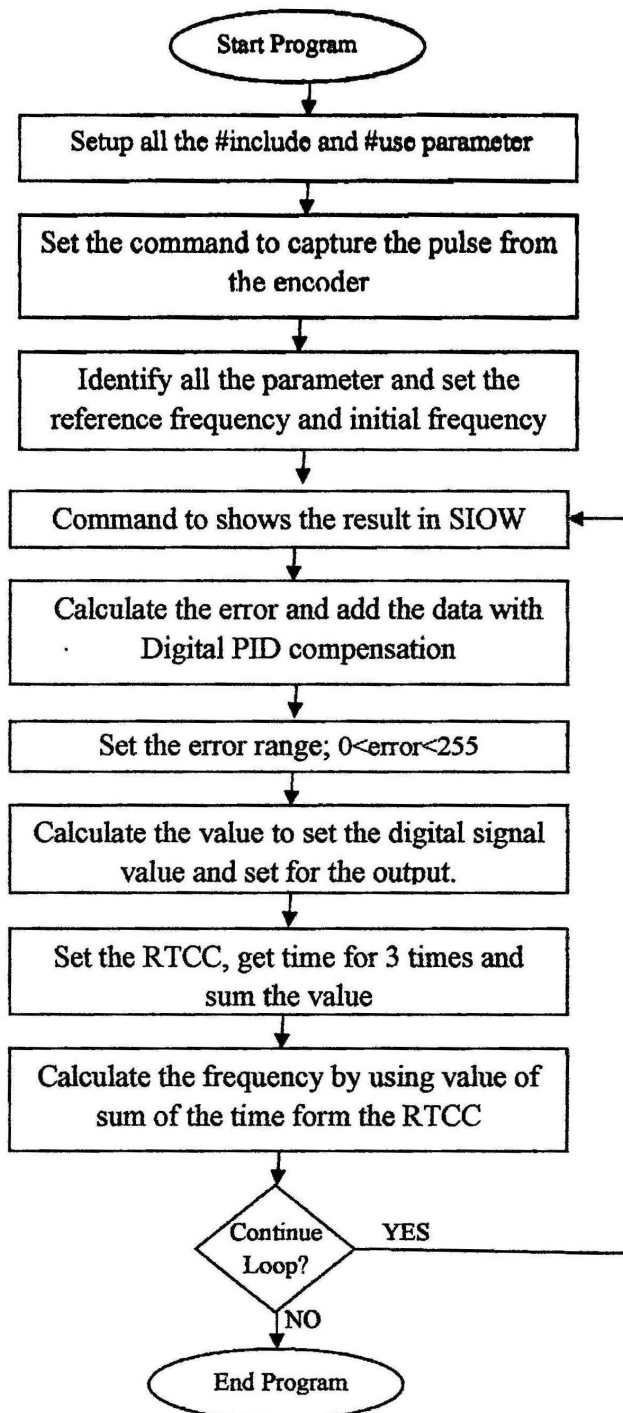


Figure 4.9: Flow Chart for the Digital PID C Program

4.3 The Mathematical Model of the DC Motor

As stated earlier in the Methodology section, to get the transfer function of the motor, it will need the value of a to complete the transfer function equation. Below is the list of table for the time constant for every voltage after normalizing.

Table 4.1: Data for Time Constant (T_c) and Transfer Function Constant (a) for Every Voltage

Voltage (V)	Time Constant (T_c)	Transfer Function Constant (a)
2	1.875ms	533
4	2ms	500
6	1.0ms	998
8	0.734ms	1362
10	0.057ms	1750
12	0.047ms	2097

From the data above, all the Transfer Function Constant is calculate to find the average value for every data. After calculate the value, the average data for the Transfer Function Constant is 1056.8.

The value for the Transfer Function Constant is entered in the transfer function equation and the DC motor transfer function will be in equation 4.1:

$$G(s) = \frac{1056.8}{s + 1056.8} \quad [4.1]$$

To make sure that the transfer function of the DC motor in equation 4.1 is right, a simulation using MATLAB Simulink was made to compare the transfer function graph get from the simulation result with the actual transfer function graph.

The comparison for both actual and simulation is shown in the Graph 4.1 and Graph 4.2. It shows that, for both graphs, the final steady state value is approximately at 1200 Hz frequency. This approved that the transfer function for the DC motor from the calculation are true.

