بسم الله الرحمن الرحيم

Palestine Polytechnic University

College of Engineering and Technology

Mechanical Engineering Department

Mechatronics Engineering

Graduation Project

Controlling of a Rod Angle Using a Fan

Project Team

Hamzah A.M. Irfa'yeh **Hamzah I.M. kattoush**

Marwan W.A. Irmieleh

Project Supervisor

Eng. Tareq Abu Hamdeyah

Hebron -Palestine

June-2009

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According to the project supervisor and according to the agreement of the testing committee members, this project is submitted to the Department of Mechanical Engineering at college of engineering and technology in total fulfillment of the requirements of the BHD.

Supervisor Signature

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Committee Members Signature

1............................ 2............................

Department Head Signature

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June -2009

جـــــامعة بــوليتـكنك فلسطـــــين
الخليـــــل- فلسطـــــين
كلية الهندسة والتكـنولوجيا
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التحكم بزاوية عصا معدنية باستخدام مروحة

أسماء الطلبة

حمزةابراهيم محمد قطوش　　　**حمزة عبد الحميد محمد ارفاعيه**

مروان و حيد عارف ابوارميلة

بناء على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندســـة الميكانيكية وذلك للوفاء بمتطلبات درجة البكالـــوريوس في الهندســـة تخصص هندسة الميكاترونكس

توقيع المشرف

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توقيع اللجنة الممتحنة

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توقيع رئيس الدائرة

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June-2009

Dedication

To Our Dear Parents…

To Our Brothers And Sisters…

To Our Families…

To Our Friends…

To whom who have taught us any letter, word or information…

To our colleges and instructors…

To whom we Respect…

To whom who have added anything to the science…

We dedicate this project…

Project Team

Acknowledgment

Here as we finished our graduation project we thank every body who has helped us to complete this work

First, special thank for **Our Dear Parents and Families** whom gave us love and for their support which gave us confidence

We want to thank our supervisor **Eng. Tareq Abu Hamdeyah** who gave us a lot of his time and experience in order to complete the project and gave us the opportunity to start scientific life and methodology in the real life by asking us to do this work

Special thanks related to all teachers and instructor in mechanical engineering department, whom gave us a valuable note on our project with encouraging us to complete the project in full way

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Finally, to our friends and to everyone who helped us and didn't need to appear their names since they appear always

Abstract

As an application of the mechatronics systems this project had suggested, the main objective of this project is scientific one, it is a direct application on mechatronics systems, since it has a control items or controllers, motions, accuracy & feedback. The project is one degree of freedom, so one fan is needed here.

The project has tow main parts; mechanical part & electrical (& digital) part, the mechanical one has a vertical-oriented fan placed on one end of a bar, this bar jointed at the middle by a hinge with a cylindrical column, the cylindrical column fixed at the bottom with a base.

The electrical (& digital) part has a keypad to input the command, a fan motor, LCD, Microcontroller, the wirings & the position detector with feedback to get an accurate position.

This project is concerning to control the angel of the middle-joint rod when rotating about the hinge by interring the intended angle on the potentiometer, this command is transmitted to electrical current, this current drives the fan motor & the fan rotates with speed according to the angle, the feedback signal decides that it's the wanted angle.

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List of symbols

Symbol	Description
F_L	Lift Force Due The Static Pressure
C_L	Lift Coefficient
A	Blade Area
V	Velocity of Air
F_d	Drag Force
D_L	Drag Coefficient
SP	Static Pressure
Z_B	Number of Blades
l	Blade Width
ω_0	Nominal Angular Velocity of The Rotating Blade
SP_0	Nominal Static Pressure of The Fan
SP_1	Static Pressure of The Fan
ω_1	Angular Velocity of The Rotating Blade
I_a	The Armature Current
V_a	Armature Input Voltage of the motor
ω	Motor Angular Velocity
K_b	The Back emf Constant
Ra	The Armature Resistance of The Motor
T_m	The Motor Output Torque
K_t	The Motor Torque Constant
$\acute{\omega}$	Angular Acceleration of The Motor
T_d	The Torque Delivered Due To Drag Force
J1	The Moment of Inertia of the fan blade

J_2	The Moment of Inertia of the Rod
R	The Radius of The Fan Blade
dr	The Change In Radius of The Fan Blade
α	The Angle of Attack
dA	Change In The Blade Area
W	Width of The Blade
M_0	The Moment About The Origin O
L_1	The Distance Between The Point of The Applied Force and The Origin
θ	Swinging Angle
ζ	Damping Ratio
ω_n	Natural Frequency
ω_d	System Frequency
T_s	Settling Time
T_r	Rise Time
T_p	Peak Time
%P.O	Percentage Overshoot
e_{ss}	Steady State Error
T	Sampling Time
f_s	Sampling Frequency
f_n	Natural Frequency in Hz
K_p	Position Error Constant
K_v	Velocity Error Constant
K_a	Acceleration Error Constant
C	Torque to Speed Constant

List of Appreviations

Appreviations	Meaning
A/D	Analog To Digital Converter
D/A	Digital to Analog Converter
LCD	Liquid Crystal Display
RPM	Revolution Per Minuet
CPU	Central Processing Unit
ROM	Read Only Memory
EPROM	Erasable Programmable ROM
RAM	Random Access Memory
CMOS	Complementary metal–oxide–semiconductor
NMOS	N-Channel MOS
PWM	Pulse Width Modulation
Op Amp	Operational Amplifier
UAV	Unmanned Aerial Vehicle
VTOL	Vertical Takeoff and Landing
ACT	Access Control Technology

Chapter One

Introduction

Contents:

1.1 General Outlook

Growing worldwide industry increasingly require faster, safer and more efficient control systems. The knowledge increases continuously with a growing positive impact on control systems and a growing negative impact on interactions among humans and their relationship with the surrounding environment. in particular, the safety of the oldest industry systems have passive security controls, and that must be in high level of search and dealing with, since our life is the most important thing we have.

This project is an application on mechatronics field, this one needs to deal with fan control systems and the dynamic models used in the development of these control systems. A control engineer needs models that are both simple enough to use for control system design but at the same time rich enough to capture all the essential features of the dynamics. This project attempts to present such models and actual fan control systems.

This project is concerning to control the angel (θ) of the middle-joint bar when rotating about the hinge by enterring the intended angle on the potentiometer or the keypad, this command is transmitted to electrical current, this current drives the fan motor and the fan rotates with speed according to the angle , the feedback signal decides that it's the wanted angle, a sketch for the system is shown in figure(1.1).

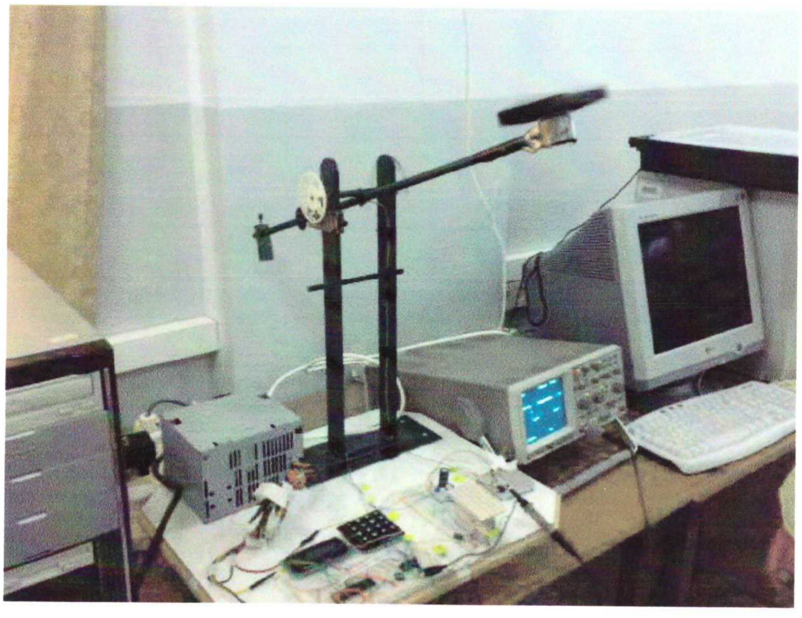


Figure (1.1) the real project photo

1.2 Project Goal

This project is very important to study controlling the rod altitude and rotation of the motor to control its height and response to any change in its position at variable altitude as result of wind speed, the integration of the rotation speed and the controlling elements of the fan is the essential to make it stable at any high.

But here the project in general has an educational goal; just to build an educational mechatronics system and control its response (the rotational speed and the height that must resulted from this control), and apply the mechanical and electrical design. The goal is to Design a mechatronics system; produce a successful design with power and electronic control feedback system. This project provides design with stable angle at stationary rod altitude.

1.3 Importance of the Project

The importance of the project is to build an educational system for studying control and mechatronics system, to study the fan dynamics, and to control the fan speed.

1.4 Elementary Components

The controlling of a rod angle using a fan system represents the integration of four basic subsystems, which are, the mechanical, electrical, control and computer, which are the four basic disciplines that make up mechatronics, as shown in figure (1.2).

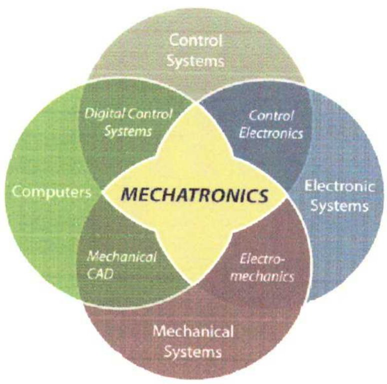


Figure (1.2) Mechatronics basic disciplines

1.5 Literature Review

The fan control was always an interesting field of study, thus there are many researches and projects that take the control of fan as the core of their studies using a wide variety of designs, software packages, and control techniques, number of these projects are in the flight field, like the "Autonomous Stabilization System for a Coaxial Helicopter"; the purpose of this project was the design of a fully autonomous stabilization system; intended for systems capable of intelligent programming and navigation [1] . Another projects are: Neural Network Learning Helicopter; this project was to design a two degree-of-freedom stationary helicopter, autonomously controlled by an evolving neural network [2], and Position control and attitude stabilization of a ducted fan VTOL UAV in crosswind; this paper describes a control strategy to stabilize the position of a Vertical Takeoff and Landing (VTOL) Unmanned Aerial Vehicle (UAV) in crosswind. [3].

Another field of projects is controlling the angle: one project which is a lever that uses a propeller to control its angle. The device consists of a lever with a DC-motor-driven propeller attached to one end. The angle of the lever is determined by an accelerometer-based PID (proportional-derivative-integral) feedback-controller. The accelerometer signal is fed into a Mega32 MCU (microcontroller unit) that the user interacts with, [4] and another project is The QNET-013 VTOL Actuator; The QNET-013 VTOL Actuator is a fundamental introduction to motion control using a fluid as the actuation medium, and into aerospace dynamics, kinematics and control. The system consists of one variable speed fan with safety guards, mounted on the end of a cantilevered arm. The fan and arm assembly pivot about an axis attached to an encoder shaft [5].

In the area of control of fan speed, there are many related studies like the "Centrifugal fan air control system"; which is a centrifugal fan provided with dampers driven by a motor having a speed control circuit. Air flows from the centrifugal fan is controlled from a point of maximum air flow to a predetermined crossover speed only by changing the velocity of the fan impeller with subsequent air flow control at air flow rates below said crossover speed being attained only by adjustment of the fan dampers [6], a velocity control system one is variable air curtain velocity control; a refrigeration system comprises a display case having an exterior and an interior. A fan blows or draws air across an evaporator coil to cool the display case. The air is blowing over a viewing area to create an air curtain .At least one sensor obtains environmental data, which is fed to a control unit .The control unit communicates with the fan and adjusts the air curtain based on the sensed environmental data [7] , And Another project is Fan control system using a microcontroller; A fan control system. The fan motor is operated normally at not greater than a preset maximum rotation speed. The fan control system has a programmable microcontroller to receive an input voltage and a rotation speed signal corresponding to the actual rotation speed of the fan motor [8].

Another kind of projects is real-time X-ray fan-beam z-axis position measurement; a precise control of fan-beam position is important to the production of highest quality CT images; failure to maintain fan-beam orientation can produce image artefacts. This paper describes a special technique which provides accurate real-time measurement of fan-beam z-axis position [9], And Variable Speed Drive Volumetric Tracking for Airflow control in Variable Air Volume Systems; Airflow control of VAV systems has been an important design and research subject, since the VAV system was first introduced. An airflow control method should: ensure the airflow to each space or zone; control outside air intake properly; and maintain a positive building pressure. Several methods have been developed to ensure air delivery to each space or zone. These methods include static pressure control and damper position control [10].

1.6 Principle of Work

In order to get a mechatronics system, two main parts should be integrated: electrical and mechanical structures, these two parts controlled with a controller, in this project a microcontroller going to be used. Referring to the mechanical part, the implemented parts are fan connected at one end of a rod (metallic rod), the rod is jointed at the middle via hinge with a vertical column (the beam must be initially balanced). When talking about the electrical parts, the microcontroller must be mentioned first, and then the keypad, which used to inter the command (the intended angle), the feedback signal could be velocity or position feedback and already the wirings to transport the signals.

1.7 Project Schedules

Table1.1 Project time-schedule for first semester

Process	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Selection of project															
Data collection															
Introduction & Background															
Mechanical Design and theory															
Writing Documentation															

Table 1.2 Project time-schedule for the second semester

Process	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
System transfer function															
Simulation															
Controller design															
Simulation															
Implementation of Design															
Programming of microcontroller															
Testing & experimentation															
Result & Conclusion															
Writing															
Final Edition of Project															

1.8 Project Budget

This budget includes the price of the component which was sold, and also includes printing costs and local study and survey. The table below (1.3) shows the estimated cost of each one.

Table1.3 Project budget

Component	Num.	Cost(NIS)
Fan	3	60
Microcontroller	2	120
Keypad+drivers	1	150
Electrical components		200
LCD	1	40
Sensor	1	60
Shaping (turning, welding …etc)		300
Tools		120
Mechanical Parts (bearings, gears …etc)		250
Transportations		300
Documentation	1	600
Total	———	**2200**

1.9 Report Content

This chapter presents the general idea of the project and its importance, in addition the field of application also, in addition conduct the literature review of the previous studies about this project, this chapter also includes the time plan for all the project activities, the tools, equipments, materials that are used in the project, and finally the total cost.

Chapter Two will discuss: the fan work principle, fan components, blade components, lifting force, drag force, stalling phenomena and the static pressure.

Then in Chapter Three the mechanical design will be described, equations and drawings described also, shape of the project showed as drawings using CATIA program.

Theory and mathematical modelling, also the block diagram of the system, then the derivate of the system equations and transfer function will be found in Chapter four.

Chapter five will describe designing the controller and finding the root locus and the transient response behaviour of the open loop and closed loop system. Digitizing the controller will be described also.

In Chapter Six we will describe the electrical and control design and electrical component that will we use in our project , microcontroller connection and keypad and the liquid crystal display and how to connect it with the microcontroller.

The Conclusion and Results will be discussed in Chapter Seven, also some problems and recommendations would be talked about in a glance.

Chapter Two

Fan Work Principle

Contents:

2.1 What Is Fan?

A fan is simply a machine for moving air and other by means of a rotating impeller using centrifugal or propeller action, or both. There are four main types of fan used for general ventilation work: centrifugal, propeller, mixed flow and axial flow. We use the axial flow fan in going to be used as this project [11].

The Fan consists of two or more blades connected together by a hub, and increasing the number of blade will increase the lifting force. Hub serves to attach the blades to the engine or motor shaft [12], as shown in figure (2.2).

Figure (2.1) General fan shape

2.2 The Fan Components

A fan consist of a hub, blades, motor or engine to drive the fan (in this project an electrical motor will be used), may be an outlet or inlet vanes are used for some application to increase the efficiency of the fan; by making an axial stream line, and maybe a venture inlet can be used also in order to increase the efficiency of the fan by increasing the volumetric flow.

2.3 Blade components

The blade is the most critical component in the fan; since the majority of the parameters of the fan depend on the blades design, such as the angle of attack, drag force, lift force .... etc, the blade could be an air foil shape or a single thickness sheet, according to the application and the efficiency needed.

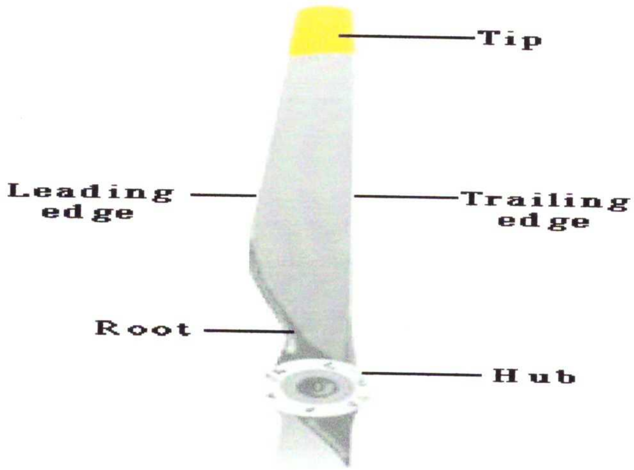


Figure (2.2) Blade components

Components of blade are, Leading Edge of the airfoil is the cutting edge that slices into the air. As the leading edge cuts the air, air flows over the blade face and the camber side. As shown in figure (2.2), Blade Tip is the outer end of the blade farthest from the hub, Blade Shank (Root) is the section of the blade nearest the hub, Blade Face is the surface of the propeller blade that corresponds to the lower surface of an airfoil, Thrust Face is the curved surface of the airfoil, Plane of Rotation is an imaginary plane perpendicular to the shaft. It is the plane that contains the circle in which the blades rotate; Blade Angle is formed between the face of an element and the plane of rotation. The blade angle throughout the length of the blade is not the same. The reason for placing the blade element sections at different angles is because the various sections of the blade travel at different speed. Each element must be designed as part of the blade to operate at its own best angle of attack to create thrust when revolving at its best design speed [13].

The chord line is an imaginary line drawn through the blade from its leading edge to its trailing edge as shown in figure (2.3). As in a wing, the leading edge is the thick edge of the blade that meets the air as the propeller rotates.

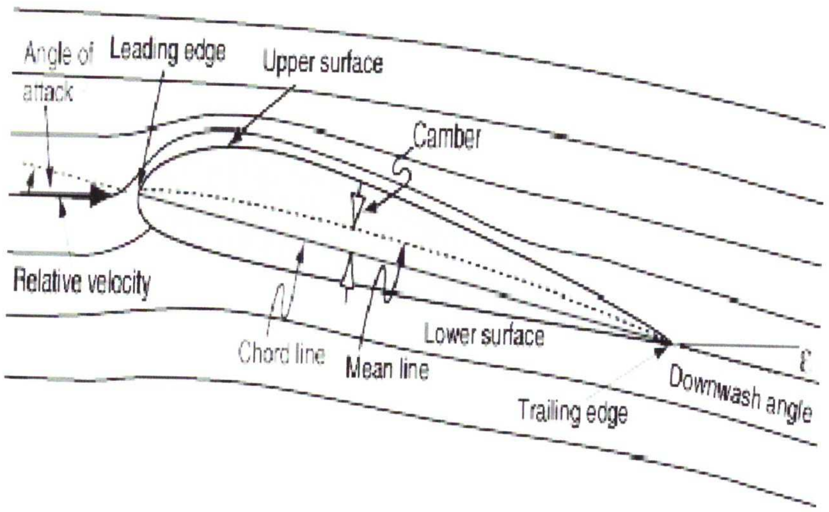


Figure (2.3) Airfoil shape

2.4 Angle of Attack

Angle of Attack is the angle between the chord of the element and the relative wind as in figure (2.4). The best efficiency of the propeller is obtained at an angle of attack around 2 to 4 degrees [14]. Angle of attack is one of the most fundamental and important quantities in aerodynamics, if not the most important. Other values like lift and drag depend on angle of attack as figure (2.5) shows [15].

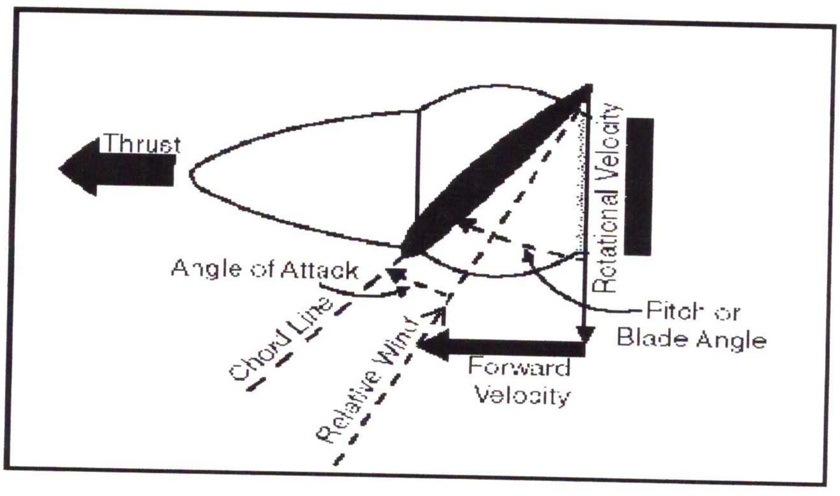


Figure (2.4) Thrust in aircraft fan

One of the prime factors that determine the amount of lift and drag produced by an airfoil is the angle of attack. The chord line in a simple airfoil can be considered to be the line drawn between the leading edge of the airfoil and its trailing edge. A symmetrical airfoil is the same shape on each side of the chord line, whereas an asymmetrical airfoil is not. In modern aircraft the airfoil thickness and shape (cross-section) changes between the fuselage and the wingtip [16].