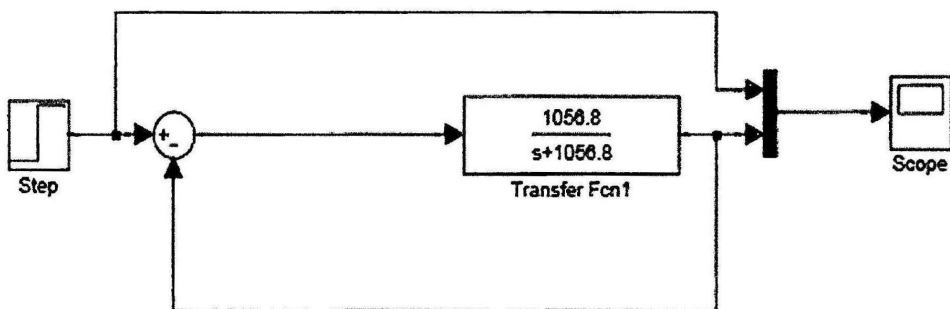


Figure 4.10: Transfer Function Simulation Using MATLAB Simulink

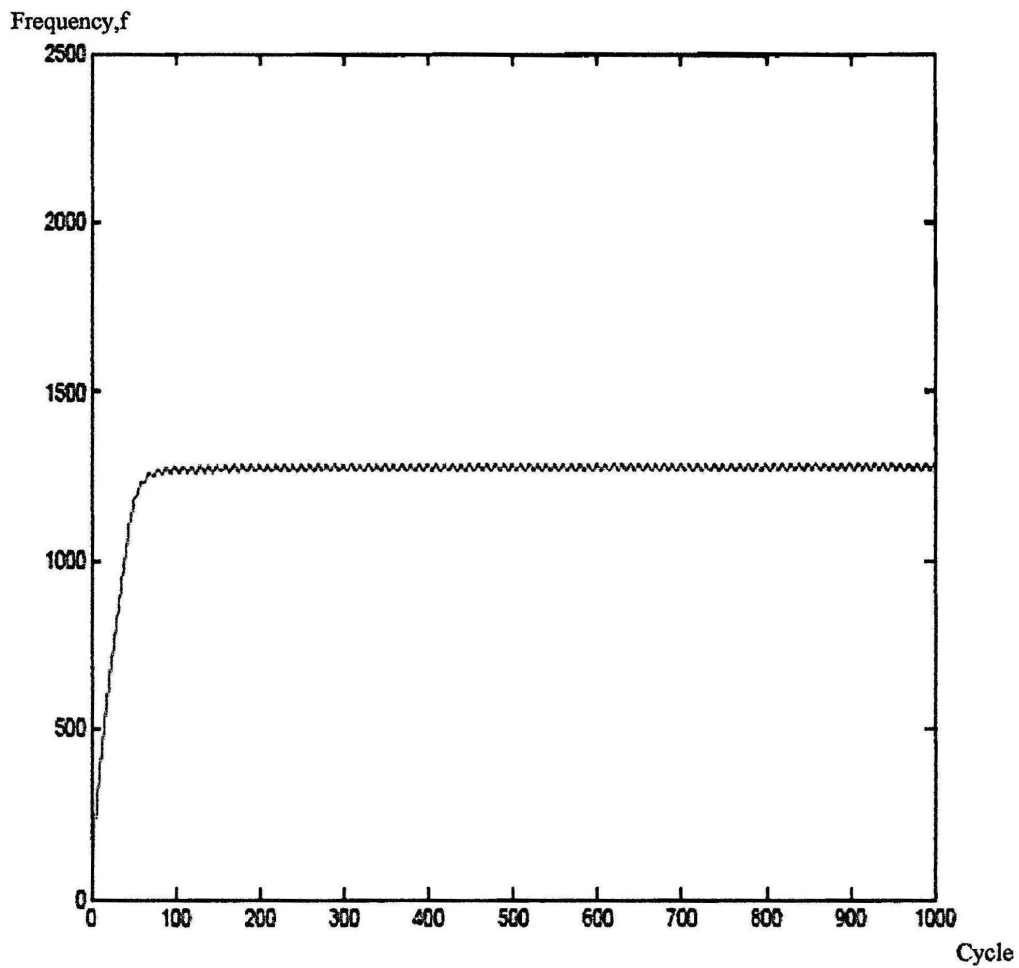


Figure 4.11: Graph for Actual Time Response with 2500Hz as Reference

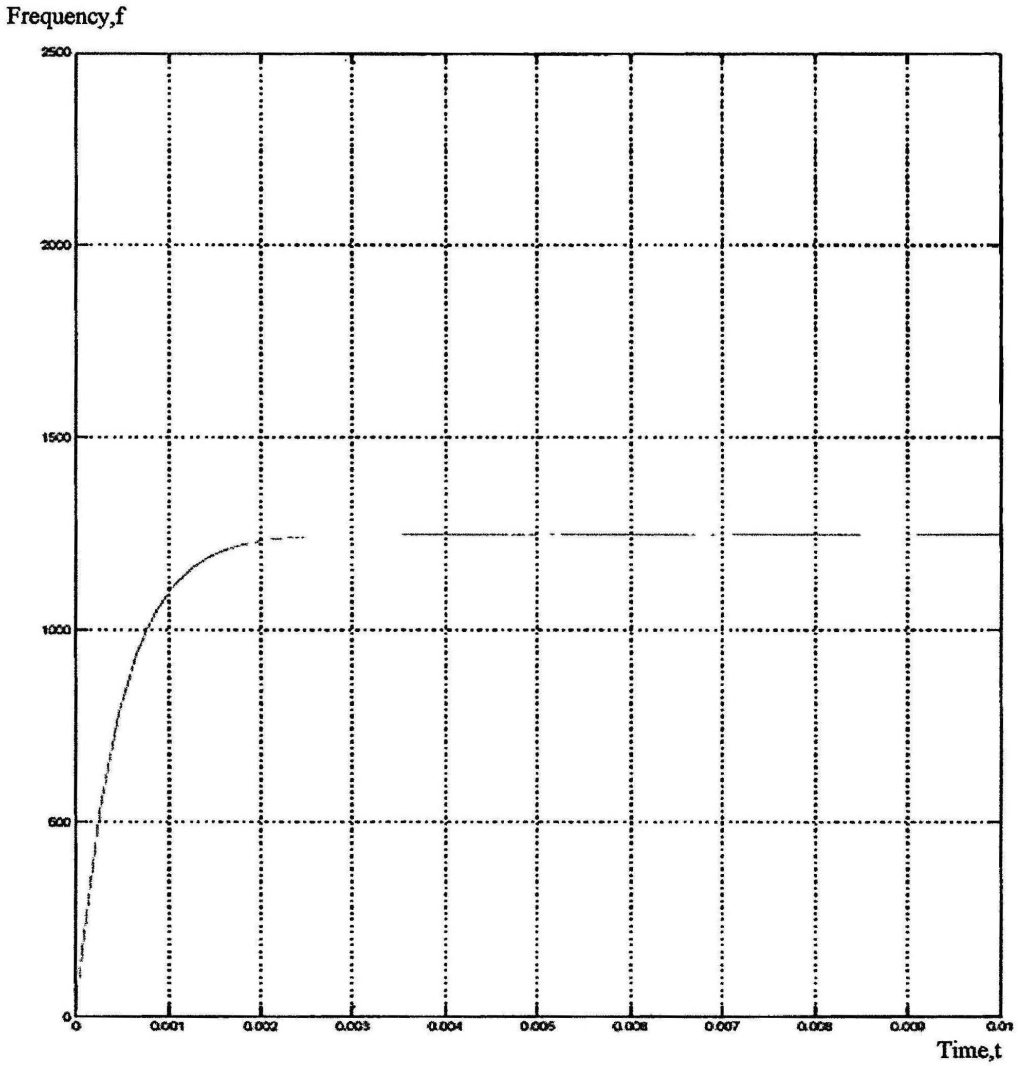


Figure 4.12: Graph for Simulation Time Response with 2500Hz as Reference

4.4 The PID Tuning

To design a PID compensator to eliminate the steady state error and improve the time response of the DC motor system, a calculation had been made to get the right PID compensator to be combined with the DC motor transfer function. The calculation is shown below:

DC motor transfer function is shown in equation 4.2:

$$G(s) = \frac{1056.8}{s + 1056.8} \quad [4.2]$$

Initial Parameter:

Percent Overshoot = 0%

Gain, $K = 1$

Pole = $-2.11e^3$

Damping Ratio = 1

Natural Frequency, $\omega_n = 2.11e^3$ rad/sec

Values get from the
Root Locus in
Appendix D

From calculation, the settling time, T_s is 1.895ms.

Designing PD:

The improvement for transient response needed is 1/3 improvement in this project.

So, the new Ts value is:

$$T_{s\text{-new}} = 0.333(T_{s\text{-old}}) = 0.333(1.895\text{ms}) = 0.631\text{ms}$$

$$\text{New Natural Frequency, } \omega_n = 4 / T_{s\text{-new}} = 4 / 0.631\text{ms} = 6.34\text{e}3 \text{ rad/sec}$$

$$\text{New Poles} = -6.34\text{e}^3$$

The new pole are not in the current actual root locus, so the position of zero need to be find that will satisfy the root locus for the new pole. From the calculation to find the zero, since the zero position is 0 degree from the new pole, it happen to be position between to zeros, according to the root locus theory, the zero must be in the middle between both pole to make it symmetry. From that can be concluded that the new zero position is at -4.225e^3 .

The transfer function for PD compensator is in equation 4.3:

$$G(s) = (s + 4225) \quad [4.3]$$

Designing PI:

To design the PI compensator, the position of zero must be put as close as to 0. In this project, the position of zero is set at 0.01 make the transfer function for PI compensator as below:

The transfer function for PI compensator is in equation 4.4:

$$G(s) = \frac{(s + 0.01)}{s} \quad [4.4]$$

By combining all the three transfer function, DC motor transfer function, PD compensator transfer function and PI compensator transfer function, can create a PID compensated transfer function.

The transfer function for PID compensated system is shown 4.5:

$$G(s) = \frac{K(1056.8)(s + 4225)(s + 0.01)}{s(s + 1056.8)} \quad [4.5]$$

From the PID compensated system transfer function, the root locus for the transfer function was drawn to find the gain, K that is suitable for the new compensated system. The root locus is shown in the Appendix E.

From the root locus, the value of Gain, K is infinity. It is hard to determine the exact value of K for the compensated system. To resolve this problem, a trial and error method can be made using MATLAB Simulink to achieve the right value of K for the compensated system. The figure shown the simulation of the compensated system is in Figure 4.13.

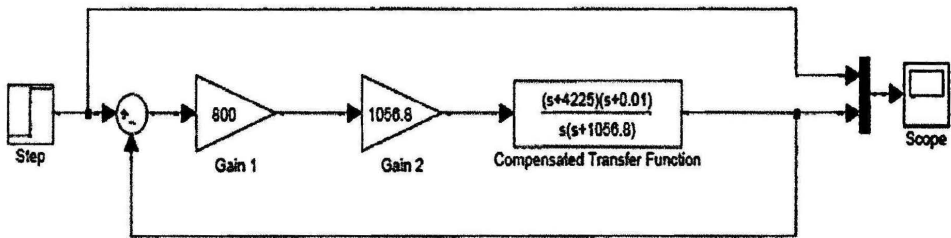


Figure 4.13: Simulation of PID Compensated System Using MATLAB Simulink

From the simulation, to check the performance of the new PID compensated system a time response graph was plot. The time response graph is shown in the Figure 4.14.