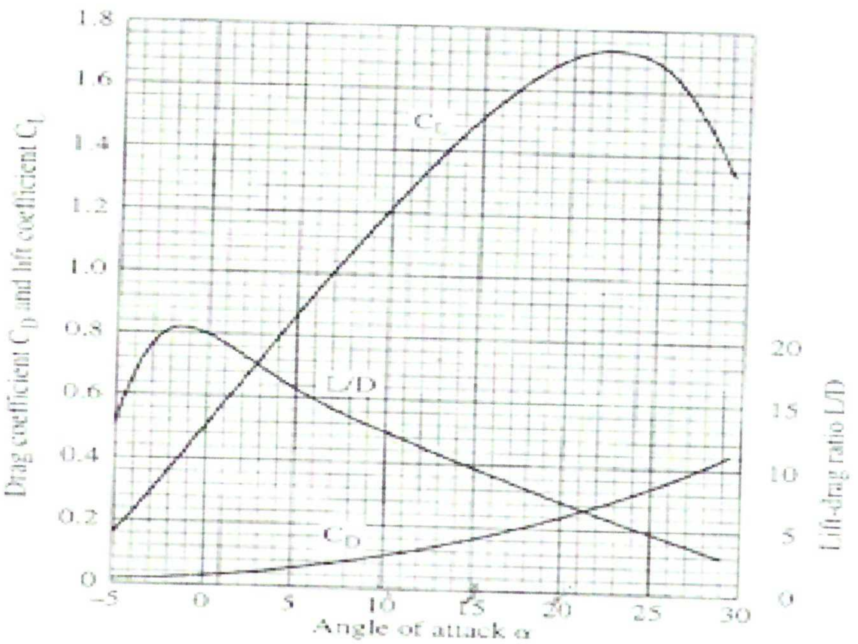


Figure (2.5) Characteristic carve for fan airfoil

2.5 Lifting force

Lift force is produced by the static pressure; as lower pressure created on the upper surface of blade compared to the pressure on the blade lower surfaces, causing the fan to be lifted upward. The special shape of the airfoil is designed so that air flowing over it will have to travel a greater distance and faster resulting in a lower pressure area thus lifting the fan upward. In some applications lift is that force which opposes the force of gravity (or weight). Lift force depends upon shape of the airfoil; the angle of attack which is already the lift coefficient depends on, the area of the surface exposed to the air stream, the square of the air speed [17].

$$L = C_L * A * V^2 / 844 \quad (2.1)$$

Where: L is the Lift force, C_L is the lift coefficient, V is the velocity of air and A is the blade area [17]. Figure (2.5) shows the characteristic carve between the angle of attack and the lift coefficient.

2.6 Drag force

The drag (D) is the resistance to the forward motion of the airfoil. It is the Undesirable, power-consuming component. When an object experiences drag forces then some of its kinetic energy will be converted ("dissipated") to heat. This is why certain airplanes and rockets must be designed to withstand significant thermal stresses [18]

$$D = C_D * A * V^2 / 844 \quad (2.2)$$

Where: D is the drag force, C_D is the drag coefficient, V is the velocity of air and A is the blade area [18].

The drag coefficient depends on the airfoil shape of the blade as we can see in figure (2.6):

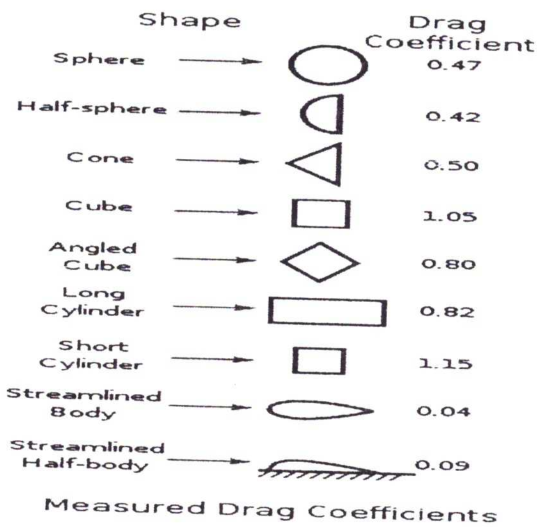


Figure (2.6) Drag coefficient and airfoil shape

Then, equation (2.3) becomes:

$$SP = K'\omega^2 \tag{2.7}$$

So:

$$\frac{SP_1}{SP_0} = \frac{K'\omega_1^2}{K'\omega_0^2} \tag{2.8}$$

Finally; the pressures vary as the square of the speed is given by the following equation:

$$\frac{SP_1}{SP_0} = \left(\frac{\omega_1}{\omega_0}\right)^2 \tag{2.9}$$

Sp1 static pressure of the fan, ω_1 angular velocity of the rotating blade, ω_0 nominal angular velocity of the rotating blade, Sp nominal static pressure of the fan [17].

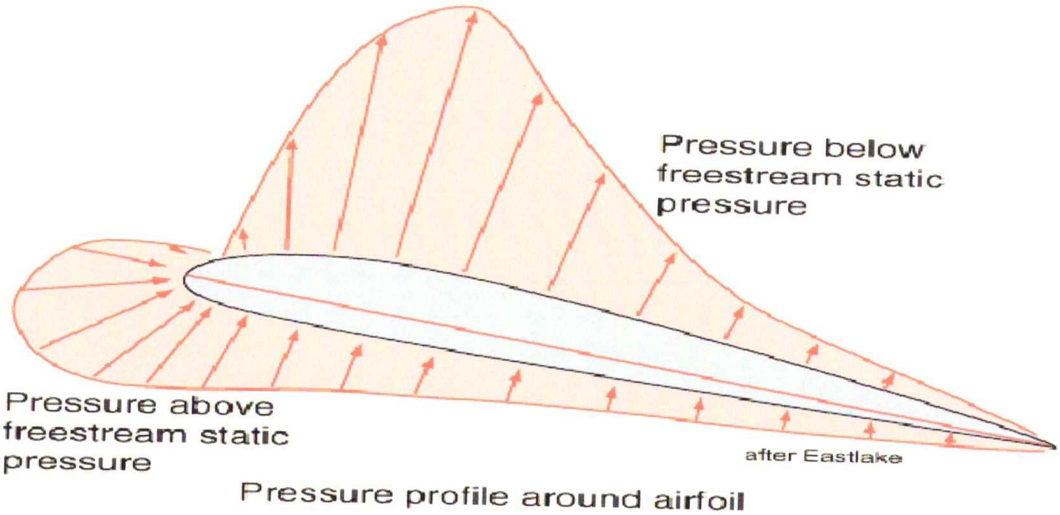


Figure (2.7) Pressure around the airfoil

Chapter Three

Mechanical Design

Contents:

3.1 General Preview

When talking about mechanical design an important thing must be mentioned first is the stress and strain calculations, but in this project these calculations not assumed since the project is simply doesn't have high loads and no high stress or high strain at this one.

Another important thing should be talked about is movements correspond to each part, friction, and normal forces on that part. In the following section all parts going to be described.

The third important thing is shaping of the project, that means the construction of the project must by good looking, but in the contrary, the shaping and the construction of the project must keep the parts to move, rotate, and translate freely without any obstacles, so the best shape design has chosen and it appear in the three dimensions (3D) views of all the parts.

3.2 Parts of the Project

3.2.1 The Base

The base is metallic figure (3.1), one of the main function of it is to hold the other parts to stay rigid and to combine parts with each other (the legs of the project), of course the base must be strong enough in order hold other parts; so the base must be deal with the weight of all that parts which transported by the column.

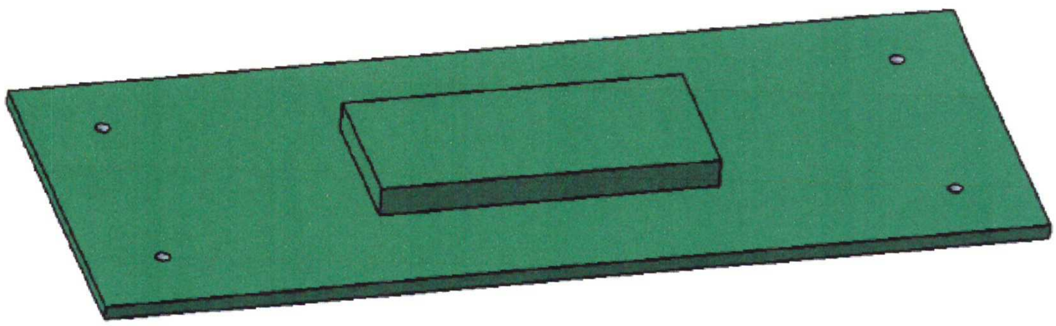


Figure (3.1) Metallic base

3.2.2 The Columns

The columns is also metallic, the main function of the tow columns is to hold the two bearings and to hold the potentiometer which used as sensor for the feedback signal.

Also the columns hold another part which is the screw as shown in figure (3.2), which used to manipulate the upper distance between the columns in order to get the appropriate position. Each bearing affect on the leg by tow forces vertical force and horizontal force but this force is not so big to be considered in our calculations. The legs are combined with the base by welding (CO_2 welding).

Figure (3.2) Columns

3.2.3 The Bearings

Bearings as shown in figure (3.3) hold the movable joint in order to keep smooth rotation without friction, the movable joint affect on each bearing by tow forces vertical and horizontal force already no internal friction in these bearings.

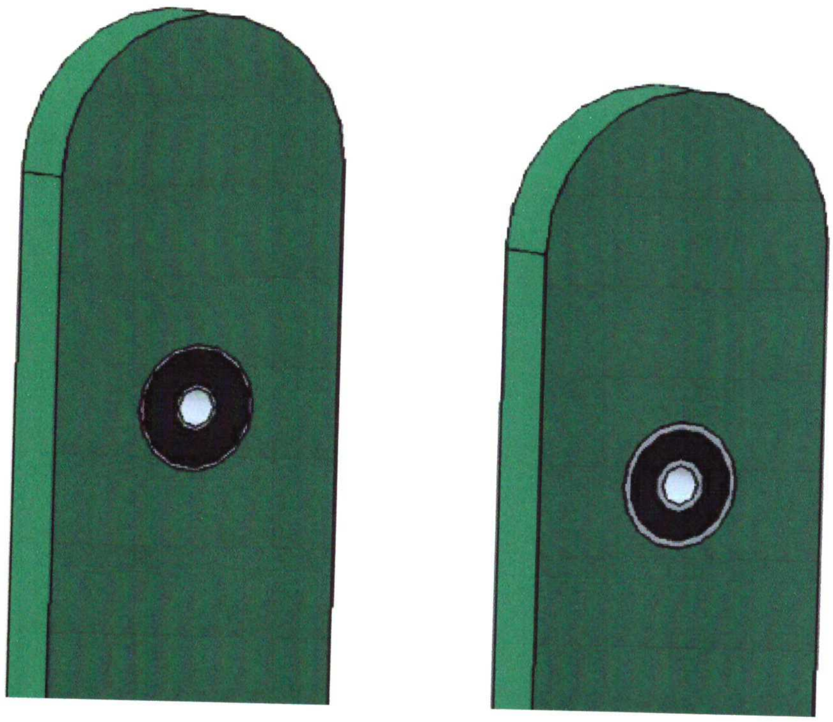


Figure (3.3) Bearings

3.2.4 The Movable joint

The movable joint is a small rod fixed between the two bearings as shown in figure (3.4). At the middle of the movable joint there is a fixed rod, and at one end of the movable joint there is a gear.

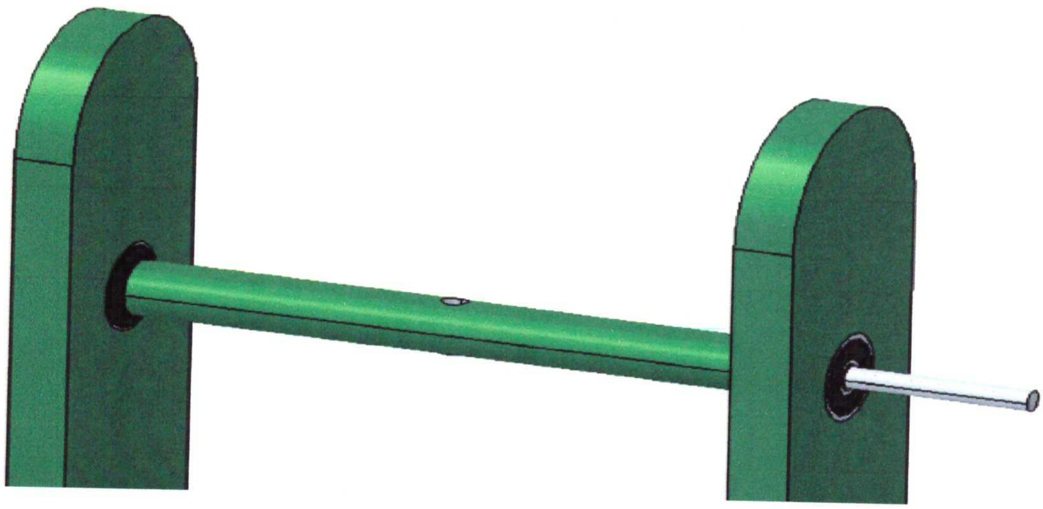


Figure (3.4) Movable joint

3.2.5 The Rod

The rod is fixed at the middle of the movable joint as shown in figure (3.5), at one end of that rode there is a fan and on the other side of this rode there is a balancing metallic piece, this metallic piece is used to balance the rod and to keep it horizontally equilibrium.

The rod configured with the movable joint via screw, the force on this screw is not big in order to be considered in the calculations.

Figure (3.5) The rod

3.2.6 Balancing Weight

The balancing weight is not fixed , so we can make any change in its position along the rode , this piece as shown in figure (3.6) has parallelogram shape drilled in order to enter the rode through it, and a screw is attached to that piece in order to tight it exactly at the wanted position on the rod .

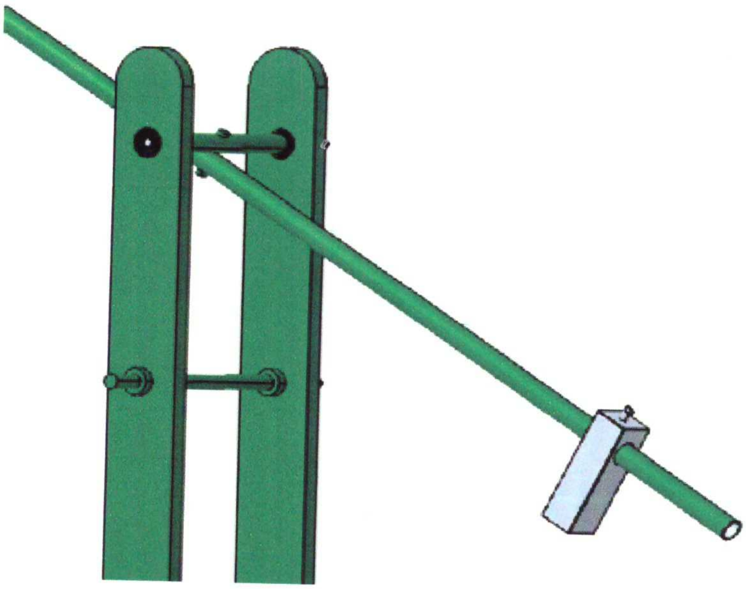


Figure (3.6) Balancing weight

3.2.7 The Fan

Since no fan with DC motor found, a fan blades attached to a 9v dc motor with no-load rotational speed 2400 rpm, so we can apply DC motor modeling control equations, the DC motor tightened with a flexible metallic sheet and this sheet linked with the end of the rod by a screw which penetrate it and pass a hole at the end of the rod as shown in figure (3.7), The blades and the hub of the fan connected with the axis of the motor at the centre of the hub by interference.

Here when the fan moved by a defined speed and stopped again the rod will back immediately to the equilibrium position.

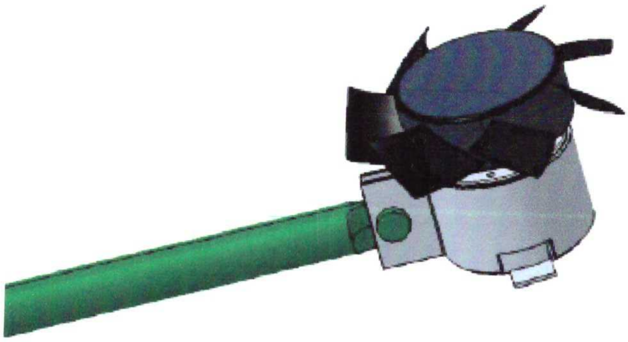


Figure (3.7) The fan

3.2.8 The Gears

Gears are used here in order to detect the feed back signal and magnificat it to make the project more precisely, the biggest number of teeth is used at the end of the movable joint and the gear with the smallest diameter and least number of teeth is used on the potentiometer as shown in figure (3.8), this makes any slight displacement on the rod reflected to the joint and then magnificated and sensed by potentiometer via engaging the gear teeth.

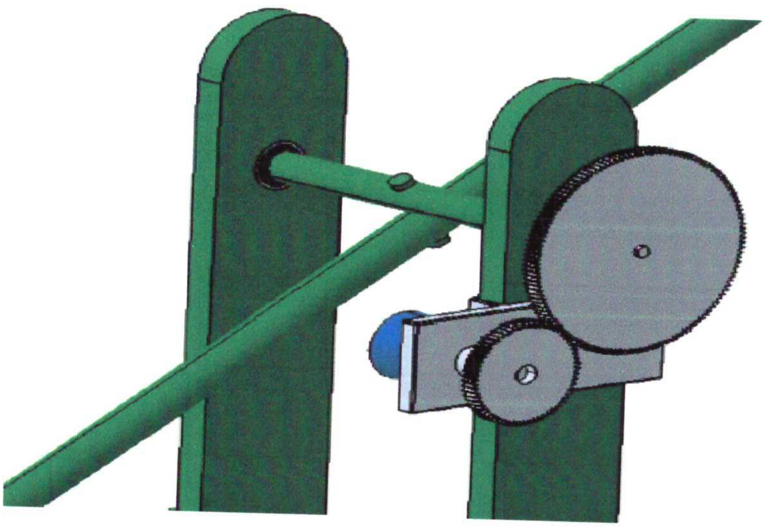


Figure (3.8) Gears

Each one of the gears connected by interference with the other parts, but not hard interference since the force isn't too big between the two gears, the first gear has 132 teeth and the second gear has 64 teeth the magnitification factor of the feedback signal will be approximately the double.

Gear Ratio: is the ratio between the number of teeth or the radius of the big gear to the number of teeth or the radius of the small gear, so

$$\frac{r_1}{r_2} = \frac{N_1}{N_2} = \frac{132}{64} = 2.0625 \cong 2 \qquad (3.1)$$

Where N_1 and N_2 are the number of teeth of the big and small gears respectively.

Magnification ratio: the square of the gear ratio, this ratio magnificates the transported torque value, so

$$\left(\frac{r_1}{r_2}\right)^2 = \left(\frac{N_1}{N_2}\right)^2 = 4.254 \qquad (3.2)$$

3.2.9 The Potentiometer base

The potentiometer is fixed by its screw which is located on its column axis, this screw tightened on metallic sheet and this metallic sheet joined with one of the columns by using also a screw as shown in figure (3.9).

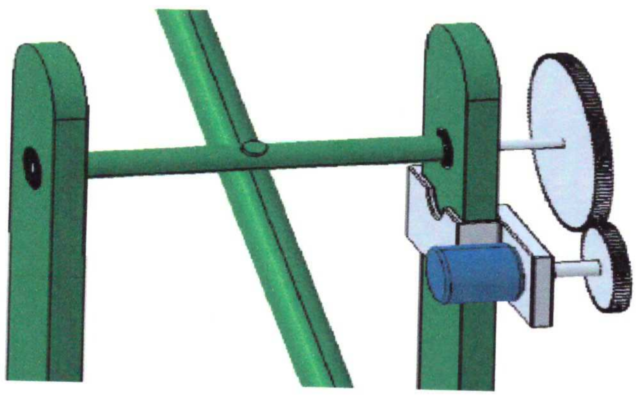


Figure (3.9) The potentiometer base

The whole project 3D view is shown in figure (3.10), its parts drew using the part design in CATIA program and then that parts assembled using the assembly design using the same program (all dimensions of the project parts are in appendix D).

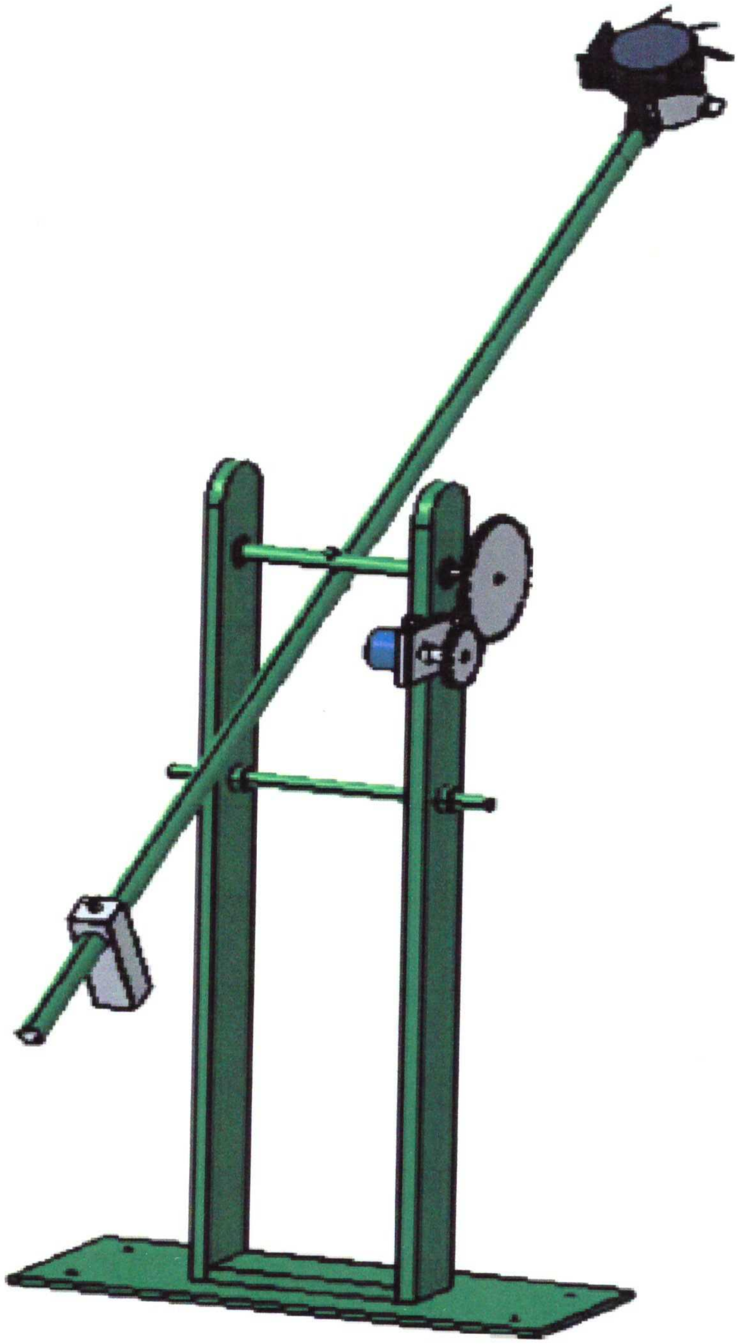


Figure (3.10) Project 3D view

Chapter Four

Theory and Mathematical Model

Contents:

4.1 Introduction

Theory and equations are an important section of the project, since the project is based on principles and assumptions that generalized to mathematical model; this mathematical model has the core of the project which the practical work depends on. The mathematical model of the project contains inputs, outputs, block diagram which relate inputs to output as a transfer function, and linearization of nonlinear equations in the block diagram.