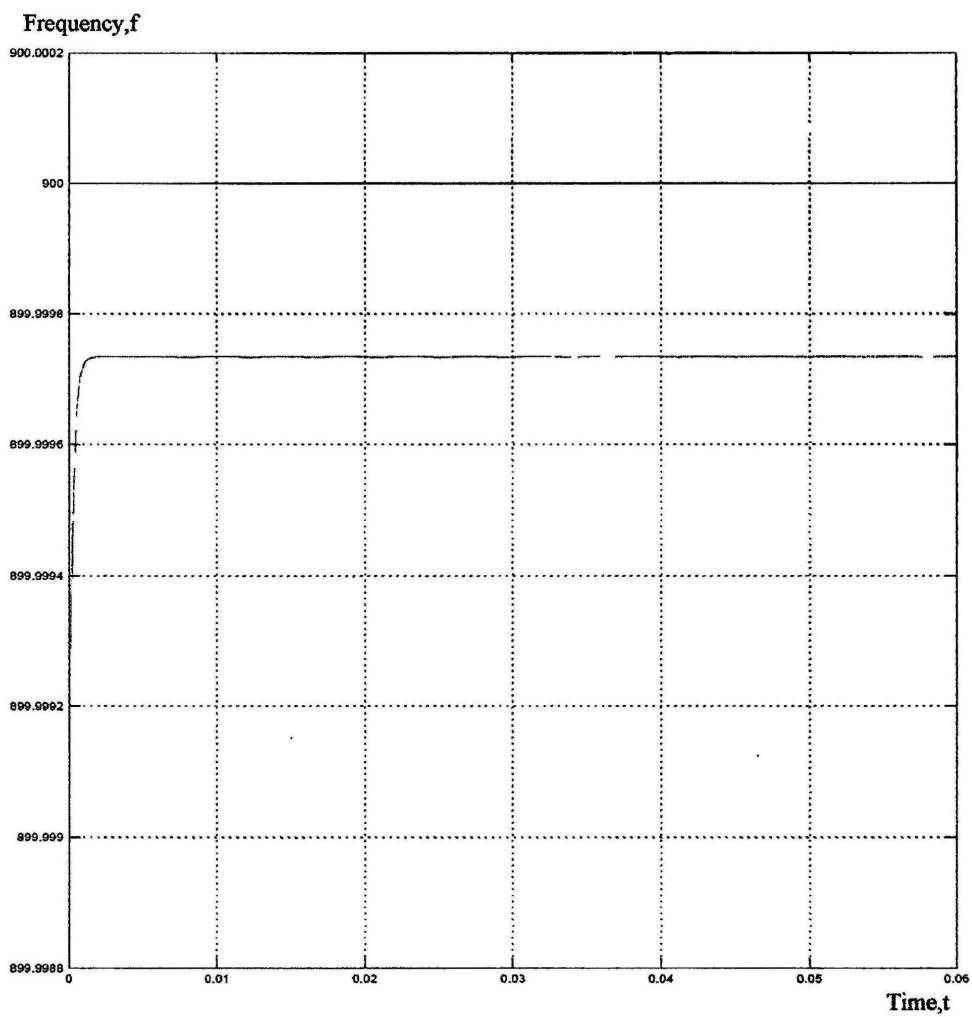


Figure 4.14: Graph for Time Response for PID Compensated System

From the Figure 4.14, it shows that there is still steady-state error occur at the system. This happen because from the root locus (refer Appendix E) it shows that the value of Gain is infinity to satisfy the system. This means that, the number for K is too big to be stated. The steady-state error value is too small and can be considered eliminated. To find the suitable value for K, an actual experiment need to be done by adjusting the C program with at the PID tuning part (refer to Appendix C). From the experiment, the suitable value of K is 800 that avoid the system from being unstable. The graph of the actual performance running with PID tuning is shown in Graph 4.4.