4.2 Equations and Derivations

The block diagram as the figure (4.1) shows, has an input which is voltage input it can be taken from a potentiometer, keyboard, or from a keypad, this voltage converted to current as the following equation shows:

$$I_a = \frac{V_a - \omega K_b}{R_a} \qquad (4.1)$$

Where: I_a is the armature current, V_a is the input voltage , ω is a motor angular velocity (rad / s) , K_b is the back emf constant (dimensionless) and Ra is the armature resistance of the motor (Ω) [20].

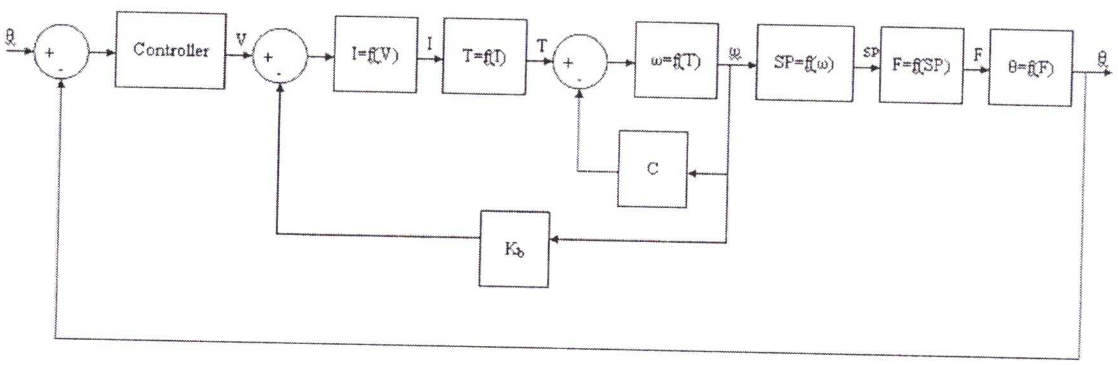


Figure (4.1) Project Block diagram

This current is directly depends on the motor torque as the relation

$$T_m = K_t I_a \qquad (4.2)$$

Where: T_m is the motor output torque (N.m) and K_t is the motor torque constant (dimensionless) [20].

Then, the motor torque related with the angular velocity of the motor as the following:

$$\dot{\omega} = \frac{T_m - T_d}{J_1} \tag{4.3}$$

Where: $\dot{\omega}$ the angular acceleration of the motor (rad/s^2), T_d is the torque delivered due to drag force (N.m) and J_1 is the moment of inertia of the fan blades (Kg/m^2) [21].

But equation (4.3) should be integrated as follows:

$$\omega = \frac{1}{J_1}\int_0^t (Tm - T_d)dt \tag{4.4}$$

With distribution property the equation will be:

$$\omega = \int_0^t \frac{T_m(t)}{J_1}dt - \int_0^t \frac{T_d}{J_1}dt \tag{4.5}$$

Note, the torque due to drag is:

$$T_d = \int_0^R F_d dr \tag{4.6}$$

R is the radius of the fan blade (m).

But the drag force is related with the area and velocity as:

$$F_d = \frac{AV^2 C_d}{844} \tag{4.7}$$

Where: F_d is the drag force (N),dr is the change in radius of the fan blade (m), A the area of the blade (m^2), V the relative velocity of the air (m/s) and C_d drag coefficient (dimensionless) [17].

Note coefficient of drag is a function of angle of attack:

$$c_d = b\alpha^2 \tag{4.8}$$

Where: b is a constant and a is the angle of attack (deg)

Also the angle of attack is function of radius:

$$\alpha = cr \tag{4.9}$$

Where: c is constant

Then, the coefficient of drag will be:

$$C_d = b(c * r)^2 \tag{4.10}$$

Let:

$$b * c^2 = a \tag{4.11}$$

Then

$$C_d = ar^2 \tag{4.12}$$

But A is variable and depends on the width and the radius of the blade as follows:

$$dA = W\, dr \tag{4.13}$$

Where: dA: change in the blade area and W: width of the blade (m)

Note that the relative velocity can be converted to an angular one, then:

$$V = \omega r \text{ [22]} \tag{4.14}$$

Then:

$$V^2 = \omega^2 r^2 \tag{4.15}$$

Where: ω is the angular velocity of the blade (rad/s)

Referring to equation (4.7) and integrating it, then:

$$F_d = \int_o^R \frac{dAV^2 C_d}{844} \tag{4.16}$$

Substituting equations (4.12), (4.13) and (4.15) in equation (4.16), then:

$$F_d = \int_o^R \frac{W\omega^2 ar^4}{844} dr \tag{4.17}$$

$$F_d = \frac{W\omega^2 ar^5}{(5)(844)}\Bigg|_0^R \tag{4.18}$$

$$F_d = \frac{W\omega^2 aR^5}{(5)(844)} \tag{4.19}$$

Return to equation (4.6) then:

$$T_d = \int_o^R \frac{W\omega^2 ar^5}{(5)(844)} dr \tag{4.20}$$

$$T_d = \frac{W\omega^2 aR^6}{(5)(6)(844)} dr \tag{4.21}$$

Substituting equation (4.21) in equation (4.5), then:

$$\omega = \int_0^t \frac{T_m(t)}{J_1} - \int_0^t \frac{W\omega^2(t) aR^6}{J_1(25320)} dt \tag{4.22}$$

Where: $\dot{\theta}(t)$: the derivative of the angle (angular velocity) (rad/s).

This angular velocity related to the static pressure as:

$$SP = \frac{SP_0}{\omega_0^2}\omega^2 \tag{4.23}$$

Where: SP: static pressure made by fans (N/m^2), SP_0 is the static pressure at the angular velocity of the fan ω_0;

The static pressure is given by the equation:

$$F_L = SP.A \tag{4.24}$$

Where F_L: lift force due the static pressure (N) and A is the area of the fan wheel (m^2) [23].

Then, the output angle should be measured, the output angle is made by the lift force, so, an equation between the angle and the force should be found.

As expressed, when applying the moment about the point O, then:

$$\sum M_0 = J_2\ddot{\theta} \tag{4.25}$$

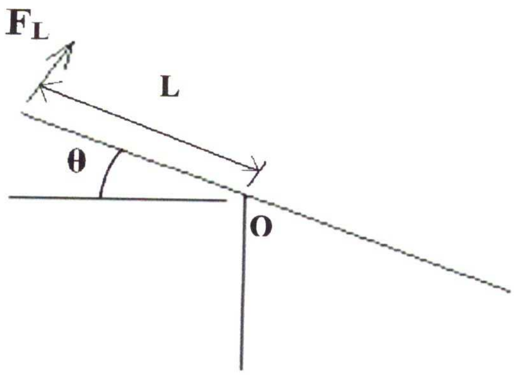


Figure (4.2) Moment Around O

Where: M_o : the moment about the origin O (N.m) figure (4.2), $\ddot{\theta}$: the second derivative of the angle (rad/s^2) and J_2: is the moment of inertia of the rod (Kg.m^2) [24].

But the moment equation is:

$$M_o = F_L L \tag{4.26}$$

Where: F_L: the applying force (N) and L is the distance between the point of the applied force and the origin (m) [24].

Then the moment will be:

$$F_L L = J_2\ddot{\theta} \tag{4.27}$$

$$\ddot{\theta} = \frac{L}{J_2}F_L \tag{4.28}$$

$$\theta = \iint \frac{LF_L}{J_2}dt \tag{4.29}$$

$$\theta = \frac{LF_L}{J_2}t^2 \tag{4.30}$$

Finally, this angle will be converted to voltage and entered to a summing point in order to detect the error (Feedback Signal) and eliminate this error.

4.3 Transfer function

In this section we will calculate the transfer function for each block depending on figure (4.1)

1- $T_m(t) = K_t I_a(t)$ (4.31)

Converting to the s domain:

$$T_m(s) = K_t I_a(s) \tag{4.32}$$

A transfer function of equation (4.32) is:

$$\frac{T_m(s)}{I_a(s)} = K_t \tag{4.33}$$

2- $\dot{\omega}(t) = \dfrac{T_m(t) - T_d(t)}{J_1}$ (4.34)

Refer to equation (4.21) and let

$$K = \frac{WaR^6}{(5)(6)(844)} \tag{4.35}$$

Equation (4.21) becomes:

$$T_d(t) = K\omega^2(t) \tag{4.36}$$

Equation (4.36) is a non linear equation since contain $\omega^2(t)$ so must be converting to a linear equation by using the following equation [20]:

$$f(\omega) = f(\omega_0) + \frac{dt}{d\omega}\Big|_{\omega=\omega_0}(\omega - \omega_0) \tag{4.37}$$

$$f(\omega) = \omega_0^2 + 2\omega_0(\omega - \omega_0) \tag{4.38}$$

$$f(\omega) = 2\omega_0\omega - \omega_0^2 \tag{4.39}$$

Equation (4.36) becomes:

$$T_d(t) = 2K\omega_0\omega(t) - K\omega_0^2 \tag{4.40}$$

Let: $K_1 = 2K\omega_0$ (4.41a)

$K_2 = K\omega_0^2$ (4.41b)

Now, equation (4.40) becomes:

$$T_d(t) = K_1\omega(t) - K_2 \tag{4.42}$$

Substituting equation (4.42) in equation (4.34), then:

$$\dot{\omega}(t) = \frac{T_m(t) - K_1\omega(t) + K_2}{J_1} \tag{4.43}$$

Derivative equation (4.43) to remove a constant K_2:

$$\ddot{\omega}(t) = \frac{\dot{T}_m(t) - K_1\dot{\omega}(t)}{J_1} \tag{4.44}$$

Converting to the s domain:

$$s^2\omega(s) = \frac{sT_m(s) - K_1 s\omega(s)}{J_1} \tag{4.45}$$

$$(J_1 s^2 + K_1 s)\omega(s) = sT_m(s) \tag{4.46}$$

A transfer function of equation (4.46) is:

$$\frac{\omega(s)}{T_m(s)} = \frac{1}{J_1 s + K_1} \tag{4.47}$$

Now: finding the transfer function to equation (4.48):

3- $SP(t) = K'\omega^2(t)$ (4.48)

Equation (4.48) is a non linear equation since contain $\omega^2(t)$ so should be converting to a linear equation by using equation (4.37), then equation (4.48) becomes:

$$SP(t) = K_3\omega(t) - K_4 \tag{4.49}$$

Where: $K_3 = 2K'\omega_0$ (4.50a)

$K_4 = K'\omega_0^2$ (4.50b)

And $K^{/}$ was defined in equation (2.4)

Derivative of equation (4.49):

$$S\dot{P}(t) = K_3\dot{\omega}(t) \tag{4.51}$$

Converting to the s domain:

$$sSP(s) = K_3 s\omega(s) \tag{4.52}$$

A transfer function of equation (4.52) is:

$$\frac{SP(s)}{\omega(s)} = K_3 \tag{4.53}$$

In the next step we will calculate the transfer function of equation (4.54):

4- $F(t) = SP(t).A$ (4.54)

Converting to the s domain:

$$F(s) = SP(s).A \tag{4.55}$$

A transfer function of equation (4.55) is:

$$\frac{F(s)}{SP(s)} = A \tag{4.56}$$

The transfer function of equation (4.29) will calculate as follow:

5- $\theta(t) = \iint \frac{L_1 F(t)}{J_2} d(t)$ (4.57)

So:

$$\ddot{\theta}(t) = \frac{L_1}{J_2} F(t) \tag{4.58}$$

Converting to the s domain:

$$s^2\theta(s) = \frac{L_1}{J_2} F(s) \tag{4.59}$$

A transfer function of equation (4.59) is:

$$\frac{\theta(s)}{F(s)} = \frac{L_1}{J_2 s^2} \qquad (4.60)$$

The following equation shows the relationship between the Ia(t) , Va(t) and ω(t) and the transfer function will appear between ω(s) and Va(s) as follows

$$6\text{-}\ I_a(t) = \frac{V_a(t) - K_b \omega(t)}{R_a} \qquad (4.61)$$

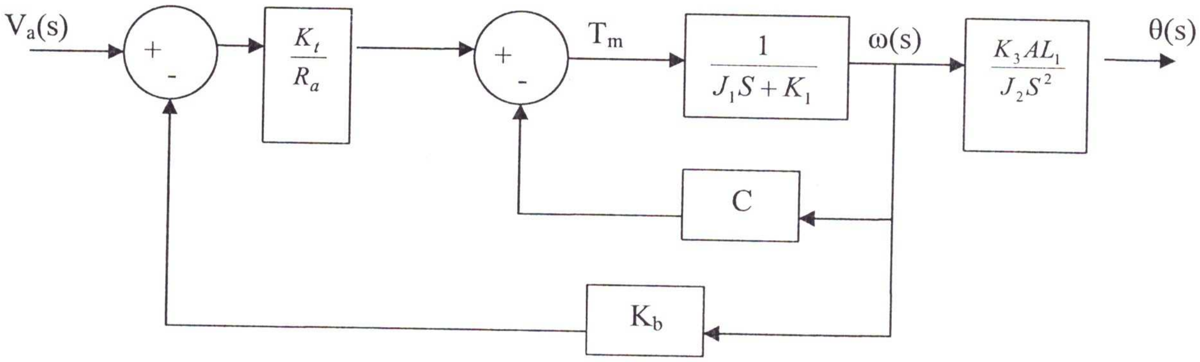


Figure (4.3) Transfer Function Between ω(s) and Va(s)

The constant C has found by the relation $T = C\omega$, by taking some readings of the speed corresponds to the current ,the torque then has found by applying equation (4.2), and after that the speed readings plotted with the torque values which found, and the constant C found to be 0.0003945

From Figure (4.3) and letting G_0 to be

$$G_0(s) = \frac{1}{J_1 S + K_1} \qquad (4.62)$$

Applying a loop to find G1, then

$$G_1(s) = \frac{\omega}{T_m} = \frac{G_0(s)}{1 + CG_0(s)} \quad [20] \qquad (4.63)$$

So,

$$G_1(s) = \frac{1}{J_1 S + K_1 + C} \qquad (4.64)$$

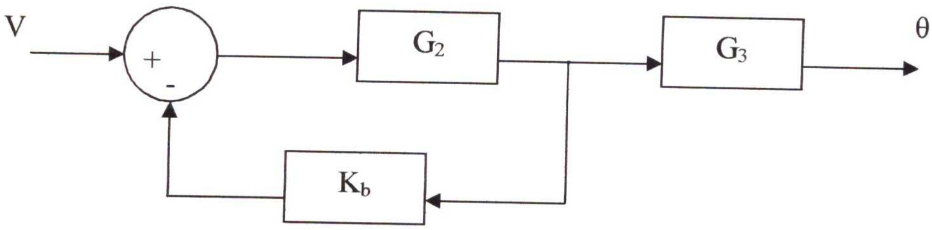


Figure (4.4) G_2 and G_3 Block Diagram

As in figure (4.3) G_2 and G_3 are:

$$G_2(s) = \frac{K_t}{R_a} G_1(s) \tag{4.65}$$

$$G_3(s) = \frac{K_3 AL_1}{J_2 S^2} \tag{4.66}$$

By feed back law and depending on figure (4.4), then

$$G_2'(s) = \frac{G_2(s)}{1 + K_b G_2(s)} \tag{4.67}$$

Substituting value of G2

$$G_2'(s) = \frac{K_t}{R_a J_1 S + R_a K_1 + R_a C + K_b K_t} \tag{4.68}$$

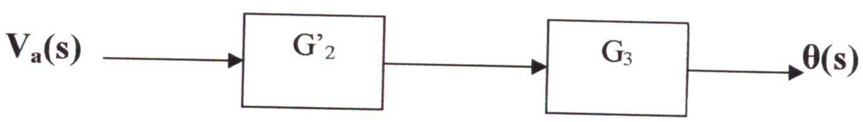


Figure (4.5) Transfer Function of the Open Loop System

Figure (4.5) used to find the transfer function $\left(\frac{\theta(s)}{V_a(s)}\right)$ for the open loop system, so

$$\frac{\theta(s)}{V_a(s)} = G_2'(s) G_3(s) \tag{4.69}$$

Substituting equations (4.66) and (4.68) in equation (4.69), then G(s) as in figure (4.6) will be

$$G(s) = \frac{K_3 K_t A L_1 / J_2}{S^2 (R_a J_1 S + R_a K_1 + R_a C + K_b K_t)} \qquad (4.70)$$

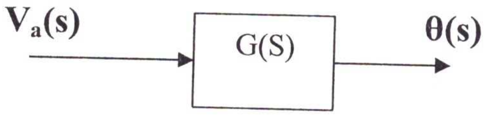


Figure (4.6) Open Loop Block Diagram

Let K_5, K_6 and K_7 to be:

$$K_5 = \frac{K_3 K_t A L_1}{J_2} \qquad (4.71)$$

$$K_6 = R_a K_1 + R_a C + K_b Kt \qquad (4.72)$$

$$K_7 = R_a J_1 \qquad (4.73)$$

Then the new transfer function as figure (4.7) shows is

$$G(s) = \frac{K_5}{S^2 (K_7 S + K_6)} \qquad (4.74)$$

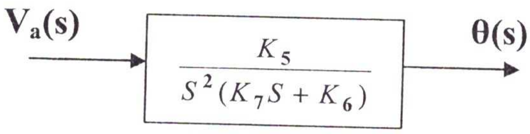


Figure (4.7) System Transfer Function

To find values of K_5, K_6 and K_7 a several constants should be measured and calculated as follows:

At V=9 the armature current measured is 0.52A and n= 1425 rpm, with an armature resistance Ra=8.5 Ω.

To get value of Kb, the speed must be in radians per second, so

$$\omega = \frac{2\pi n}{60} = 149.22\ rad/s \quad [21] \tag{4.75}$$

Referring to equation (4.1) and applying the current, voltage, and rotational speed, then, the motor constant will be

$$K_b = 0.0307 \tag{4.76}$$

In order to find the current-torque constant equation (4.2) must be recalled

$$T_m = K_t I_a \tag{4.77}$$

But 1st, the torque should be found, so, the power calculation is used here as

$$P_{in} = \frac{P_{out}}{\eta} \tag{4.78}$$

Where Pin is the motor input electrical power, Pout is the motor power mechanical output power, and η is the efficiency of the motor [21].

When putting the power values, equation (4.75) will be

$$V_a I_a = \frac{T_m \omega}{\eta} \quad [21] \tag{4.79}$$

Assuming a value for the efficiency $\eta = 0.85$, then the torque will be

$$T_m = 0.0267\ N.m \tag{4.80}$$

Referring to equation and putting the torque value, the constant value is

$$K_t = 0.051 \tag{4.81}$$

By revising vibration equations, the moment of inertia of the fan blades could be found by the formula

$$J_1 = \sum m_i r_i^2 + J_d \tag{4.82}$$

Where (depending on figure (4.8)) mi as shown at the figure is the blade mass, ri is the distance between the center of mass of the blade and the center of mass of the fan, and Jd is the moment of inertia of the fan hub [22].

Then equation (4.82) will be

$$J_1 = 7m_i r_i + \frac{1}{2}mR^2 \tag{4.83}$$

Where m is the mass of the fan hub and R is the radius of the fan hub [22].

By substituting all known values, equation (4.83) will give J_1 value as

$$J_1 = 2.9 * 10^{-5}\ Kg.m^2 \tag{4.84}$$

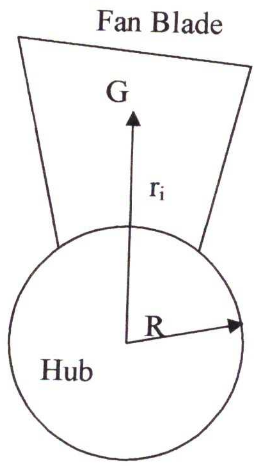


Figure (4.8) Moment of Inertia of the Fan Blades

The moment of inertia of the rod can be found as seen in figure (4.9) by

$$J_2 = \frac{1}{2}mr^2 + \frac{1}{12}mL^2 + m_3 d_1^2 + m_2 d_2^2 \tag{4.85}$$

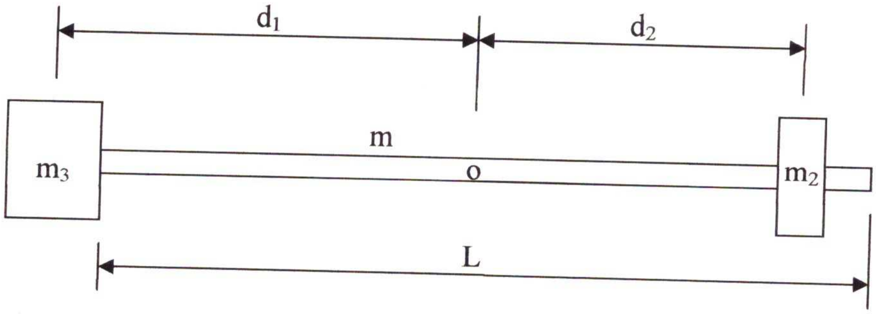


Figure (4.9) Moment of Inertia of the Rod

Where m is the mass of the rod, r is the inner radius of the hollow rod, L the rod length, m_2 is the mass of the balancing metallic piece, m_3 is the mass of the motor and the fan, d_1 is the distance between the centre of mass of the rod and the centre of mass of the motor, and d_2 is the distance between the centre of mass of the rod and the centre of mass of the metallic weight [22].