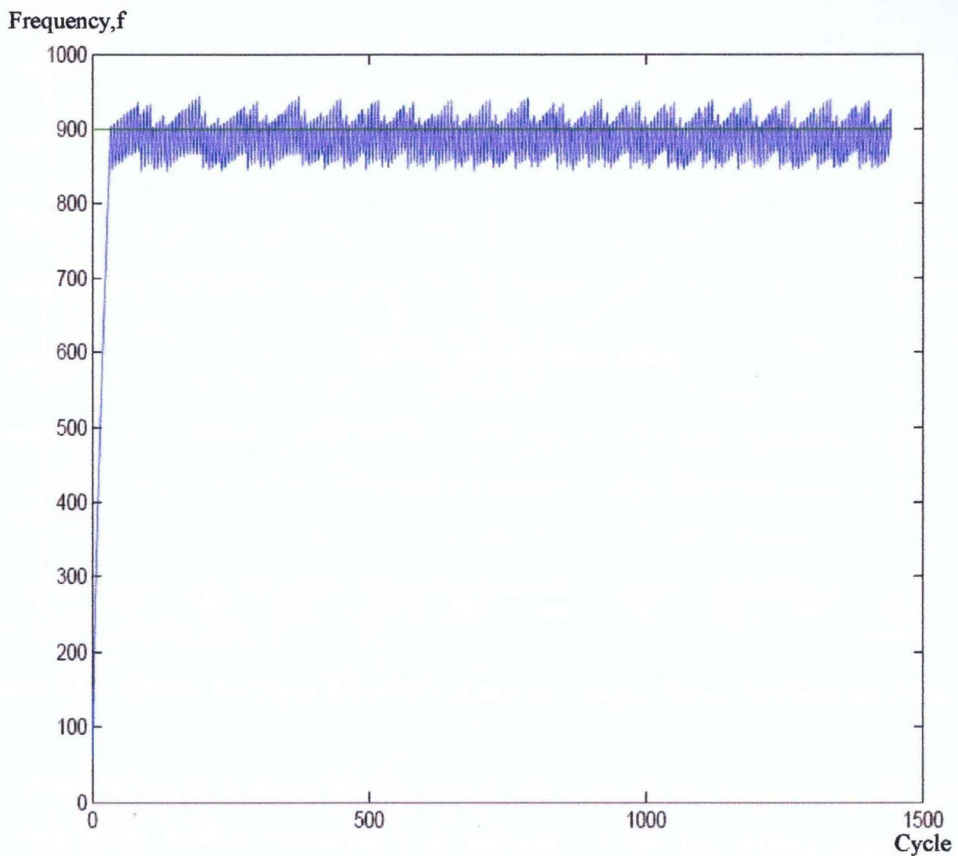


Figure 4.15: Graph for Actual Time Response with PID Compensated

4.5 The System Performance with Digital PID Compensated During Drilling the PCB

When everything is completed, the last test required to observe the performance of the system when compensated with Digital PID during Drilling operation of PCB. The graph showing the time response of the compensated system is shown in Graph 4.5.

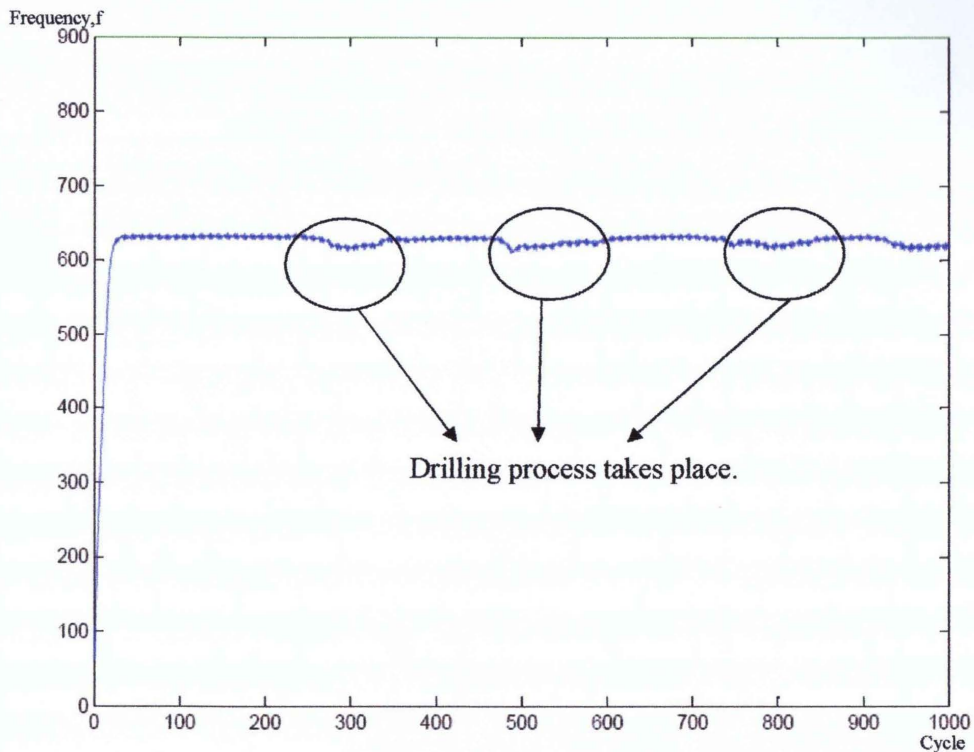


Figure 4.16: Graph for Time Response of the DC Motor When Drilling the PCB

From the graph, it shows that the system will maintain the frequency at the same level even while drilling operation is in process. When the drilling started, the frequency will decrease, but because of the feedback system, the controller will eliminate the error and run the motor at the desired frequency.

CHAPTER 5

CONCLUSION

5.1 Conclusion

From this project, it is clear that the Digital PID controller can be use to control the speed of the Permanent Magnet DC Motor. In whatever condition, the Digital PID will always maintain the speed of the DC motor to always running at desired speed. Other than that, due to the operation of the Digital PID is based on the C program installed in the PIC, it is much easier to set the PID to follow any system that closely equal with the current DC motor use (analog PID cannot do this job easily due to the restriction of the electronic component). The Digital PID also had been proved to eliminate the steady state error of the system response and at the same time improve the transient response of the system. The disturbance, which in this project is the friction during drilling process also had been control to improve the performance of the DC motor during drilling process.

5.2 Recommendation

After completing this project, there is some recommendation idea that can be use for further study in improvising this project. The idea recommendation will include the more advanced controller use, the type of system that can be control and the hardware use to build the controller circuit.

The improvement can be made to make the speed control of the DC motor become more efficient is to use more advanced controller. The example of the advanced controller is fuzzy-logic. By using more advanced controller, it may fully eliminate the steady error and improve the transient response to become more faster.