Then the value of J_2 is

$$J_2 = 41.5 * 10^{-3} Kg.m^2 \qquad (4.86)$$

The area of the fan wheel is given by

$$A = r^2 \pi \quad [23] \qquad (4.87)$$

Then the value of this area is

$$A = 0.00985 \ m^2 \qquad (4.88)$$

Rearranging equation (4.36) to find K value, the equation has been

$$K = \frac{T_d}{\omega^2} \qquad (4.89)$$

Then the value of K will be

$$K = 1.2 * 10^{-6} \qquad (4.90)$$

Back to equation (4.41a) to find K_1 value, then the value of K_1 becomes

$$K_1 = 358.128 * 10^{-6} \qquad (4.91)$$

Getting back to equation (4.54) in order to get the static pressure value

$$SP_0 = \frac{F_1}{A} \tag{4.92}$$

But F_2 was measured via a balance as a mass so,

$$F_2 = mg \quad [23] \tag{4.93}$$

Then the value of F_2 in Newton's is

$$F_2 = 0.2698\ N \tag{4.94}$$

In order to get the value of F_1 the moment of inertia about the pin has been taken

$$\sum M_0 = 0 \tag{4.95}$$

Then this formula will be

$$F_1 L_1 - F_2 L_2 = 0 \tag{4.96}$$

Then, value of F_1 become

$$F_1 = 0.2278\ N \tag{4.97}$$

Then the static pressure at the nominal speed will be

$$SP_0 = 23.127\ Pa \tag{4.98}$$

Substituting this value in equation (4.48) to get value of K', then the value of K' is

$$K' = 1.04 * 10^{-3} \tag{4.99}$$

Using equation (4.50a) to find the value of K_3, so the value of K_3 become

$$K_3 = 0.3104 \tag{4.100}$$

Looking for value of K_5 using equation (4.71), then the value of K_5 is

$$K_5 = 1.447 * 10^{-3} \tag{4.101}$$

Referring to equation (4.72) to get value of K_6, And K_6 then will be

$$K_6 = 125.645 * 10^{-5} \tag{4.102}$$

Seeking for value of K_7 by using equation (4.73), then K_7 value has been

$$K_7 = 24.65 * 10^{-5} \tag{4.103}$$

After substituting values of K_5, K_6 and K_7, then the transfer function is to be

$$G(s) = \frac{5.87}{S^2(S+32.3)} \tag{4.104}$$

All the previews equations will be subsequently used in the control and controller designs.

4.4 State Space Model:

This section calculates the state space of the open loop system $(G(s))$

Now, finding associated differential equation:

$$(s^3 + 32.3s^2)\theta(s) = 5.87V_a(s) \tag{4.105}$$

Take the inverse Laplace transform:

$$\dddot{\theta}(t) + 32.3\ddot{\theta}(t) = 5.87v_a(t) \tag{4.106}$$

Select state variable as successive derivative of θ.

Equation (4.88) is a 3rd order differential equation, so we have three states (x_1, x_2 & x_3) :

Let $x_1 = \theta(t)$ (4.107a)

$$x_2 = \dot{\theta}(t) \tag{4.107b}$$

$$x_3 = \ddot{\theta}(t) \tag{4.107c}$$

Then,

$$\dot{x}_1 = x_2 \tag{4.108a}$$

$$\dot{x}_2 = x_3 \tag{4.108b}$$

$$\dot{x}_3 = -32.3x_3 + 5.87v_a(t) \tag{4.108c}$$

And the out put is

$$y = \theta = x_1 \tag{4.108d}$$

Converting equations (4.90a), (4.90b) and (4.90c) to vector-matrix form

Then the state space model become

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & -32.3 \end{bmatrix}}_{A} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ 0 \\ 5.87 \end{bmatrix}}_{B} v_a(t) \tag{4.109a}$$

And the out put matrix is

$$y = \underbrace{\begin{bmatrix} 1 & 0 & 0 \end{bmatrix}}_{C} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + 0 \tag{4.109b}$$

Where: A: is a system matrix

B: is an input matrix

C: is an output matrix

Chapter Five

Control System Design and Simulation

Contents:

5.1 Introduction

Each system in nature has its own response, in order to get a stable response a compensator must be attached to it. Some stable systems have an unwanted dynamic behaviour (undesired response) so; the internal structure and response should be developed by using a compensator (controller) such as PD, PID, Lead ….etc, to get the desired specifications of the transient response and steady state response.

5.2 Uncompensated system response

The uncompensated system of the project is unstable since the root locus of the two poles at the origin goes to the right hand of the imaginary axis. The third pole at the left goes to infinity to the left hand direction, as shown in figure (5.1).

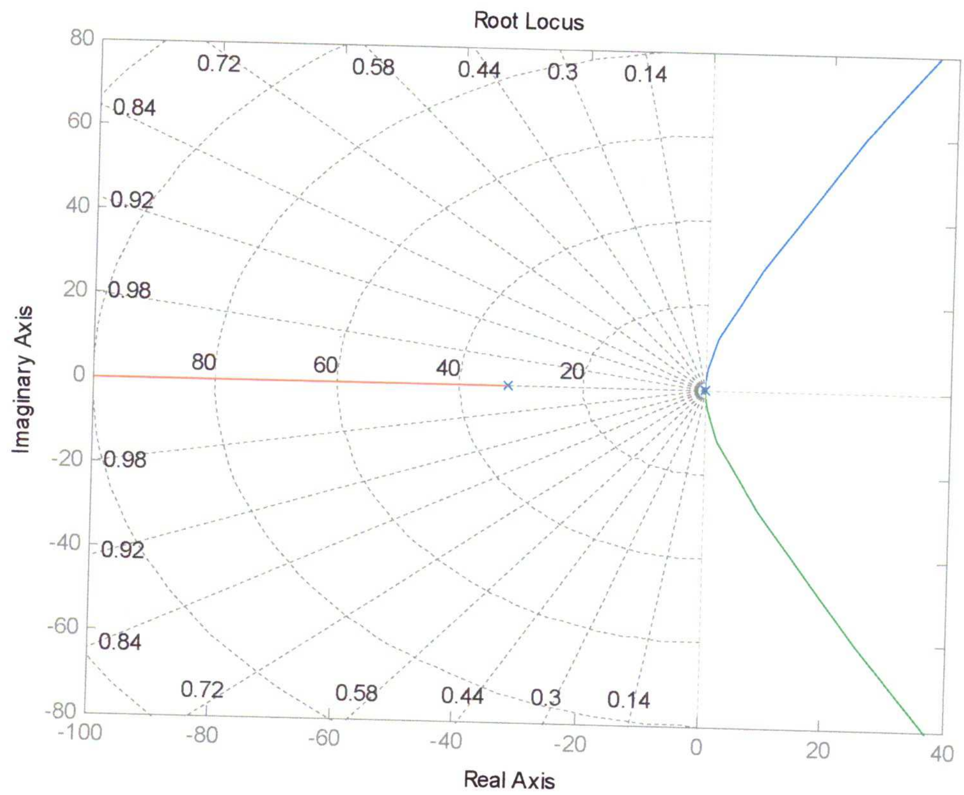


Figure (5.1) The uncompensated system Root Locus

Matlab:

```
>> num=[5.87];
>> den=[1 32.3 0 0];
>> g=tf(num,den);
>> rlocus(g)
>> grid
```

Using Matlab software to find the response of the closed loop uncompensated system and applying the transfer function of equation (4.104), as in figure (5.2).

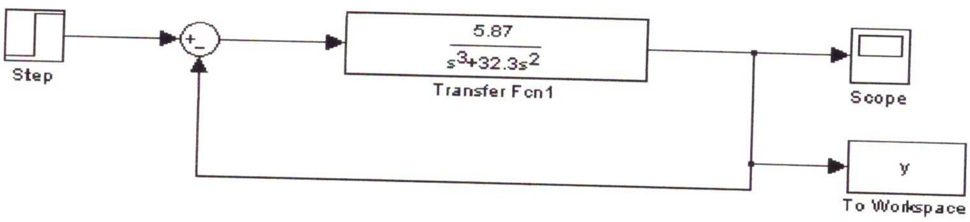


Figure (5.2) Simulink model of the closed loop uncompensated system

The transient response of the system is oscillatory as shown in figure (5.3) and the oscillations are getting higher and higher since no damping so; to avoid the destruction, a controller must be designed.

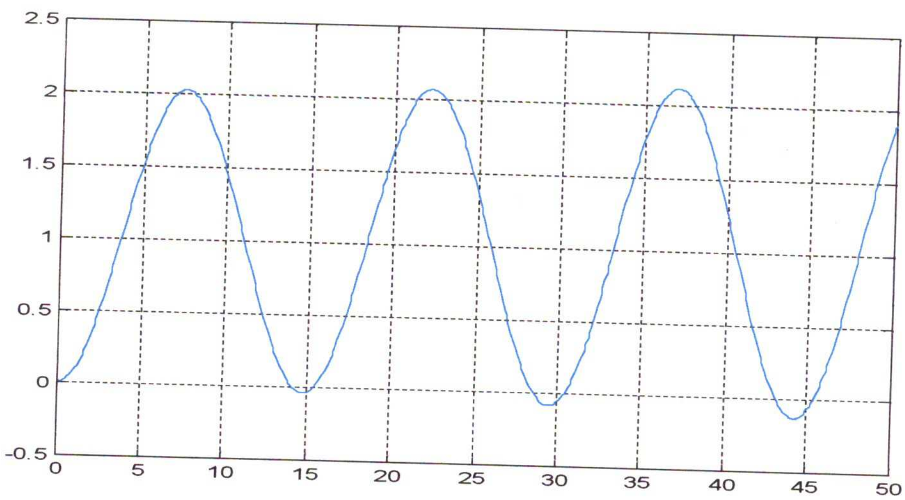


Figure (5.3) The Transient Response of the uncompensated System

5.3 Designing the Compensator

Depending on the previous results a PD controller will be used to stabilize the system and improve steady state response then the steady state error going to be checked so as to determine if an I element is needed or not.

Let choose the dominant poles at:

$$S_{1,2} = -6.0348 \pm j3.5927 \tag{5.1}$$

And finding the transient response specifications

$$S_{1,2} = -\zeta\omega_n \pm j\omega_d \quad [20] \tag{5.2}$$

$$\zeta\omega_n = 6.0348 \tag{5.3}$$

Then the natural frequency is

$$\omega_n = \frac{6.0348}{\zeta} \tag{5.4}$$

And the system frequency is

$$\omega_d = 3.5927 \tag{5.5}$$

$$\omega_d = \omega_n\sqrt{1-\zeta^2} \quad [20] \tag{5.6}$$

Substituting equations 5.4 and 5.5 in 5.6, then

$$3.5927 = \frac{6.0348}{\zeta}\sqrt{1-\zeta^2} \tag{5.7}$$

Then the damping ratio has a value

$$\zeta = 0.86 \tag{5.8}$$

And natural frequency become

$$\omega_n = 7.02\ rad/s \tag{5.9}$$

The settling time is

$$T_s = \frac{4}{\zeta\omega_n} = 0.662\ s \quad [20] \tag{5.10}$$

The rise time is

$$T_r = \frac{2.16\zeta + 0.6}{\omega_n} = 0.35\ s \quad [20] \tag{5.11}$$

The peak time is

$$T_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} = \frac{\pi}{\omega d} = 0.874\ s \quad [20] \tag{5.12}$$

And the percentage overshoot has a value

$$\%P.O = e^{-\zeta\pi / \sqrt{1-\zeta^2}} = 0.5\% \quad [20] \tag{5.13}$$

5.3.1 Designing PD controller

The PD controller is preferred to be used in this project, since there are two poles at origin and we need to zero, then, the PD controller transfer function is

$$G_c(s) = K_P + K_D S \quad [25] \tag{5.14}$$

By taking K_D out of the brackets

$$G_c(s) = K_D(S + \frac{K_P}{K_D}) = K_c(S + a) \tag{5.15}$$

Where: $K_c = K_D$ (5.16)

$a = K_P / K_D$ (5.17)

The characteristic equation is given by

$$q(s) = 1 + \frac{\overline{K}(S + a)}{S^2(S + 32.3)} \tag{5.18}$$

Zero of open loop: -a.

Pole of open loop: 0, 0, -32.3

Now s_1 should belong to root locus as shown in figure (5.4)

Then the angle equation is

$$\Sigma\angle(s_1 + z_i) \_ \Sigma\angle(s_1 + p_j) = r(180^0) \text{ [25]} \tag{5.19}$$

$$r(180^0) = \Phi - (\theta_1 + \theta_2 + \theta_3) \tag{5.20}$$

$$r(180^0) = \Phi - (149.23 + 149.23 + 7.79) \tag{5.21}$$

$$r(180^0) = \Phi - 306.25 \tag{5.22}$$

Let r = -1 to get the minimum positive value of Φ

$$\mathbf{\Phi = 126.25^o} \tag{5.23}$$

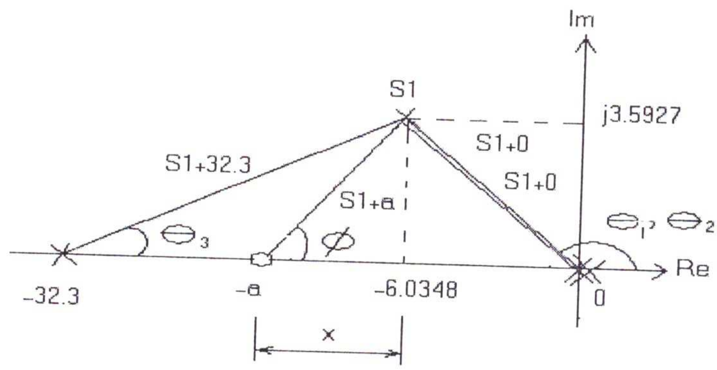


Figure (5.4) Desired Pole Location of the Control System

Now

$$\tan\Phi = \frac{3.5927}{x} \tag{5.24}$$

$x = -2.634$ (5.25)

Then:

$a = 6.0348 - 2.634 = 3.4$ (5.26)

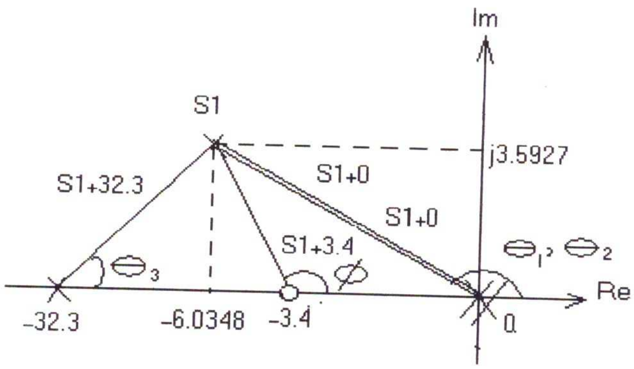


Figure (5.5) Finding the Gain of the System

We will find $\overline{K}$ using figure (5.5)

$$\frac{1}{\overline{K}} = \frac{|S_1 + 3.4|}{|S_1 + 0||S_1 + 0||S_1 + 32.3|} = \frac{(4.455)}{(7.023)(7.023)(26.51)} \text{ [25]} \quad (5.27)$$

The gain is

$\overline{K} = 293.5$ (5.28)

The gain is equal the DC gain by the controller gain

$\overline{K} = K_c(5.87)$ (5.29)

Then the controller gain become

$$K_C = \frac{293.5}{5.87} = 50 \quad (5.30)$$

The transfer function of the compensator

$G_c(s) = 50(S + 3.4)$ (5.31)

The transfer function of the compensated system will be

$$G(s) * G_c(s) = \frac{293.5(S + 3.4)}{S^2(S + 32.3)} \qquad (5.32)$$

The system is type number two, so produces zero steady state error for both step input and ramp input, but produces constant steady state error for parabolic input.

To check that

$$S_{1,2} = -6.0349 \pm j3.5927 \qquad (5.33)$$

are the poles of the closed loop system:

Take the closed loop of the compensated system.

$$\frac{\theta(s)}{V_a(s)} = \frac{G_c(s)G(s)}{1 + G_c(s)G(s)} \qquad (5.34)$$

So, q(s) for the closed loop system is

$$q(s) = 1 + \frac{293.5(s + 3.4)}{s^2(s + 32.3)} \qquad (5.35)$$

Equating q(s) with zero

$$s^3 + 32.3s^2 + 293.5s + 997.9 = 0 \qquad (5.36)$$

Results of this equation are

$$S_{1,2} = -6.0349 \pm j3.5927 \qquad (5.37)$$

$$S_3 = -20.2304 \qquad (5.38)$$

5.3.2 Steady state error

1. Step input

$$R(s) = \frac{1}{S} \qquad (5.39)$$ [20]

The steady state error of step input is given by

$$e_{SS} = \frac{1}{1 + K_P} \text{ [20]} \tag{5.40}$$

So, the position error constant will be

$$K_P = \lim_{s \to 0} G_c(s)G(s) = \infty \text{ [20]} \tag{5.41}$$

And then, the steady state error become

$$e_{SS} = \frac{1}{1 + \infty} = 0.0 \tag{5.42}$$

2. Ramp input

$$R(s) = \frac{1}{S^2} \text{ [20]} \tag{5.43}$$

The steady state error for a ramp input is

$$e_{SS} = \frac{1}{Kv} \text{ [20]} \tag{5.44}$$

The velocity error constant is found by

$$K_v = \lim_{s \to 0} SG_c(s)G(s) = \infty \text{ [20]} \tag{5.45}$$

Then

$$e_{SS} = \frac{1}{\infty} = 0.0 \tag{5.46}$$

3. Parabolic input

$$R(s) = \frac{1}{S^3} \text{ [20]} \tag{5.47a}$$

The steady state error for a parabolic input is given by

$$e_{SS} = \frac{1}{K_a} \text{ [20]} \tag{5.47b}$$

The acceleration error constant will be

$$K_a = \lim_{s \to 0} S^2 G_c(s)G(s) = 30.9 \quad [20] \tag{5.48}$$

then

$$e_{SS} = \frac{1}{30.9} = 0.0324 \tag{5.49}$$

5.3.3 Compensated system response

The root locus of the closed loop compensated system as in figure (5.6) shows that the poles are located at the stability region, one is going to the controller zero and two are going to infinity, so the new system of the project is stable.

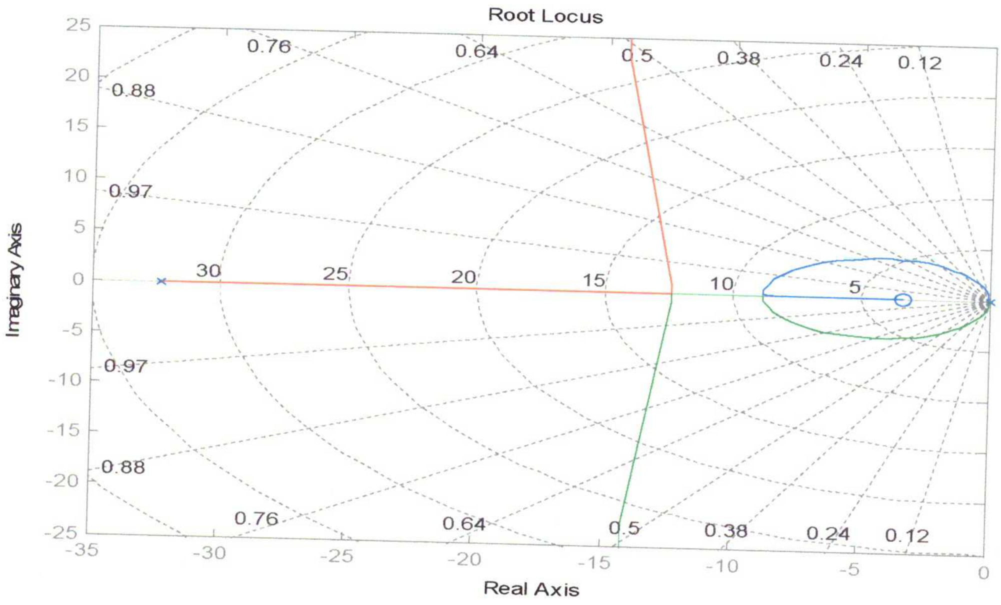


Figure (5.6) The root locus of the compensated system

Matlab:

>> num=[293.5 997.9];

>> den=[1 32.3 0 0];

```
>> g=tf(num,den);

>> rlocus(g)

>> grid
```

The Simulink model of the closed loop compensated system with step input, shown as in figure (5.7):

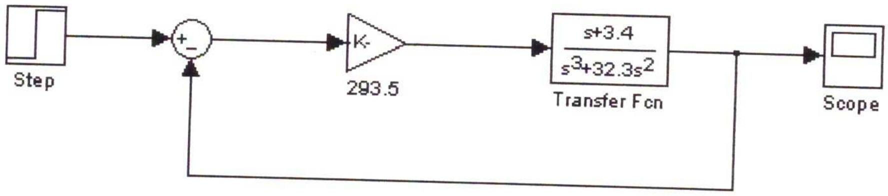


Figure (5.7) The Simulink model of compensated system

And the response of the closed loop compensated system as in figure (5.8) is having overshoot approximately 25%, settling time approximately 1s, and peak time approximately 0.31s, these values are different from the calculated values since the nature of the system couldn't be controlled exactly by classical method (the poles couldn't be put wherever), so the chosen poles are not dominant and that hard to find a dominant poles, so this response is acceptable.

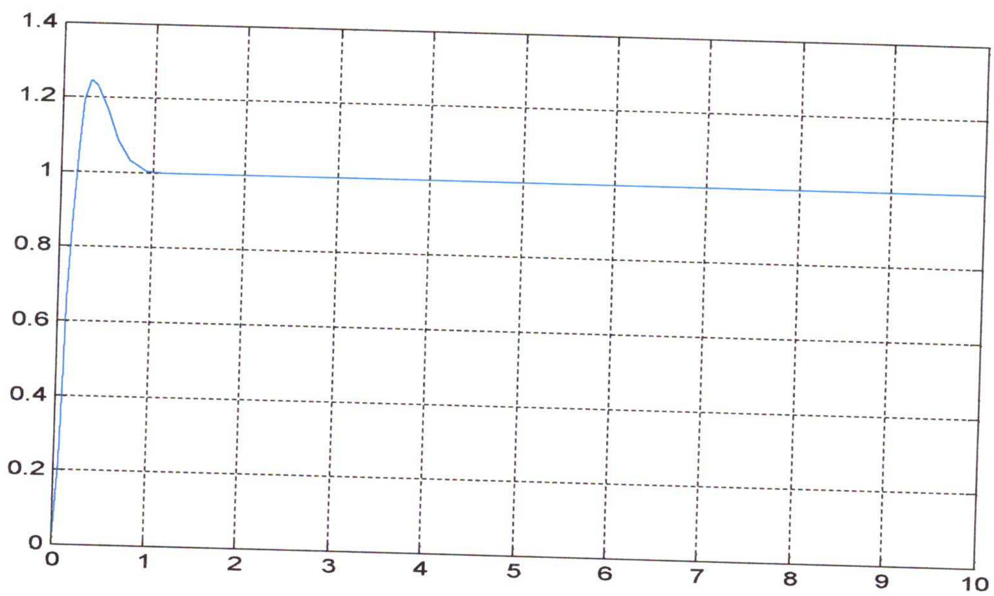


Figure (5.8) The response of the closed loop compensated system

But the steady state error is the same as the calculated values (e_{ss}=0.0), and the oscillations vanished, so the system won't get the resonance.

5.3.4 Compensated System Behaviour with Disturbance

The disturbance signal is unwanted, unestimated signal found usually from nature, so a step disturbance signal added to the system in order to find the error generated by that signal and determining the usage of the I element in the system. The disturbance signal is assumed to be a static pressure one as shown in figure (5.9) and figure (5.10).

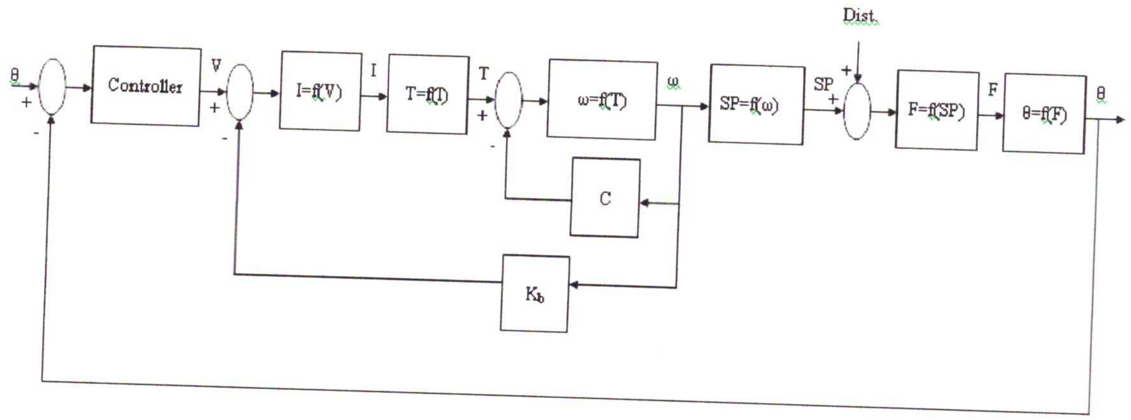


Figure (5.9) The Disturbance Signal

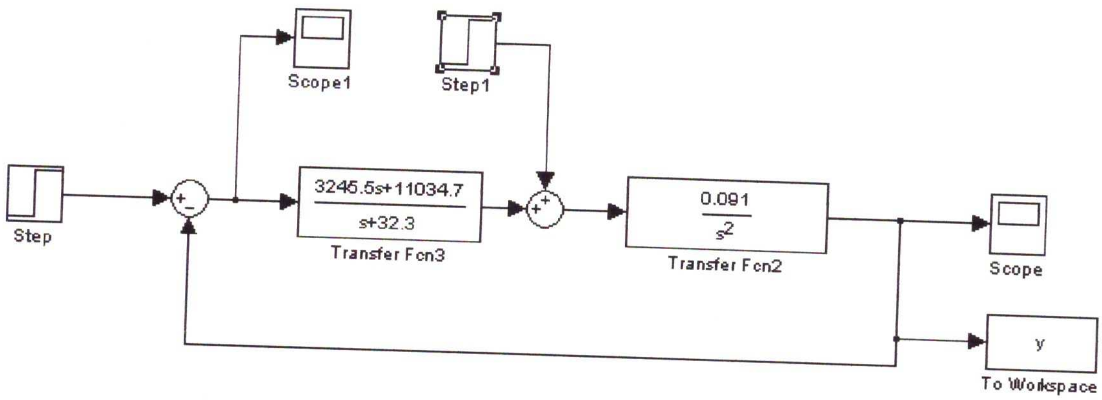


Figure (5.10) The Simulink model of compensated system with Disturbance

So, the simulations done one time with presence of disturbance and another time without the disturbance so as to compare the responses and show the error in both cases when the controller is implemented, the simulations was as in figure (5.11) and (5.12) without disturbance and with disturbance respectively:

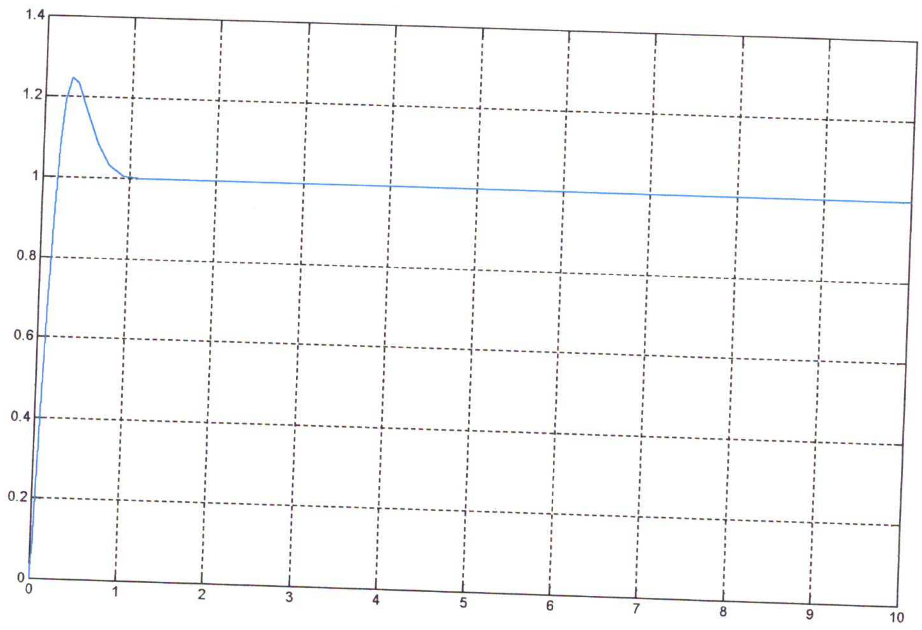


Figure (5.11) The response of the compensated system without Disturbance

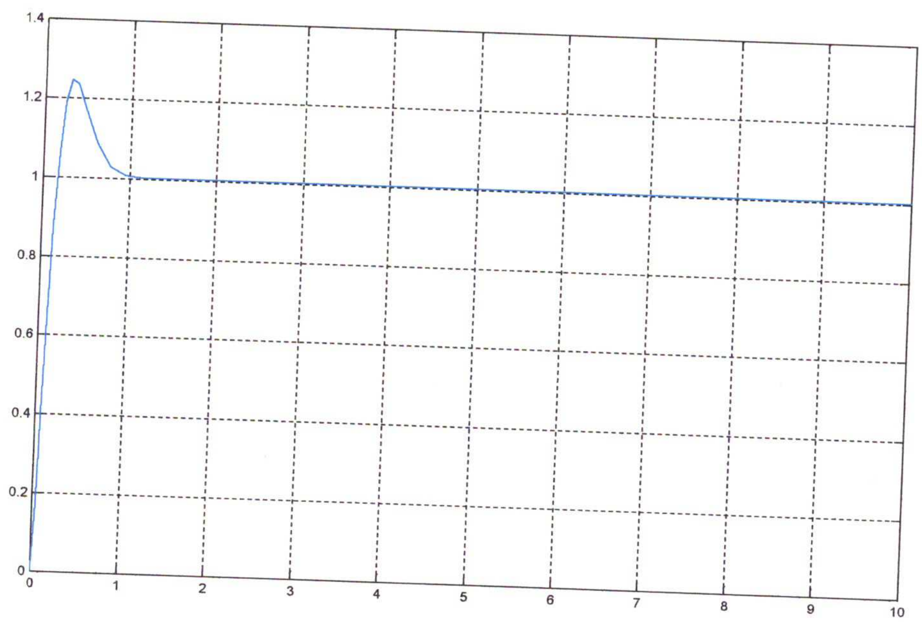


Figure (5.12) The response of the compensated system with Disturbance

The response in figure (5.11) shows that after the settling time the signal is exactly one, but in figure (5.12) shows that the signal is not exactly one and the error signal of the system with disturbance is less than 0.003 as shown in figure (5.13)

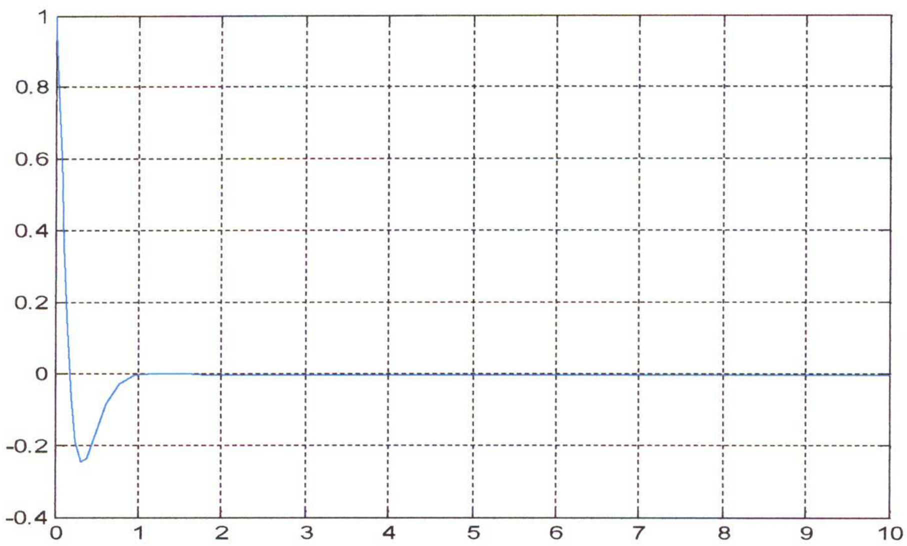


Figure (5.13) The Error Signal of the System with Disturbance

5.3.5 Digitize the Continuous Compensator

In general when applying a microcontroller in the system, a difference equation must be found. in general, the digital system as shown in figure (5.14) has already the continuous system transfer function, A/D converters, the Zero Order Hold (ZOH), and the discrete controller transfer function.

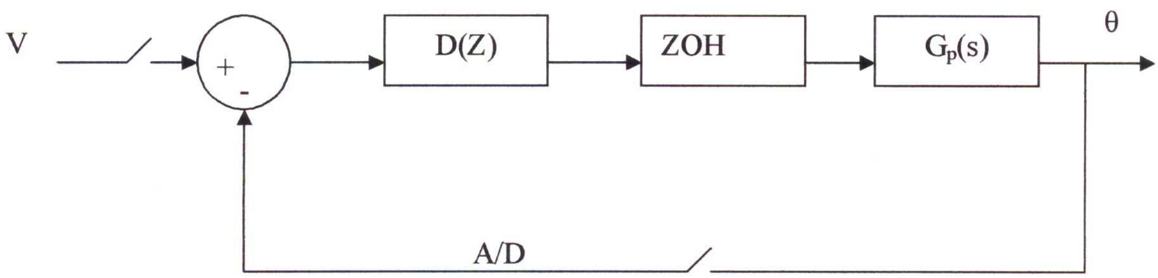


Figure (5.14) The Digitized Control System

By Tustin method, when converting to discrete system, every S must be substituted by the formula:

$$s = \frac{2}{T}\left(\frac{1 - Z^{-1}}{1 + Z^{-1}}\right) \quad [26] \tag{5.50}$$

But the controller transfer function is

$$G_c(s) = 50(S + 3.4) \tag{5.51}$$

Substituting s, then

$$D(z) = 50\left(\frac{2}{T}\left(\frac{1 - Z^{-1}}{1 + Z^{-1}}\right) + 3.4\right) \tag{5.52}$$

But the sampling time must be found 1st, depending on the natural frequency.

$$\omega_n = 7.02\ rad/s \tag{5.53}$$

The frequency in Hz is

$$f_n = \frac{\omega_n}{2\pi} = \frac{7.02}{2\pi} = 1.117\ Hz \quad [26] \tag{5.54}$$

The sampling frequency should be larger than the double of the system frequency to avoid Aliasing phenomena which causes the output of the ZOH differs from the input (the ZOH converts the digital signal to analog one, the analog output of the ZOH must has approximately similar frequency to the digital input, but when the sampling time is larger than the suitable sampling time, the output will has absolutely different frequency from the input frequency, this phenomena is called Aliasing), so

$$f_s > 2f_n \quad [26] \tag{5.55}$$

Let assume the sampling frequency to be 200 times the system frequency to be in the safe side, so

$$f_s = 200\ f_n = 223.4\ Hz \tag{5.56}$$

Then the sampling time is

$$T = \frac{1}{f_s} = 0.0045\ s \quad \text{[26]} \tag{5.57}$$

Substituting T in the discrete transfer function

$$D(z) = 50\left(\frac{2}{0.0045}\left(\frac{1 - Z^{-1}}{1 + Z^{-1}}\right) + 3.4\right) \tag{5.58}$$

Then the digital transfer function of the controller is

$$D(z) = \left(\frac{22392 - 22052\ Z^{-1}}{1 + Z^{-1}}\right) \tag{5.59}$$

Matlab:

```
>> Ds=tf(50*[1 3.4],[1])

Transfer function:

50 s + 170

>> Dz=c2d(Ds,0.0045,'tustin')

Transfer function:

2.239e004 z - 2.205e004

-----------------------

        z + 1

Sampling time: 0.0045
```

Now to find the difference equation:

$$D(z) = \left(\frac{22392 - 22052 Z^{-1}}{1 + Z^{-1}} \right) = \frac{U(z)}{E(z)} \tag{5.60}$$

$$(1 + Z^{-1})U(z) = (22392 - 22052 Z^{-1})E(z) \tag{5.61}$$

Converting from Z-domain into difference equation

$$u(k) + u(k-1) = 22392 \ e(k) - 22052 \ e(k-1) \tag{5.62}$$

Then the difference equation must be in the order

$(current \cdot input) = \mathbf{(22392)} * (Current \cdot error \cdot signal) - \mathbf{(22052)} * (past \cdot error \cdot signal) - (previous \cdot input)$ [26] .

So,

$$u(k) = 22392 \ e(k) - 22052 \ e(k-1) - u(k-1) \tag{5.63}$$

Equation (5.63) will be subsequently used when programming the microcontroller using C language.

Chapter Six

Electrical Design and Microcontroller

Contents:

6.1 Electrical and Digital Components

When preparing the electrical design for this project the electrical motor and the controller was mentioned first, and then the keypad or the potentiometer, which used to inter the command (the intended angle), the feedback signal is position feedback using potentiometer to determine the output, a small LCD in order to monitor the output of the system, already the wirings to transport the signals and the converters (D/A or A/D converters), an amplifiers and transistor used in the project. In this chapter these components will be discussed in details, all project electrical components and their connections are described in figure (6.1).

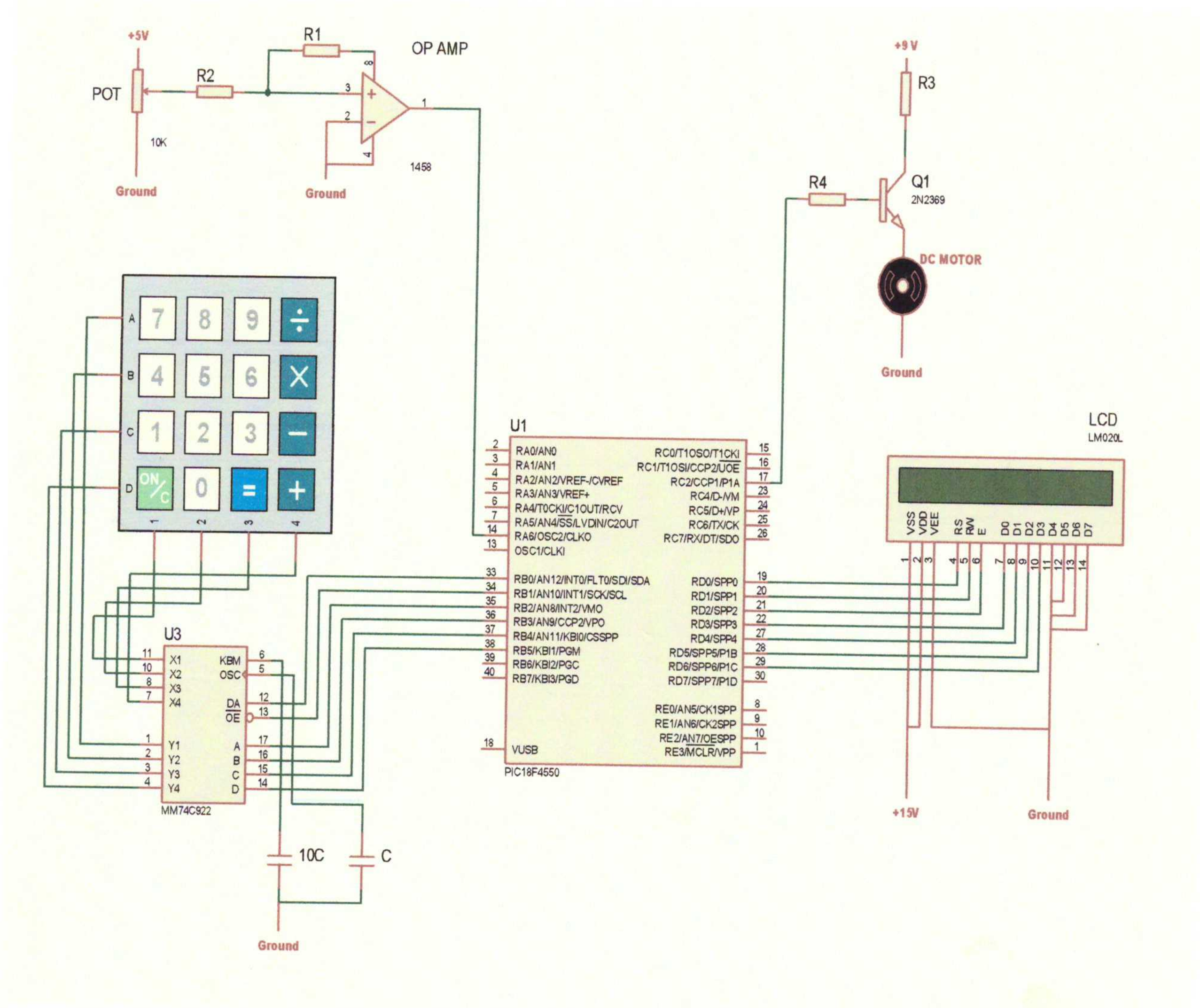


Figure (6.1) Project electrical connections

6.2 Choosing Motor Specifications

The used motor for this project was chose as the desired torque, speed, efficiency, and power which delivered by a fan, so, a small DC motor with terminal voltage equal 9V and terminal current 0.52A is assumed good to be implemented since it gives all the previous desired specifications.

6.3 Microcontroller

Microcontroller assumed the brain of this system, since the PD controller programmed in it, also the rest of the electrical and digital components are connected with it, and so it will be described in detail.

6.3.1 Introduction to Microcontroller

A microcontroller is a computer-on-a-chip, or a single-chip computer. Micro suggests that the device is small, and controller tells you that the device might be used to control objects, processes, or events. Microcontrollers can be found in all kinds of things these days. Any device that measures, stores, controls, calculates, or displays information is a candidate for putting a microcontroller inside. The largest single use for microcontrollers is in automobiles; just about every car manufactured today includes at least one microcontroller for engine control, and often more to control additional systems in the car. In desktop computers, you can find microcontrollers inside keyboards, modems, printers, and other peripherals. In test equipment, microcontrollers make it easy to add features such as the ability to store measurements, to create and store user routines, and to display messages and waveforms. Consumer products that use microcontrollers include cameras, video recorders, compact-disk players, and ovens [27].

6.3.2 Choosing a chip

All microcontrollers contain a CPU, within each device family, usually a selection of family members are found, each with different combinations of options. For example, the 8052-BASIC is a member of the 8051 family of microcontrollers, which includes chips with program memory in ROM or EPROM, and with varying amounts of RAM and other features. The version that best suits the system's requirements must be selected. Microcontrollers are also characterized by how many bits of data they process at once, with a higher number of bits generally indicating a faster or more powerful chip. Eight-bit chips are popular for simpler designs, but 4-bit, 16-bit, and 32-bit architectures are also available. The PIC 18F4550 is an 8-bit chip. [27]

Power consumption is another consideration, especially for battery-powered systems. Chips manufactured with CMOS processes usually have lower power consumption than those manufactured with NMOS processes. Many CMOS devices have special standby or "sleep" modes that limit current consumption to as low as a few microamperes when the circuits are inactive. Using these modes, a data logger can reduce its power consumption between samples, and power up only when it's time to take data. [27]

The PIC microcontroller (PIC 18F4550) from Microchip has chosen in this project since its found easily, has a lot of ports (port A, B, C, D and E), can be programmed simply and it give all characteristics that the project needs. PIC18F4550 ports is shown in figure (6.2).