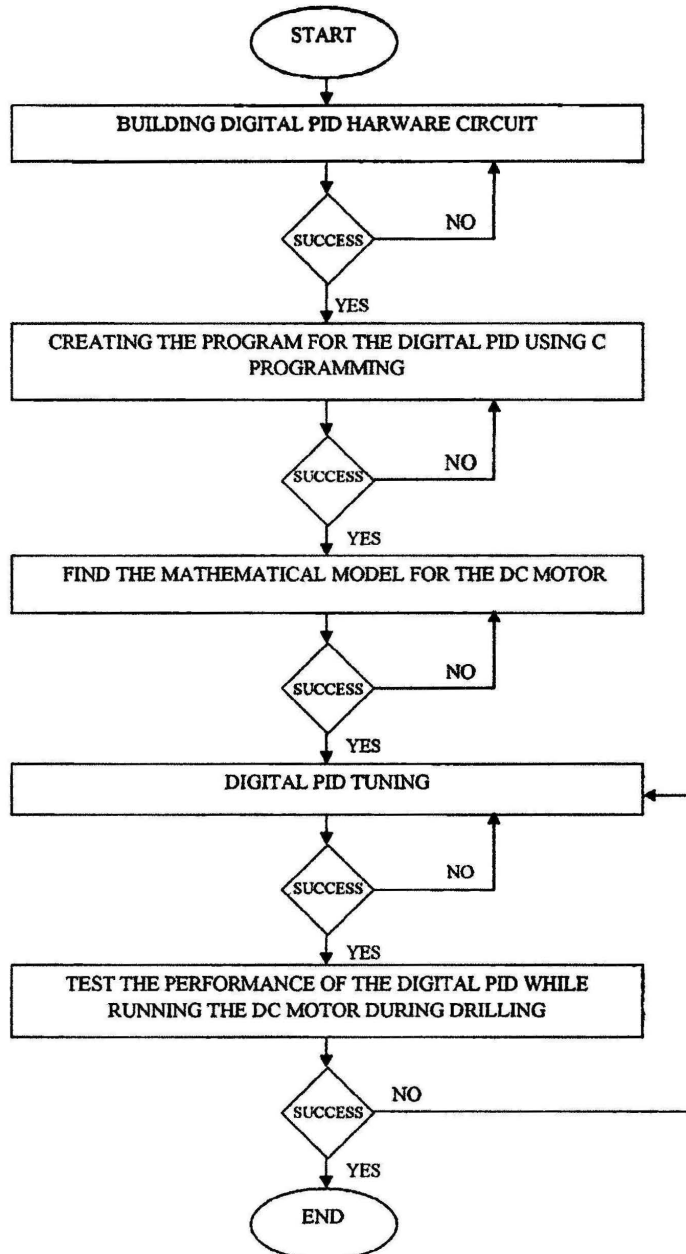
Next improvement can be made is to design a controller that can control a speed of the DC motor that use for heavy duty drilling process. In this project, the Digital PID controller can only speed of the DC motor that use for light drilling operation, in this project the drilling material is PCB. For next study, the controller may be design so that it can also control the speed of the DC motor no matter what type of drilling operation the DC motor involve. This will widen the compatibility of the controller and make the controller more reliable.

Last improvement can be made is to use electronic component that more reliable and more durable to build the hardware of the controller. By using better electronic component, it can avoid any unstable condition when the controller running at the top performance. Using better electronic component also can increase the maximum voltage the controller can handle and avoid component damage when the controller is overloading.

REFERENCES

1. Bolton W. *Mechatronics Electrical Control Systems in Mechanical and Electrical Engineering*. Third Edition. England: Pearson Education Limited, 2003.
2. de Silva C. W. *Mechatronics: An Integrated Approach*. :CRC Press LLC. 2000.
3. Dubay G. K. *Fundamentals of Electrical Drives*. :Alpha Science International Ltd. 2001.
4. Ellis G. *Control System Engineering Guidance: Practical Guide*. Third Edition :Elsevier Inc. 2004
5. Kalpakjian S. and Schmid S. R. *Manufacturing Engineering and Technology*. Fourth Edition: Prentice Hall International. 2001.
6. Nise N. S. *Control System Engineering*. Fourth Edition: John & Wiley Sons Inc. 2004.
7. Patrick D. R. and Fardo S. W. *Rotating Electrical Machines and Power Systems*. Second Edition. Indian Trail Lilburn, GA: Prentice Hall. 1997.
8. Philips C. L. and Nagile H. T. *Digital Control System Analysis and Design*. Third Edition: Prentice Hall Inc. 1995.
9. Warmick K. and Rees D. *Industrial Digital Control Systems, Revised Edition*: Peter Peregrins Ltd. 1988.

APPENDIX A
METHODOLOGY FLOWCHART



APPENDIX C

C PROGRAM FOR DIGITAL PID

```

#include <16F877a.h> //give command to use
PIC165877a

#fuses HS,NOWDT,NOPROTECT,NOLVP //main reset

#use delay(clock=20000000) //delay clock is set to 20MHz

#use rs232(baud=115200, xmit=PIN_C6, rcv=PIN_C7) //RS232 port will be use

#include <ctype.h> //c type programming will be use

#include <math.h> //math equation will be use

void wait_for_low_to_high() //|
{ //|
    while(input(PIN_C0)); //|
    delay_us(1); //|
    while(!input(PIN_C0)); //|
} //|
//|command to capture pulse length from encoder

void wait_for_low() //|port C0 will be the input port
{ //|delay 1us is use to avoid counting delay
    while(!input(PIN_C0)) //|
    delay_us(1); //|
    while(input(PIN_C0)); //|
} //|

```

```

void main()
{

float freq,freq_ref,speed_motor,error;           //
                                                //Identify all parameter want

int32 value,time1,time2,time3,average_total_time,total_time; // to use

freq_ref=2500;           //set the frequency reference
freq=0;                 //reset the frequency to zero

set_tris_b(0x00);       //set all port B to be output, to be use for Digital-to-Analog
converter

while (TRUE)           //start of the loop
{
    printf("%5.1f %5.1f %5.1f %LU
%LU\r\n",freq,freq_ref,error,value,average_total_time); //display data in SIOW

    error=800*(freq_ref-freq); //PID tuning part

    if(error>freq_ref) error=freq_ref; //control the range of the digital number
    if(error<0) error=0;           // make sure the error will be 0-255 only

    value=(error/freq_ref)*255;     //calculate value for the digital signal

    output_b(value);               //the value become the output for port B

```

```

setup_timer_1( T1_INTERNAL| T1_DIV_BY_8 ); //
set_timer1(0); //
wait_for_low_to_high(); //
wait_for_low(); //
time1=get_timer1(); // real time clock counter(RTCC) will
setup_timer_1(T1_DISABLED); // be use
//

setup_timer_1( T1_INTERNAL| T1_DIV_BY_8 ); //Timer 1 is set
set_timer1(0); //three times data is sampled to have
wait_for_low_to_high(); // a stable data
wait_for_low(); //
time2=get_timer1(); //
setup_timer_1(T1_DISABLED); //
//

setup_timer_1( T1_INTERNAL| T1_DIV_BY_8 ); //
set_timer1(0); //
wait_for_low_to_high(); //
wait_for_low(); //
time3=get_timer1(); //
setup_timer_1(T1_DISABLED); //

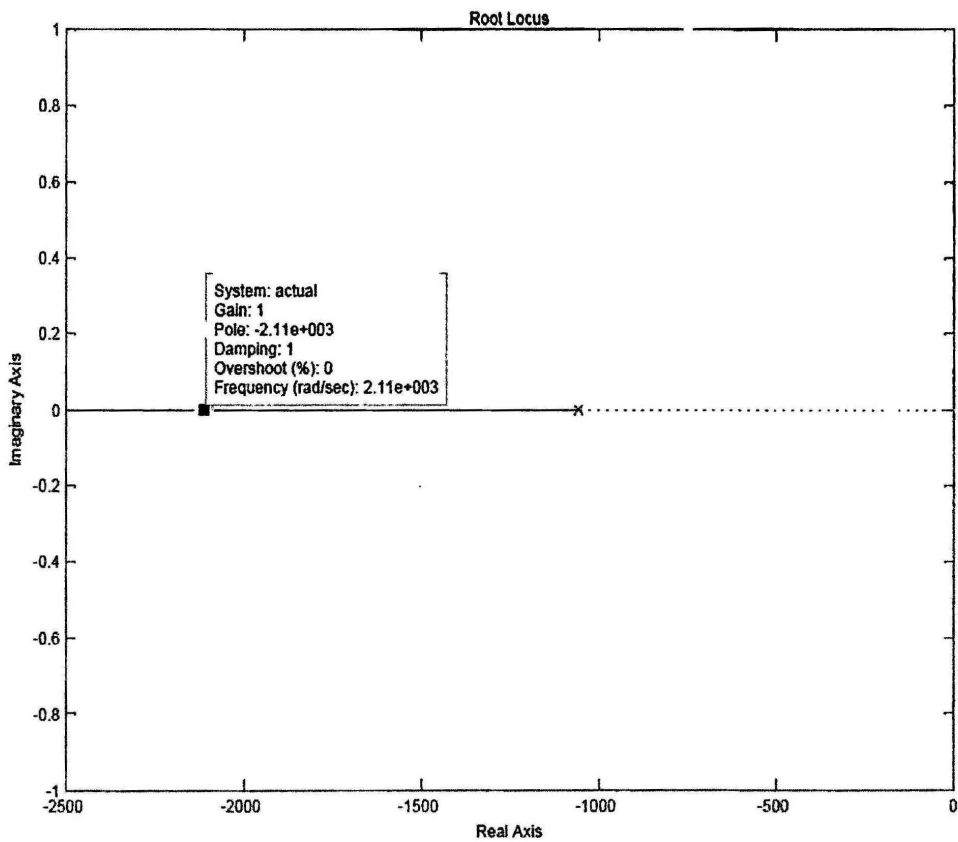
total_time=time2+time3; //calculate the sum of the counting

average_total_time=total_time/2; //calculate the average of the counting

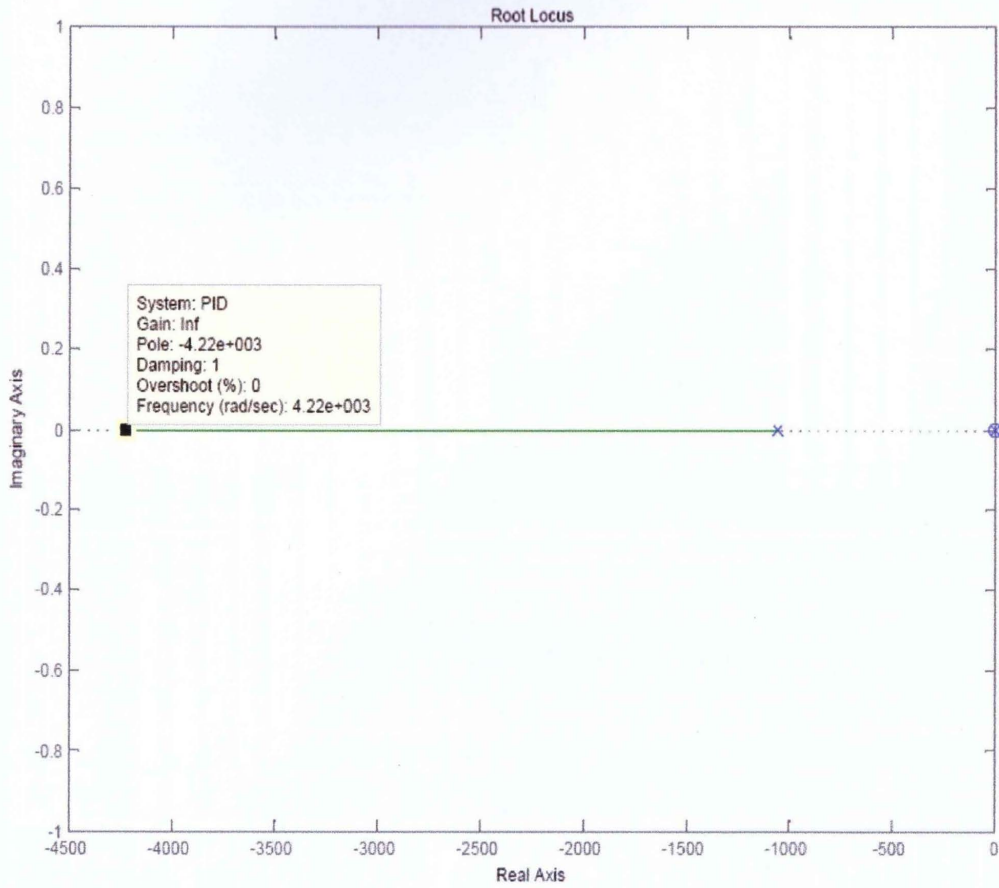
freq=1/(average_total_time*0.0000016); //calculate the frequency of the motor
}
}