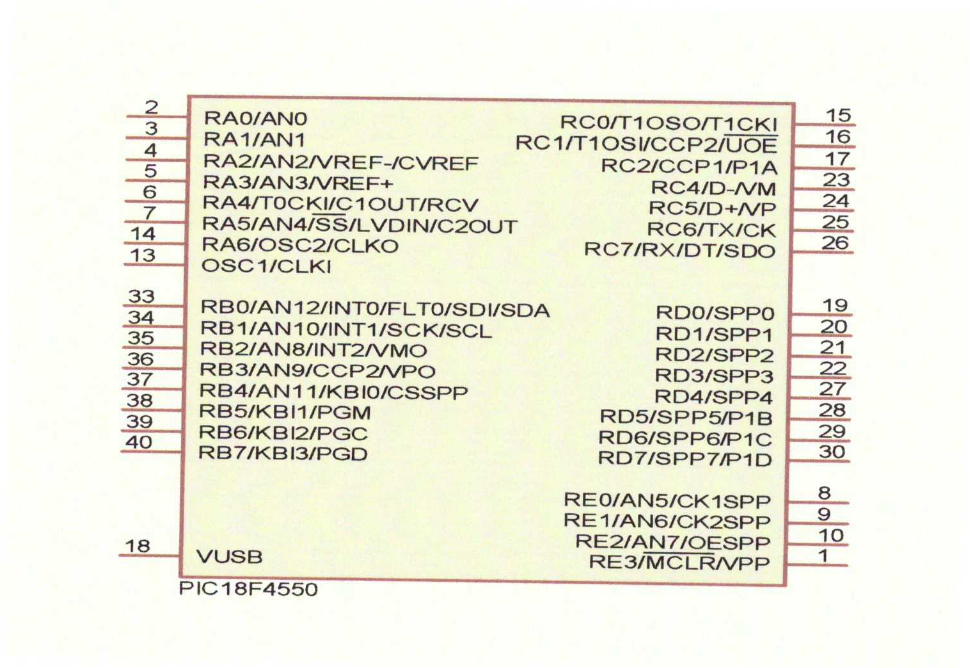


Figure (6.2) PIC 18F4550

6.3.3 Wiring and connections

Connections and wiring are being done using the data sheet of all electrical components and Integrated Circuits (ICs), programming the microcontroller sometimes restrict the connections or maybe determine a new parts to be used and connected such as using a transistor to transmit the Pulse Width Modulation signal (PWM) to the motor since its maximum output is 5V.

6.3.4 Writing the Control Program

When it's time to write the program that controls the project, the options include using machine code, assembly language, or a higher-level language. Which programming language selected depends on things like desired execution speed, program length, and convenience, as well as what's available in the price range [27]. The chosen programming language is C since it the best suitable to be used in this project.

6.3.5 Testing and Debugging

After writing a program, or a section of one, it's time to test it and as necessary, find and correct mistakes to get it working properly. The process of ferreting out and correcting mistakes is called debugging. Easy debugging and troubleshooting can make a big difference in how long it takes to get a system up and running. As with programming, several options are found here as well [27]. Testing and debugging of the project was performed by the MPLAPB program.

6.4 Keypad

A keypad is a set of buttons arranged in a block which usually bear digits and other symbols but not a complete set of alphabetical letters. If it mostly contains numbers then it can also be called a numeric keypad. Keypads are found on many alphanumeric keyboards and on other devices such as calculators, combination locks and telephones which require largely numeric input, In order to identify the keypad type, its function in the project should be known first, there are many types of digital keypads to choose [28].

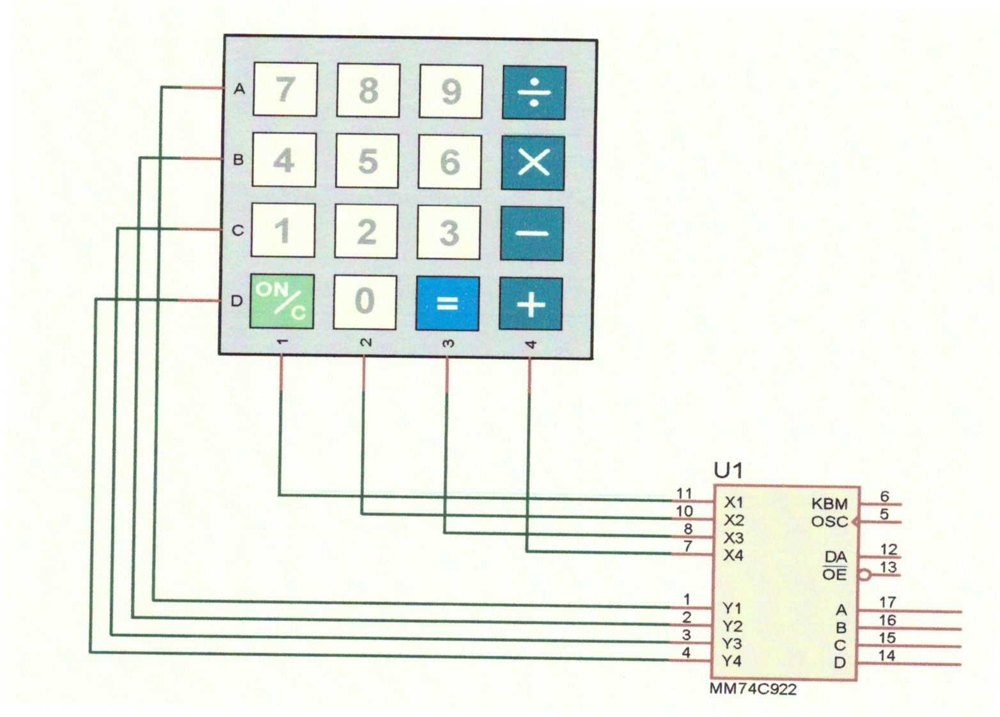


Figure (6.3) Keypad and its driver

The desired keypad of the project is 4*4, this keypad connected with an Encoder (MM74C922) in order to make the program easier and simpler, an encoder used to transport the digital signal to the microcontroller by the data busses A,B,C, and D as shown in figure (6.3).

6.5 The Potentiometer

To control a system, a feed back signal should be recognized determine the error signal to get a more precise system, the sensor which determine that feed back signal here is a potentiometer as mentioned as figure (6.4), the applied voltage on the potentiometer must be maximum 5V DC since the input of the microcontroller can accept a maximum voltage of 5V DC.

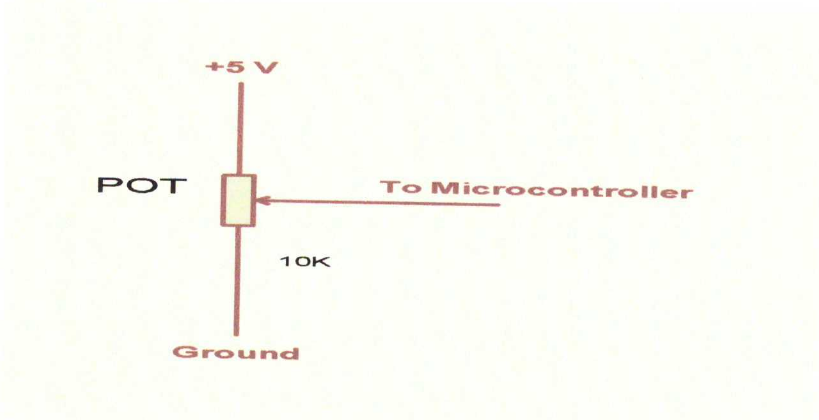


Figure (6.4) Potentiometer connections

For each angle displaced by the rod of the project, by the voltage divider law, the voltage changing calculated to be:

$$V_p = \frac{2(V_{in})(R_p)}{R} \qquad (6.1)$$

Where Vp is the voltage changed by displacing the rod by one degree, Vin is the voltage applied on the potentiometer terminals, Rp is the resistance changed by displacing the rod by one degree (Rp multiplied by two, since one degree displacement by the rod is magnificated the double by the gears), and R is the whole potentiometer resistance, but Rp could be found by

$$R_p = \frac{R}{360 * turns} = \frac{10000}{360\ (10)} = 2.777\ \Omega \qquad (6.2)$$

Then the voltage changing is:

$$V_p = 0.002777\ V \qquad (6.3)$$

6.6 LCD

LCD (Liquid Crystal Display) is used here to monitor the system's parameters; LCD technology is based on the properties of polarized light. Two thin, polarized panels sandwich a thin liquid-crystal gel that is divided into individual pixels. An X/Y grid of wires allows each pixel in the array to be activated individually. The pixel darkens in proportion to the voltage applied to it for a bright detail, a low voltage is applied to the pixel; for a dark shadow area, a higher voltage is applied [29]. Pins of the LCD which used here are shown in figure (6.5).

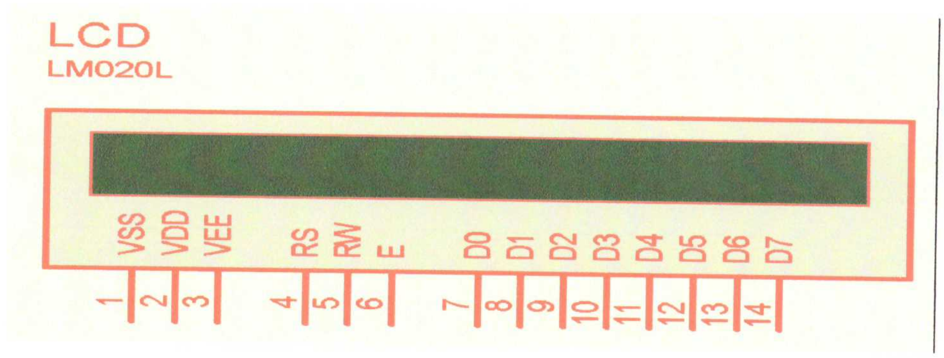


Figure (6.5) LCD pins

6.7 The Regulator

Sometimes a regulator is important when converting the voltage level or when a specified voltage must be entered to a device or an IC in exact level, here the regulator used to convert the voltage level from 12V to 9V to be used for the motor, another regulator used to enter an exact voltage of 5V to the microcontroller input voltage, the regulator input could be any voltage but the out put is specified as figure (6.6) shows.

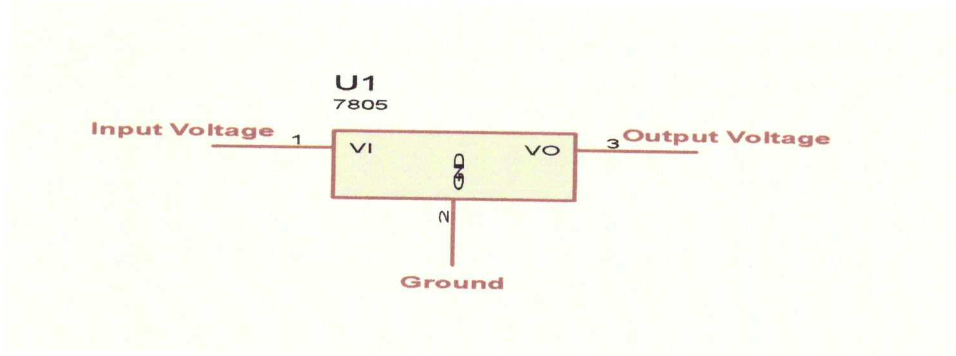


Figure (6.6) Regulator

6.8 Analog to Digital Converter

The microcontroller has a built in A/D, so no need to bring an A/D converter, but A/D prepared by programming to be used in the project. The resolution of the A/D of the microcontroller is 5bit, so the readable voltage signal for the A/D is 1024/5=0.0048V, but the voltage change resulted by displacing the rod by one degree is 0.002777, so this signal must be amplified so as to be a readable signal to the A/D.

6.9 The Amplifier

As mentioned before, the potentiometer output voltage is going to be amplified using an operational amplifier, the input signal of the amplifier is amplified to be twenty times its value, this amplification value can be achieved by setting the value of R1/R2 to be 20 an Operational Amplifier (Op Amp) is shown in figure (6.7) connected with the potentiometer.

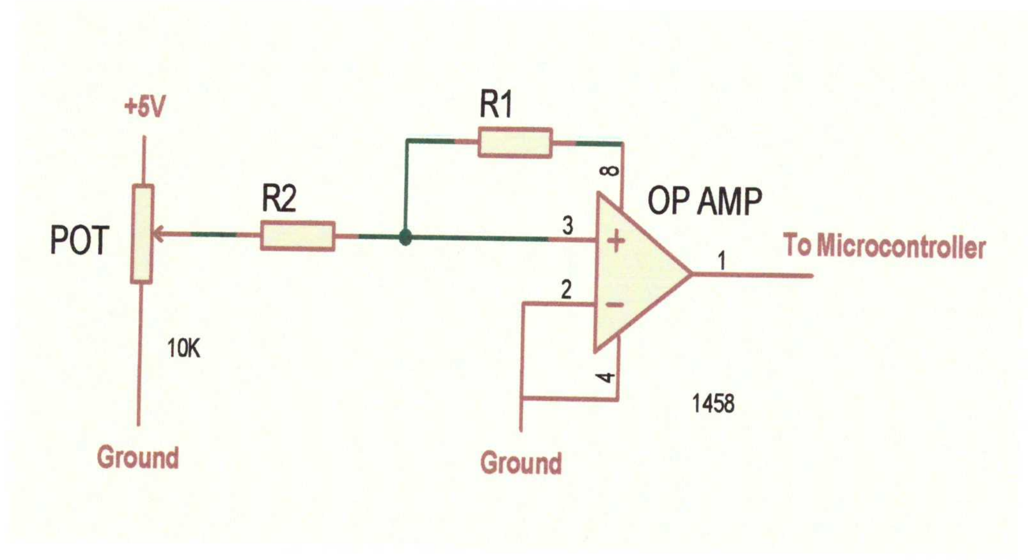


Figure (6.7) Amplifier connections

6.10 PWM (Pulse Width Modulation)

PWM is an important property in the microcontroller which used her to control the voltage that drives the motor; the PWM mode produces a PWM output at 10bit resolution. A PWM output is basically a square waveform with a specified period and duty cycle as shown in figure (6.8).

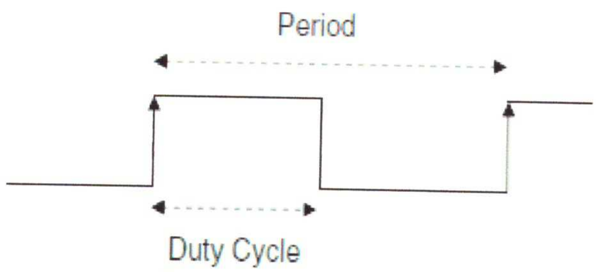


Figure (6.8) PWM Shape

The output signal of the PWM is connected with the base line in a transistor to get a higher current on the collector side; there are two resistors on the base and on the collector to protect the motor and to prevent short circuits as shown in figure (6.9).

Chapter Seven

Conclusion and Recommendations

Contents:

7.1 Results and conclusion

Controlling a rod angle using a fan is a suitable project to be performed at this region and in this university, since it's absolutely simple and doesn't want neither high technology and sophisticated equipments nor high level programming languages that not available in the local markets, so the project was totally applicable and performable with the offered capabilities to the project team.

Project in realty is approximately 70% like the simulations and calculations of the project due to some assumptions and linearization of functions such as Taylor series. Sure there are errors when taking some readings while measuring of constants and variables, such as in finding the masses of parts to calculate the inertias and in finding the nominal static pressure of the fan where was some flashing readings (unstable readings). Of course little of uncertainties in the project have been found because of the nature of the project in addition, the errors due to differences between the real and simulated systems of the same project.

When using PIC microcontroller, it took more time than other work, especially when using C programming language but there are instructions in C language associated with each microcontroller type, these instructions compiled with the appropriate libraries, those libraries come with the microcontroller software (MPLAB software program). Another important thing to be mentioned her is that to download the program after finishing programming of the PIC, a debugger or programmer should be attached between the computer and the PIC device in order to write the program in the PIC memory (EPROM) and to prepare it to usage.

7.2 Problems and Recommendations

As a project; there were some problems that were faced during performing the project, the first one was in applying the DC motor control equations on the DC fan since fans have truly brushless DC motor, the brushless motor is AC motor but there was a conversions circuits to convert from DC to AC voltage, so the DC model was not applicable to the fan motor therefore, a fan blades were attached to DC motor, then the DC motor control model was applied easily on that motor. So, a further more research can be continued here to find the mathematical model for the brushless fans.

Another problem was faced is the small signal which detected by the potentiometer, it was too little to be readable by the A/D of the PIC input, this problem was solved by putting an amplifier between the PIC input and the output line of the potentiometer, but maybe there are another solutions could be capable her such as finding a microcontroller with higher A/D input sensitivity and so on.

An important point must be mentioned her is the control characteristics of the project behaviour, such as overshoot and settling time, the calculated overshoot of the compensated system was extremely different from real one since poles was undominant and so no dominant poles can be found in classical approach, but real settling time was approximately identical with the calculated one, so its appear that some characteristics could be chosen (settling time) instead of other characteristics (overshoot). That is an interesting field to be search which is to improve the response characteristics of the system by finding a way to choose dominant poles and to get the desired results.

PIC chip was hard to program and no microcontroller curriculum taught in mechatronics program in PPU, so it's preferred to the university to teach such curriculum in mechatronics.

When performing practical project it was a problem all the time to not find the convenient place to work in inside PPU campuses there is no projects lab for mechatronics students with a supervisor, so a recommendation her is to establish a modern projects lab with the appropriate equipments and with a technician supervisor to help students who doing experiments or trying something on their projects any time.

References

[1] http://instruct1.cit.cornell.edu/courses/ee476/FinalProjects/s2006/rg242/webpage/ece%20476.htm#Introduction

[2] http://courses.cit.cornell.edu/ee476/FinalProjects/s2008/ras94_mrm58_deb48/ras94_mrm58_deb48/HelicopterWebsite.html

[3] http://www.ifac-papersonline.net/Detailed/31152.html

[4] http://courses.cit.cornell.edu/ee476/FinalProjects/s2004/tl92/tl92_nh48_476 finalproj/index.htm

[5] http://www.quanser.com/NET/WebImages/NewsCast/Documents/Organization_7/QNET%20013_014_015_preliminary_information_2.pdf

[6] http://www.freepatentsonline.com/4225289.html

[7] http://www.wipo.int/pctdb/en/wo.jsp?wo=2003071901

[8] http://www.freepatentsonline.com/6779981.html

[9] http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=293436

[10] http://www.bes-tech.net/pdf/BT11.pdf

[11] http://www.vent-axia.com/knowledge/handbook/section1/whatisafan.asp

[12] http://en.wikipedia.org/wiki/Fan_(mechanical)

[13] http://www.thaitechnics.com/propeller/prop_intro.html

[14]http://www.free-online-private-pilot-ground-school.com/propeller-aerodynamics.html

[15] http://www.aerospaceweb.org/question/aerodynamics/q0165.shtml

[16]http://www.hsc.csu.edu.au/engineering_studies/aero_eng/aeronautical/Wind_Tunnel_final1.html

[17] Frank P.Bleier, Fan handbook selection, Application, and design, New York, McGrw_Hill, 1998.

[18] http://en.wikipedia.org/wiki/Drag_(physics)

[19] http://www2.basf.us//PLASTICSWEB/displayanyfile?id=0901a5e180004891

[20] Control System Engineering, forth edition, Norman S.Nise, 2004

[21] Fundamentals of Electrical Drives, G.K Dubey, Narosa publishing hous, 1995

[22] Engineering Mecanics volume 2, Dynamics, second edition, J.L. Meriam and L.G. Kraige, 1986

[23] Practical Hydraulic systems, Ravi Doddnurar, 2005

[24] Mechanics of Materials, fourth edition, J.M. Gere and S.P. Timoshenko, 1991

[25] Modern Control Engineering, fourth edition, Katsuhiko Ogata

[26] Digital Control System Analysis and Design, third edition, charles L. Phillips and H. Troy Nagle

[27] Jan Axelson,The Microcontroller Idea Book, Circuits, Programs, & Applications Featuring the 8052-BASIC Microcontroller, 1994, by Jan Axelson,

[28] http://www.idsemergencymanagement.com/emergency_management/corporate/act_5prox_digital_keypad/3776/newsrelease_content.html

[29] http://www.dtvcity.com/lcdtv/lcdtvresources.html

[30] Electronic Devices, fourth edition, Thomas L. Floyd, 1992

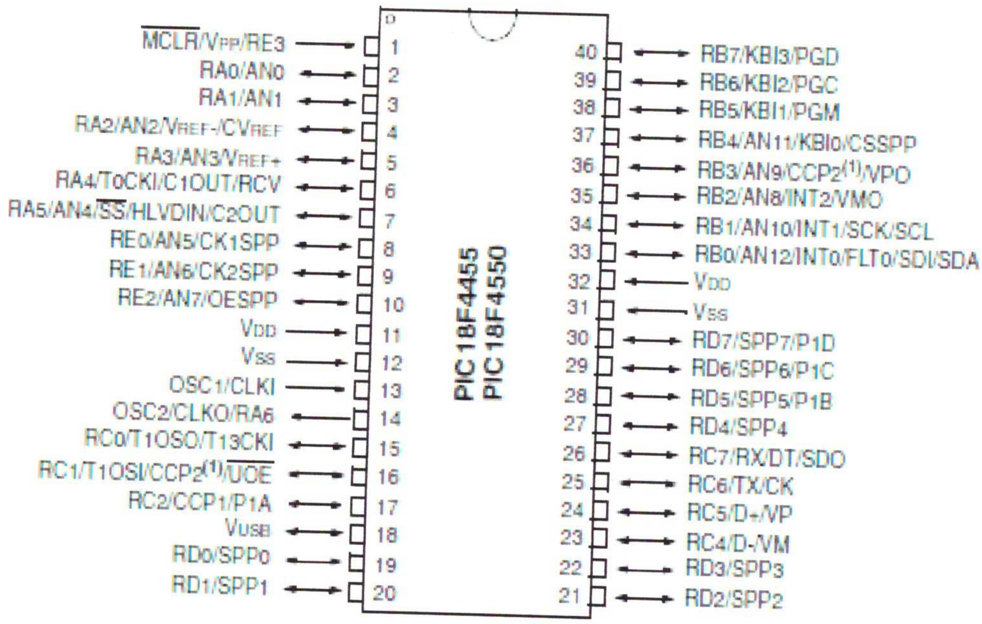
Appendices

Appendix A

Electrical Components Datasheet

PIC18F4550

40-Pin PDIP



Note 1: RB3 is the alternate pin for CCP2 multiplexing.