```

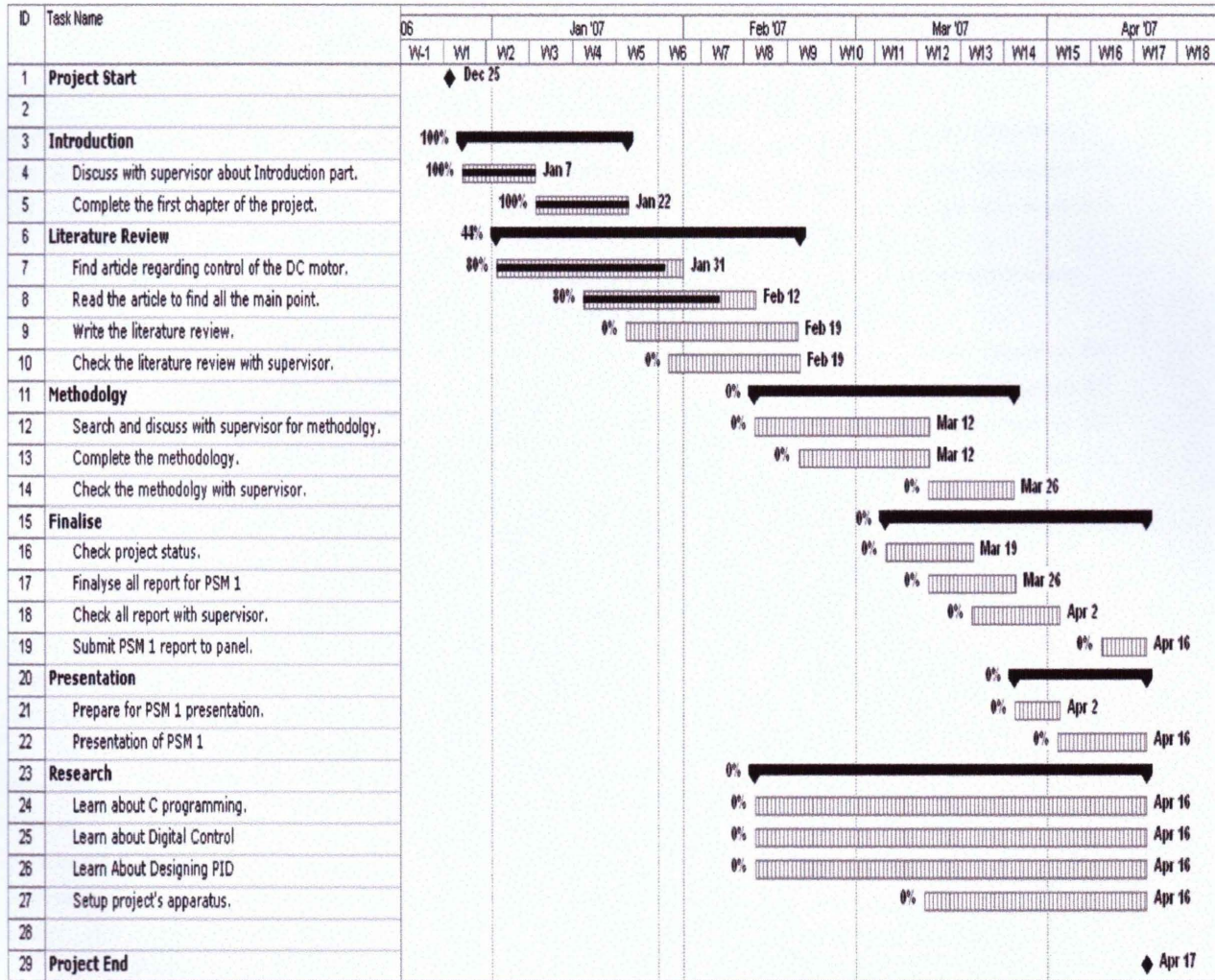
APPENDIX D
ROOT LOCUS FOR ACTUAL DC MOTOR SYSTEM



APPENDIX E
ROOT LOCUS FOR DC MOTOR SYSTEM WITH DIGITAL PID
COMPENSATED



GANTT CHART FOR FINAL YEAR PROJECT 1



APPENDIX G

GANTT CHART FOR FINAL YEAR PROJECT 2