PIC18F2455/2550/4455/4550

28/40/44-Pin, High-Performance, Enhanced Flash, USB Microcontrollers with nanoWatt Technology

Universal Serial Bus Features:

- USB V2.0 Compliant
- Low Speed (1.5 Mb/s) and Full Speed (12 Mb/s)
- Supports Control, Interrupt, Isochronous and Bulk Transfers
- Supports up to 32 Endpoints (16 bidirectional)
- 1-Kbyte Dual Access RAM for USB
- On-Chip USB Transceiver with On-Chip Voltage Regulator
- Interface for Off-Chip USB Transceiver
- Streaming Parallel Port (SPP) for USB streaming transfers (40/44-pin devices only)

Power-Managed Modes:

- Run: CPU on, peripherals on
- Idle: CPU off, peripherals on
- Sleep: CPU off, peripherals off
- Idle mode currents down to 5.8 μA typical
- Sleep mode currents down to 0.1 μA typical
- Timer1 Oscillator: 1.1 μA typical, 32 kHz, 2V
- Watchdog Timer: 2.1 μA typical
- Two-Speed Oscillator Start-up

Flexible Oscillator Structure:

- Four Crystal modes, including High Precision PLL for USB
- Two External Clock modes, up to 48 MHz
- Internal Oscillator Block:
  - 8 user-selectable frequencies, from 31 kHz to 8 MHz
  - User-tunable to compensate for frequency drift
- Secondary Oscillator using Timer1 @ 32 kHz
- Dual Oscillator options allow microcontroller and USB module to run at different clock speeds
- Fail-Safe Clock Monitor:
  - Allows for safe shutdown if any clock stops

Peripheral Highlights:

- High-Current Sink/Source: 25 mA/25 mA
- Three External Interrupts
- Four Timer modules (Timer0 to Timer3)
- Up to 2 Capture/Compare/PWM (CCP) modules:
  - Capture is 16-bit, max. resolution 5.2 ns ($T_{CY}/16$)
  - Compare is 16-bit, max. resolution 83.3 ns (T_{CY})
  - PWM output: PWM resolution is 1 to 10-bit
- Enhanced Capture/Compare/PWM (ECCP) module:
  - Multiple output modes
  - Selectable polarity
  - Programmable dead time
  - Auto-shutdown and auto-restart
- Enhanced USART module:
  - LIN bus support
- Master Synchronous Serial Port (MSSP) module supporting 3-wire SPI (all 4 modes) and I²C™ Master and Slave modes
- 10-bit, up to 13-channel Analog-to-Digital Converter module (A/D) with Programmable Acquisition Time
- Dual Analog Comparators with Input Multiplexing

Special Microcontroller Features:

- C Compiler Optimized Architecture with optional Extended Instruction Set
- 100,000 Erase/Write Cycle Enhanced Flash Program Memory typical
- 1,000,000 Erase/Write Cycle Data EEPROM Memory typical
- Flash/Data EEPROM Retention: > 40 years
- Self-Programmable under Software Control
- Priority Levels for Interrupts
- 8 x 8 Single-Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):
  - Programmable period from 41 ms to 131s
- Programmable Code Protection
- Single-Supply 5V In-Circuit Serial Programming™ (ICSP™) via two pins
- In-Circuit Debug (ICD) via two pins
- Optional dedicated ICD/ICSP port (44-pin devices only)
- Wide Operating Voltage Range (2.0V to 5.5V)

Device	Program Memory		Data Memory		I/O	10-Bit A/D (ch)	CCP/ECCP (PWM)	SPP	MSSP		EAUSART	Comparators	Timers 8/16-Bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)					SPI	Master I²C™			
PIC18F2455	24K	12288	2048	256	24	10	2/0	No	Y	Y	1	2	1/3
PIC18F2550	32K	16384	2048	256	24	10	2/0	No	Y	Y	1	2	1/3
PIC18F4455	24K	12288	2048	256	35	13	1/1	Yes	Y	Y	1	2	1/3
PIC18F4550	32K	16384	2048	256	35	13	1/1	Yes	Y	Y	1	2	1/3

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
$\overline{\text{MCLR}}$/VPP/RE3	1	18	18			Master Clear (input) or programming voltage (input).
$\overline{\text{MCLR}}$				I	ST	Master Clear (Reset) input. This pin is an active-low Reset to the device.
VPP				P		Programming voltage input.
RE3				I	ST	Digital input.
OSC1/CLKI	13	32	30			Oscillator crystal or external clock input.
OSC1				I	Analog	Oscillator crystal input or external clock source input.
CLKI				I	Analog	External clock source input. Always associated with pin function OSC1. (See OSC2/CLKO pin.)
OSC2/CLKO/RA6	14	33	31			Oscillator crystal or clock output.
OSC2				O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO				O	—	In RC mode, OSC2 pin outputs CLKO which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6				I/O	TTL	General purpose I/O pin.

PIC18F2455/2550/4455/4550

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTA is a bidirectional I/O port.
RA0/AN0	2	19	19			
RA0				I/O	TTL	Digital I/O.
AN0				I	Analog	Analog input 0.
RA1/AN1	3	20	20			
RA1				I/O	TTL	Digital I/O.
AN1				I	Analog	Analog input 1.
RA2/AN2/VREF-/CVREF	4	21	21			
RA2				I/O	TTL	Digital I/O.
AN2				I	Analog	Analog input 2.
VREF-				I	Analog	A/D reference voltage (low) input.
CVREF				O	Analog	Analog comparator reference output.
RA3/AN3/VREF+	5	22	22			
RA3				I/O	TTL	Digital I/O.
AN3				I	Analog	Analog input 3.
VREF+				I	Analog	A/D reference voltage (high) input.
RA4/T0CKI/C1OUT/RCV	6	23	23			
RA4				I/O	ST	Digital I/O.
T0CKI				I	ST	Timer0 external clock input.
C1OUT				O	—	Comparator 1 output.
RCV				I	TTL	External USB transceiver RCV input.
RA5/AN4/$\overline{\text{SS}}$/HLVDIN/C2OUT	7	24	24			
RA5				I/O	TTL	Digital I/O.
AN4				I	Analog	Analog input 4.
$\overline{\text{SS}}$				I	TTL	SPI slave select input.
HLVDIN				I	Analog	High/Low-Voltage Detect input.
C2OUT				O	—	Comparator 2 output.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-ups on all inputs.
RB0/AN12/INT0/FLT0/SDI/SDA	33	9	8			
RB0				I/O	TTL	Digital I/O.
AN12				I	Analog	Analog input 12.
INT0				I	ST	External interrupt 0.
FLT0				I	ST	Enhanced PWM Fault input (ECCP1 module).
SDI				I	ST	SPI data in.
SDA				I/O	ST	I²C™ data I/O.
RB1/AN10/INT1/SCK/SCL	34	10	9			
RB1				I/O	TTL	Digital I/O.
AN10				I	Analog	Analog input 10.
INT1				I	ST	External interrupt 1.
SCK				I/O	ST	Synchronous serial clock input/output for SPI mode.
SCL				I/O	ST	Synchronous serial clock input/output for I²C mode.
RB2/AN8/INT2/VMO	35	11	10			
RB2				I/O	TTL	Digital I/O.
AN8				I	Analog	Analog input 8.
INT2				I	ST	External interrupt 2.
VMO				O	—	External USB transceiver VMO output.
RB3/AN9/CCP2/VPO	36	12	11			
RB3				I/O	TTL	Digital I/O.
AN9				I	Analog	Analog input 9.
CCP2(1)				I/O	ST	Capture 2 input/Compare 2 output/PWM 2 output.
VPO				O	—	External USB transceiver VPO output.
RB4/AN11/KBI0/CSSPP	37	14	14			
RB4				I/O	TTL	Digital I/O.
AN11				I	Analog	Analog input 11.
KBI0				I	TTL	Interrupt-on-change pin.
CSSPP				O	—	SPP chip select control output.
RB5/KBI1/PGM	38	15	15			
RB5				I/O	TTL	Digital I/O.
KBI1				I	TTL	Interrupt-on-change pin.
PGM				I/O	ST	Low-Voltage ICSP™ Programming enable pin.
RB6/KBI2/PGC	39	16	16			
RB6				I/O	TTL	Digital I/O.
KBI2				I	TTL	Interrupt-on-change pin.
PGC				I/O	ST	In-Circuit Debugger and ICSP programming clock pin.
RB7/KBI3/PGD	40	17	17			
RB7				I/O	TTL	Digital I/O.
KBI3				I	TTL	Interrupt-on-change pin.
PGD				I/O	ST	In-Circuit Debugger and ICSP programming data pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

3: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the DEBUG Configuration bit is cleared.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number PDIP	Pin Number QFN	Pin Number TQFP	Pin Type	Buffer Type	Description
						PORTC is a bidirectional I/O port.
RC0/T1OSO/T13CKI	15	34	32			
RC0				I/O	ST	Digital I/O.
T1OSO				O	—	Timer1 oscillator output.
T13CKI				I	ST	Timer1/Timer3 external clock input.
RC1/T1OSI/CCP2/$\overline{UOE}$	16	35	35			
RC1				I/O	ST	Digital I/O.
T1OSI				I	CMOS	Timer1 oscillator input.
CCP2(2)				I/O	ST	Capture 2 input/Compare 2 output/PWM 2 output.
$\overline{UOE}$				O	—	External USB transceiver $\overline{OE}$ output.
RC2/CCP1/P1A	17	36	36			
RC2				I/O	ST	Digital I/O.
CCP1				I/O	ST	Capture 1 input/Compare 1 output/PWM 1 output.
P1A				O	TTL	Enhanced CCP1 PWM output, channel A.
RC4/D-/VM	23	42	42			
RC4				I	TTL	Digital input.
D-				I/O	—	USB differential minus line (input/output).
VM				I	TTL	External USB transceiver VM input.
RC5/D+/VP	24	43	43			
RC5				I	TTL	Digital input.
D+				I/O	—	USB differential plus line (input/output).
VP				I	TTL	External USB transceiver VP input.
RC6/TX/CK	25	44	44			
RC6				I/O	ST	Digital I/O.
TX				O	—	EUSART asynchronous transmit.
CK				I/O	ST	EUSART synchronous clock (see RX/DT).
RC7/RX/DT/SDO	26	1	1			
RC7				I/O	ST	Digital I/O.
RX				I	ST	EUSART asynchronous receive.
DT				I/O	ST	EUSART synchronous data (see TX/CK).
SDO				O	—	SPI data out.

Legend: TTL = TTL compatible input; ST = Schmitt Trigger input with CMOS levels; O = Output; CMOS = CMOS compatible input or output; I = Input; P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

3: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{DEBUG}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number PDIP	QFN	TQFP	Pin Type	Buffer Type	Description
						PORTD is a bidirectional I/O port or a Streaming Parallel Port (SPP). These pins have TTL input buffers when the SPP module is enabled.
RD0/SPP0	19	38	38			
RD0				I/O	ST	Digital I/O.
SPP0				I/O	TTL	Streaming Parallel Port data.
RD1/SPP1	20	39	39			
RD1				I/O	ST	Digital I/O.
SPP1				I/O	TTL	Streaming Parallel Port data.
RD2/SPP2	21	40	40			
RD2				I/O	ST	Digital I/O.
SPP2				I/O	TTL	Streaming Parallel Port data.
RD3/SPP3	22	41	41			
RD3				I/O	ST	Digital I/O.
SPP3				I/O	TTL	Streaming Parallel Port data.
RD4/SPP4	27	2	2			
RD4				I/O	ST	Digital I/O.
SPP4				I/O	TTL	Streaming Parallel Port data.
RD5/SPP5/P1B	28	3	3			
RD5				I/O	ST	Digital I/O.
SPP5				I/O	TTL	Streaming Parallel Port data.
P1B				O	—	Enhanced CCP1 PWM output, channel B.
RD6/SPP6/P1C	29	4	4			
RD6				I/O	ST	Digital I/O.
SPP6				I/O	TTL	Streaming Parallel Port data.
P1C				O	—	Enhanced CCP1 PWM output, channel C.
RD7/SPP7/P1D	30	5	5			
RD7				I/O	ST	Digital I/O.
SPP7				I/O	TTL	Streaming Parallel Port data.
P1D				O	—	Enhanced CCP1 PWM output, channel D.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

3: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{DEBUG}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTE is a bidirectional I/O port.
RE0/AN5/CK1SPP	8	25	25			
RE0				I/O	ST	Digital I/O.
AN5				I	Analog	Analog input 5.
CK1SPP				O	—	SPP clock 1 output.
RE1/AN6/CK2SPP	9	26	26			
RE1				I/O	ST	Digital I/O.
AN6				I	Analog	Analog input 6.
CK2SPP				O	—	SPP clock 2 output.
RE2/AN7/OESPP	10	27	27			
RE2				I/O	ST	Digital I/O.
AN7				I	Analog	Analog input 7.
OESPP				O	—	SPP output enable output.
RE3	—	—	—	—	—	See $\overline{MCLR}$/VPP/RE3 pin.
VSS	12, 31	6, 30, 31	6, 29	P	—	Ground reference for logic and I/O pins.
VDD	11, 32	7, 8, 28, 29	7, 28	P	—	Positive supply for logic and I/O pins.
VUSB	18	37	37	O	—	Internal USB 3.3V voltage regulator output.
NC/ICCK/ICPGC[3]	—	—	12			No Connect or dedicated ICD/ICSP™ port clock.
ICCK				I/O	ST	In-Circuit Debugger clock.
ICPGC				I/O	ST	ICSP programming clock.
NC/ICDT/ICPGD[3]	—	—	13			No Connect or dedicated ICD/ICSP port clock.
ICDT				I/O	ST	In-Circuit Debugger data.
ICPGD				I/O	ST	ICSP programming data.
NC/$\overline{ICRST}$/ICVPP[3]	—	—	33			No Connect or dedicated ICD/ICSP port Reset.
$\overline{ICRST}$				I	—	Master Clear (Reset) input.
ICVPP				P	—	Programming voltage input.
NC/ICPORTS[3]	—	—	34			No Connect or 28-pin device emulation.
ICPORTS				P	—	Enable 28-pin device emulation when connected to VSS.
NC	—	13	—	—	—	No Connect.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

3: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{DEBUG}$ Configuration bit is cleared.

TL084
TL084A - TL084B

GENERAL PURPOSE J-FET QUAD OPERATIONAL AMPLIFIERS

- WIDE COMMON-MODE (UP TO V_{CC}^{+}) AND DIFFERENTIAL VOLTAGE RANGE
- LOW INPUT BIAS AND OFFSET CURRENT
- OUTPUT SHORT-CIRCUIT PROTECTION
- HIGH INPUT IMPEDANCE J–FET INPUT STAGE
- INTERNAL FREQUENCY COMPENSATION
- LATCH UP FREE OPERATION
- HIGH SLEW RATE : 16V/µs (typ)

N
DIP14
(Plastic Package)

D
SO14
(Plastic Micropackage)

P
TSSOP14
(Thin Shrink Small Outline Package)

ORDER CODE

Part Number	Temperature Range	Package		
		N	D	P
TL084M/AM/BM	-55°C, +125°C	•	•	•
TL084I/AI/BI	-40°C, +105°C	•	•	•
TL084C/AC/BC	0°C, +70°C	•	•	•
Example : TL084CN, TL084CD				

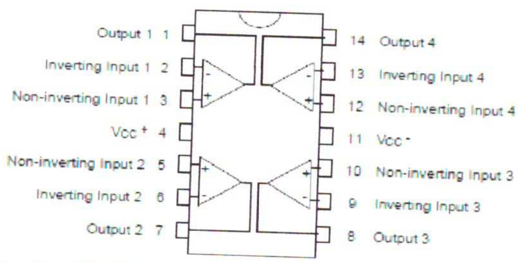
N = Dual in Line Package (DIP)
D = Small Outline Package (SO) - also available in Tape & Reel (DT)
P = Thin Shrink Small Outline Package (TSSOP) - only available in Tape & Reel (PT)

DESCRIPTION

The TL084, TL084A and TL084B are high speed J–FET input quad operational amplifiers incorporating well matched, high voltage J–FET and bipolar transistors in a monolithic integrated circuit.

The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient.

PIN CONNECTIONS (top view)



austriamicrosystems

Voltage Regulator

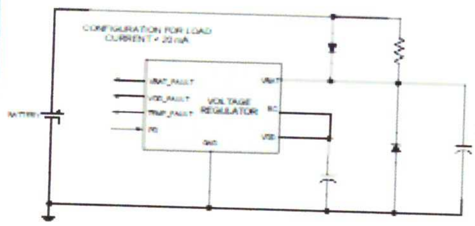
Key Features

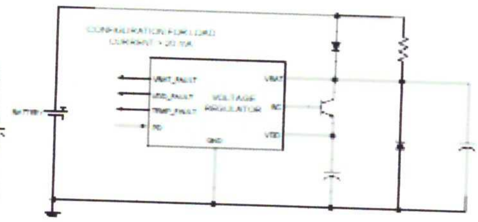
- Vbat monitor with fault signal generation when Vbat is out of operative range
- Vdd monitor with intelligent reset generation based on Vdd level
- Internal protections against transients up to 40V
- Over-temperature monitor
- Power down mode

General Description

This block provides a stable regulated output voltage starting from a battery input with the maximum current load allowed by the thermal package limitation (worst case 20mA). Higher current can be delivered using an external NPN transistor. External capacitors are required on the regulated line (VDD) and the battery supply voltage (VBAT). Battery input is monitored and a fault signal becomes active when VBAT is out of its operative range (an hysteresis is provided). VDD also is monitored and a fault signal becomes active when VDD is below a defined voltage threshold (an hysteresis is provided). Internal protections are designed to handle transients up to 40V. An external 45V zener diode between VBAT and ground with a 500Ω resistor in series with the battery supply and the VBAT pin is required to protect the device from power transients. An external blocking diode is required to provide reverse battery protection. Over-temperature monitor turns off the circuit when the die temperature exceeds the fixed threshold. The circuit has a power-down mode to permit very low standby currents.

Typical Application Diagrams





Key Parameters	Symbol	Min.	Max.	Notes
Battery Supply Voltage	VBAT	7V	18V	Load dump 42V.
Output Voltage	VDD	4.75V	5.25V	Recommended external capacitor >100nF. 20mA max. load, higher current with external transistor.
Temperature Threshold	Toff	160°C		Hysteresis >10 degrees
Ambient Temperature	Tamb	-40°C	85°C	

For detailed information:
info@austriamicrosystems.com
http://www.austriamicrosystems.com/

Revision 1.0, 08/27/03

FAIRCHILD
SEMICONDUCTOR™

October 1987
Revised January 1999

MM74C922 • MM74C923
16-Key Encoder • 20-Key Encoder

General Description

The MM74C922 and MM74C923 CMOS key encoders provide all the necessary logic to fully encode an array of SPST switches. The keyboard scan can be implemented by either an external clock or external capacitor. These encoders also have on-chip pull-up devices which permit switches with up to 50 kΩ on resistance to be used. No diodes in the switch array are needed to eliminate ghost switches. The internal debounce circuit needs only a single external capacitor and can be defeated by omitting the capacitor. A Data Available output goes to a high level when a valid keyboard entry has been made. The Data Available output returns to a low level when the entered key is released, even if another key is depressed. The Data Available will return high to indicate acceptance of the new key after a normal debounce period; this two-key roll-over is provided between any two switches.

An internal register remembers the last key pressed even after the key is released. The 3-STATE outputs provide for easy expansion and bus operation and are LPTTL compatible.

Features

- 50 kΩ maximum switch on resistance
- On or off chip clock
- On-chip row pull-up devices
- 2 key roll-over
- Keybounce elimination with single capacitor
- Last key register at outputs
- 3-STATE output LPTTL compatible
- Wide supply range: 3V to 15V
- Low power consumption

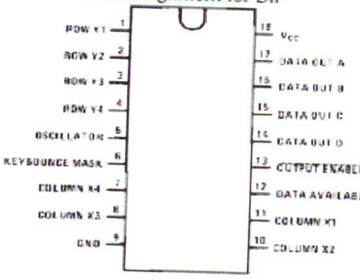
Ordering Code:

Order Number	Package Number	Package Description
MM74C922N	N18A	18-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300" Wide
MM74C922WM	M20B	20-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-013, 0.300" Wide
MM74C923WM	M20B	20-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-013, 0.300" Wide
MM74C923N	N20A	20-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300" Wide

Device also available in Tape and Reel. Specify by appending suffix letter "X" to the ordering code.

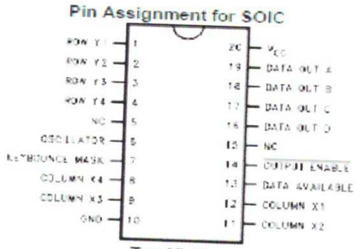
Connection Diagrams

Pin Assignment for DIP



Top View
MM94C922

Pin Assignment for SOIC



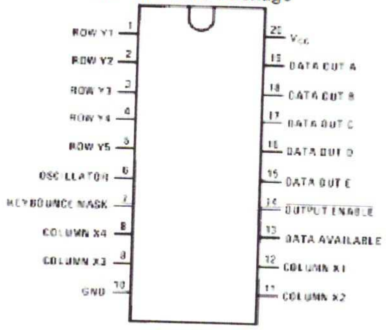
Top View
MM74C922

 DS006037.prf

www.fairchildsemi.com

Connection Diagrams (Continued)

Pin Assignment for
DIP and SOIC Package



Top View
MM74C923

Truth Tables

(Pins 0 through 11)

Switch Position		0 Y1,X1	1 Y1,X2	2 Y1,X3	3 Y1,X4	4 Y2,X1	5 Y2,X2	6 Y2,X3	7 Y2,X4	8 Y3,X1	9 Y3,X2	10 Y3,X3	11 Y3,X4
DATA OUT	A	0	1	0	1	0	1	0	1	0	1	0	1
	B	0	0	1	1	0	0	1	1	0	0	1	1
	C	0	0	0	0	1	1	1	1	0	0	0	0
	D	0	0	0	0	0	0	0	0	1	1	1	1
	E (Note 1)	0	0	0	0	0	0	0	0	0	0	0	0

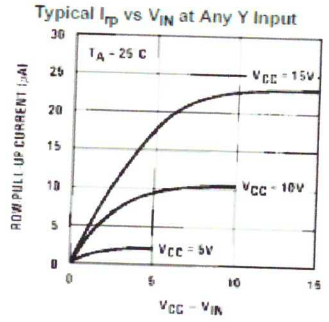
(Pins 12 through 19)

Switch Position		12 Y4,X1	13 Y4,X2	14 Y4,X3	15 Y4,X4	16 Y5(Note 1), X1	17 Y5 (Note 1), X2	18 Y5 (Note 1), X3	19 Y5 (Note 1), X4
DATA OUT	A	0	1	0	1	0	1	0	1
	B	0	0	1	1	0	0	1	1
	C	1	1	1	1	0	0	0	0
	D	1	1	1	1	0	0	0	0
	E (Note 1)	0	0	0	0	1	1	1	1

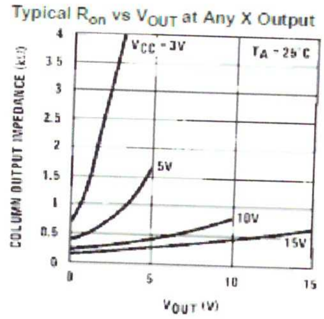
Note 1: Omit for MM74C922

Typical Performance Characteristics

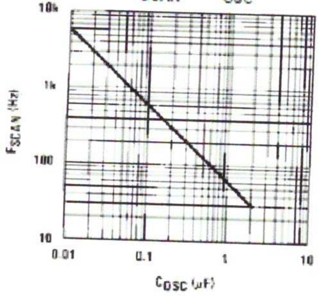
Typical I_{rp} vs V_{IN} at Any Y Input



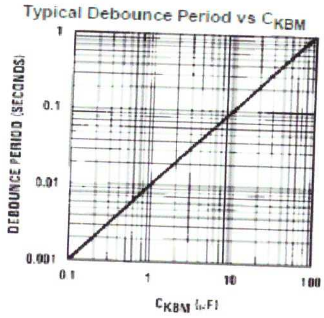
Typical R_{on} vs V_{OUT} at Any X Output



Typical F_{SCAN} vs C_{OSC}

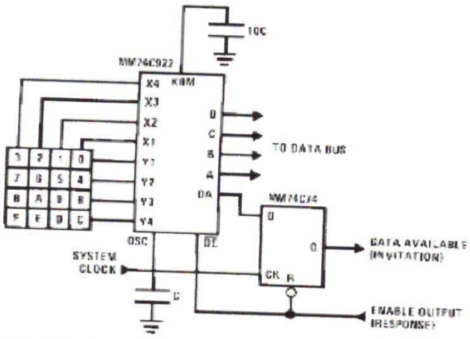


Typical Debounce Period vs C_{KBM}



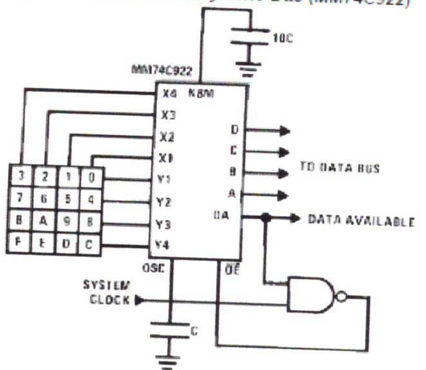
Typical Applications

Synchronous Handshake (MM74C922)



The keyboard may be synchronously scanned by omitting the capacitor at osc. and driving osc. directly if the system clock rate is lower than 10 kHz

Synchronous Data Entry Onto Bus (MM74C922)



Outputs are enabled when valid entry is made and go into 3-STATE when key is released.

The keyboard may be synchronously scanned by omitting the capacitor at osc. and driving osc. directly if the system clock rate is lower than 10 kHz

Appendix B

Weights of the Project Parts

Part Name	Wight of the Part (g)
Rod	67.63
Fan	51.58
Motor	70.64
Balancing Weight	165.71
Motor Home	19.68
Blade	1.71

Appendix C

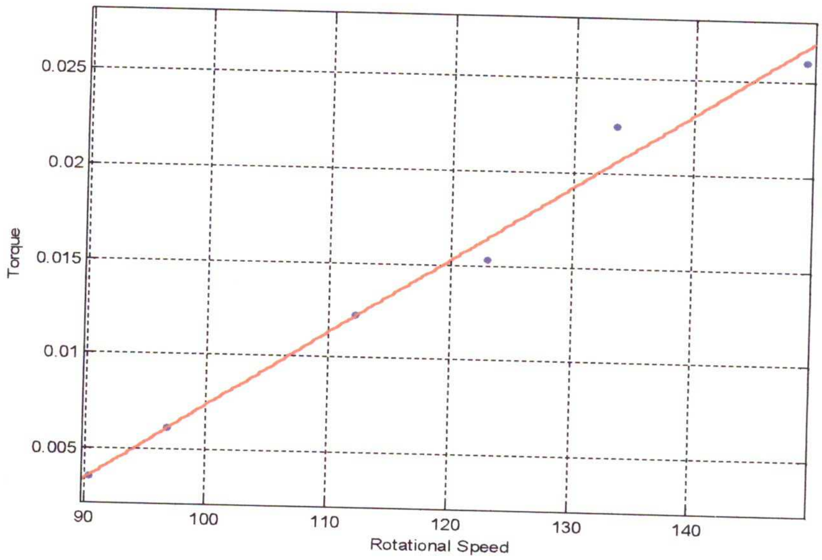
Experiment to Find a Value of C

Armature Voltage (V)	Armature Current (A)	Rotational Speed (rad/s)	Mechanical Torque (N.m)
2	0.07	90.327	0.00357
3	0.12	96.78	0.00612
5	0.24	112.18	0.01224
7	0.3	123.05	0.0153
8	0.44	133.518	0.02244
9	0.51	149.22	0.02601

$$T = K_t I_a$$
$$K_t = 0.051$$
$$T = C\omega$$
$$C = 0.000395$$

Matlab:

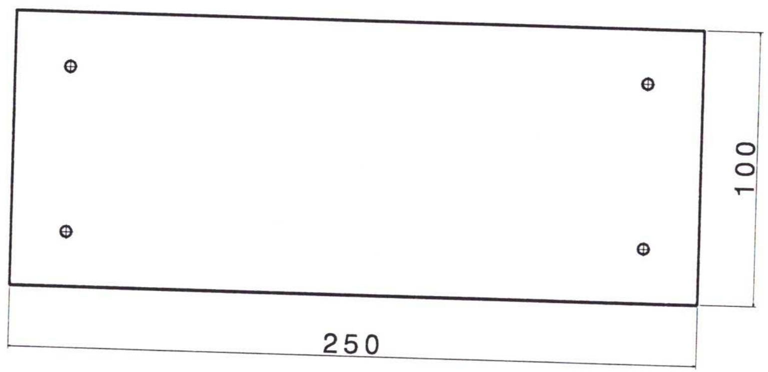
```
>> w=[90.327 96.78 112.18 123.05 133.518 149.22];
>> T=[0.00357 0.00612 0.01224 0.0153 0.02244 0.02601];
>> cftool
```



Appendix D

Project Components Drawing

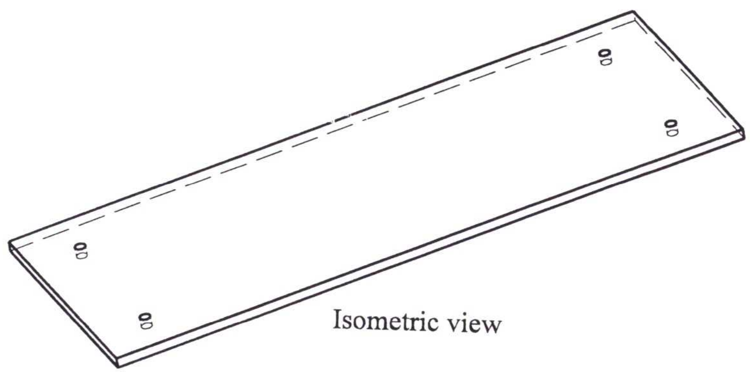
The Lower Base



Front view

Left view

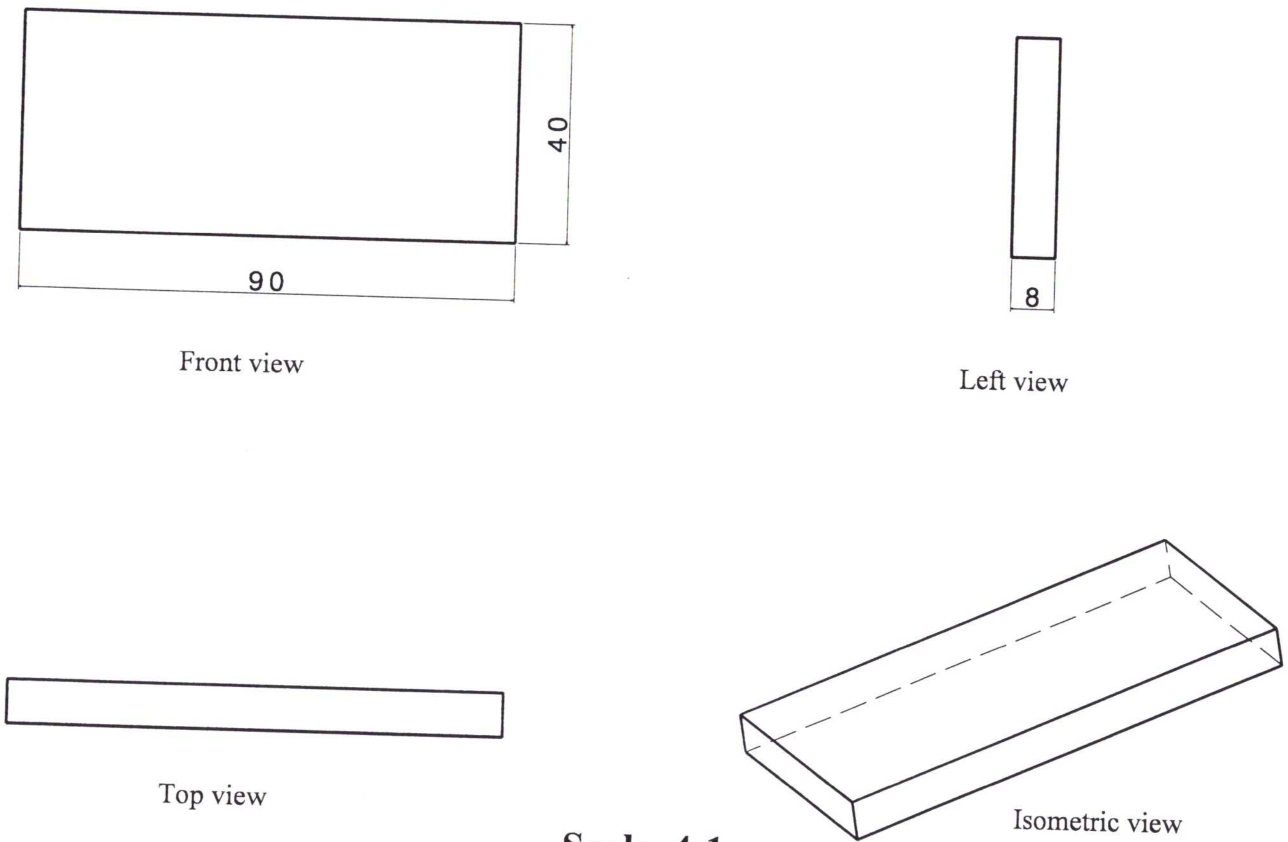
Top view



Isometric view

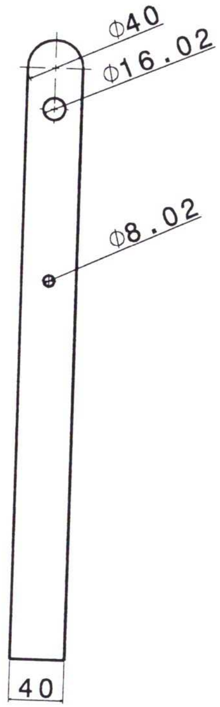
Scale 2:1
All Dimensions in mm

The Upper Base



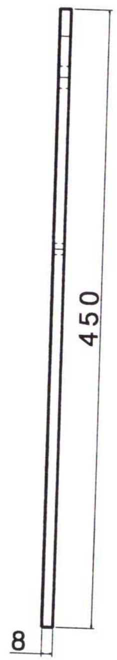
Scale 4:1
All Dimensions in mm

The Column



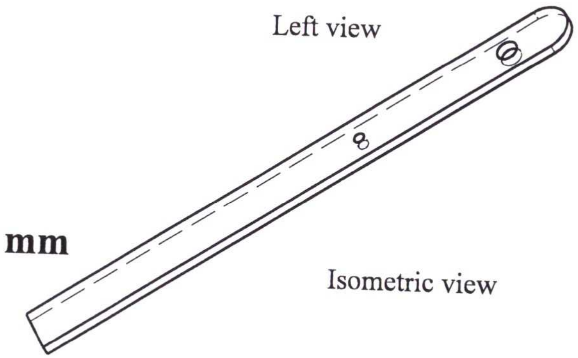
Front view

Top view



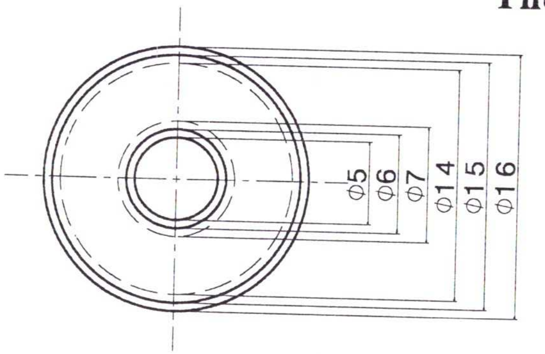
Left view

Scale 1:1
All Dimensions in mm

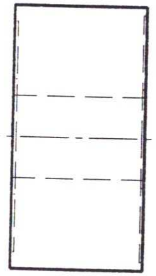


Isometric view

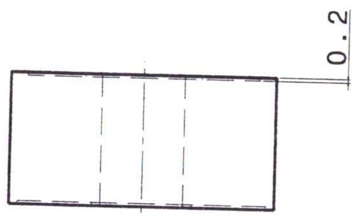
The Bering



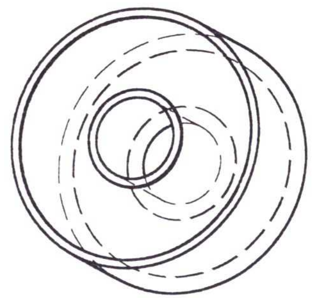
Front view



Left view



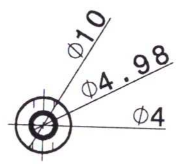
Top view



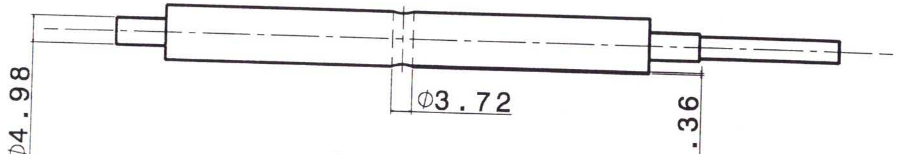
Isometric view

Scale 12:1
All Dimensions in mm

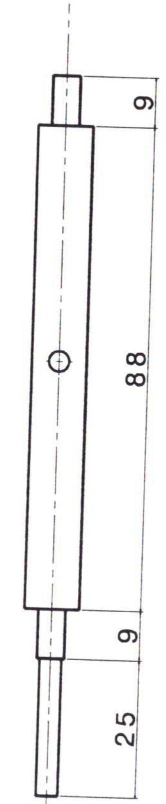
The Movable Joint



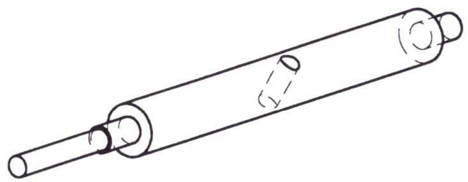
Front view



Left view



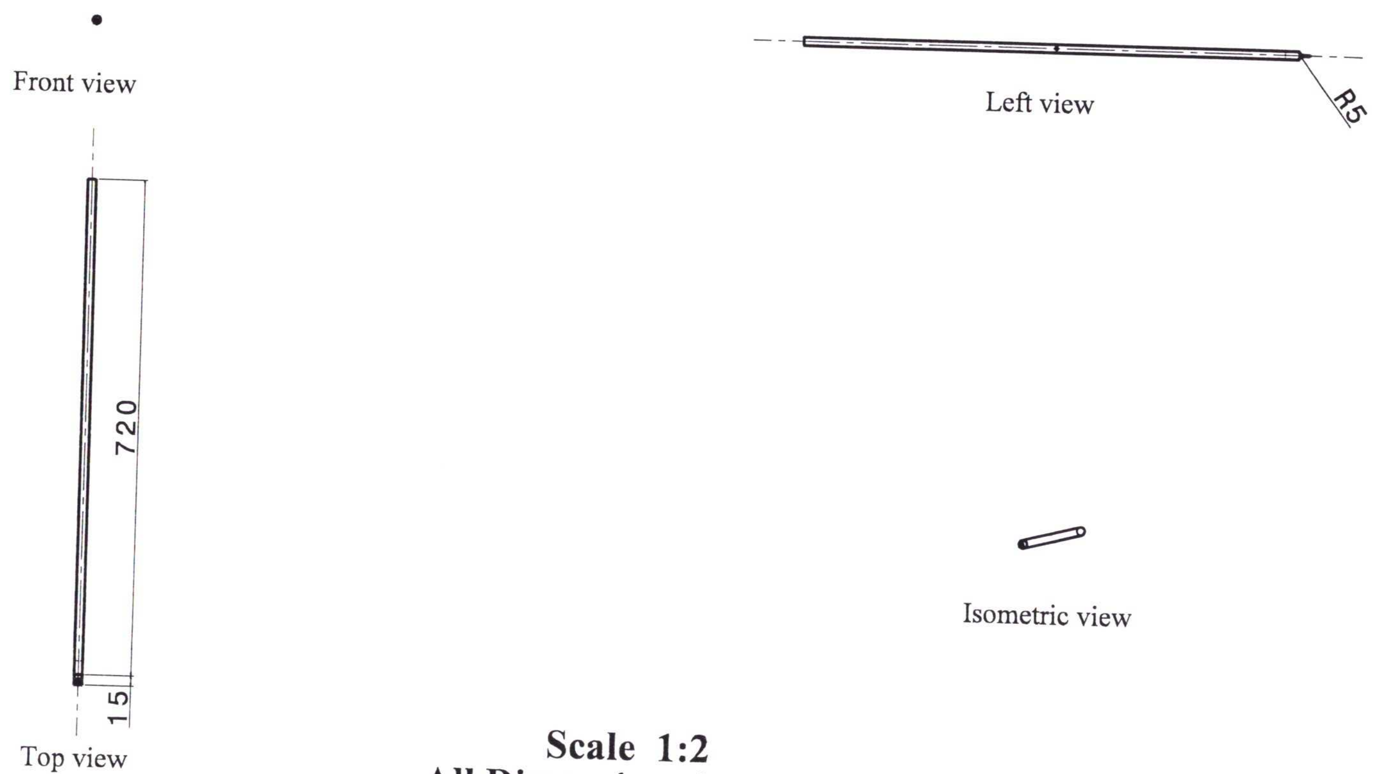
Top view



Isometric view

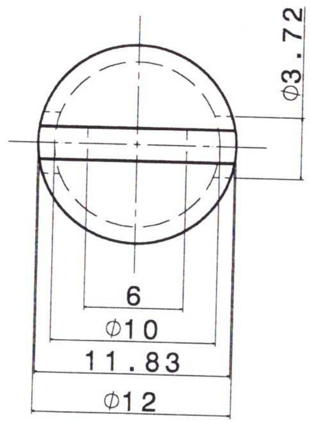
Scale 4:1
All Dimensions in mm

The Rod

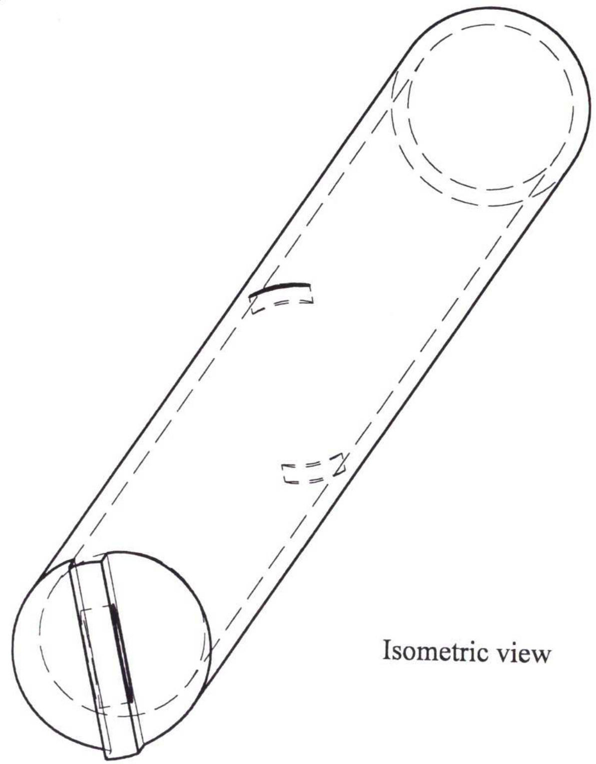


Scale 1:2
All Dimensions in mm

The Rod



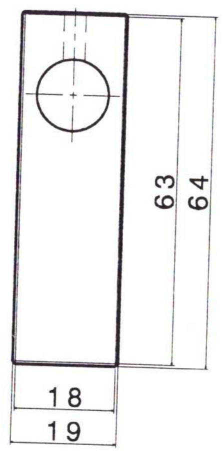
Front view



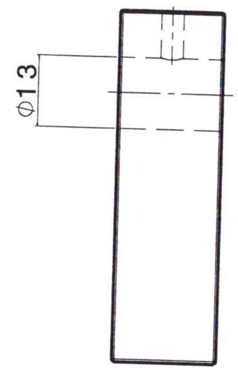
Isometric view

Scale 12:1
All Dimensions in mm

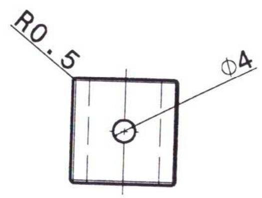
The Balancig Weight



Front view

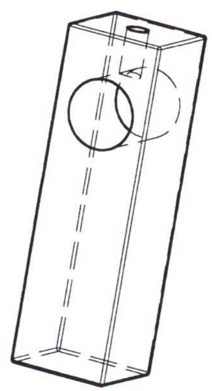


Left view



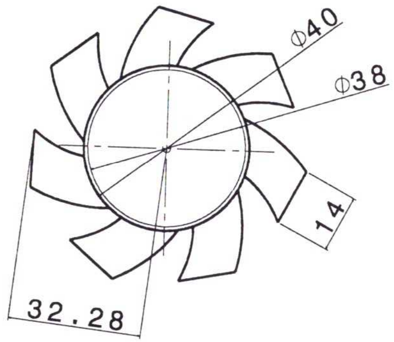
Top view

Scale 4:1
All Dimensions in mm

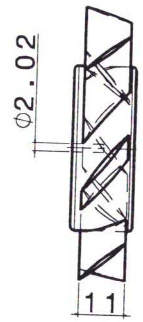


Isometric view

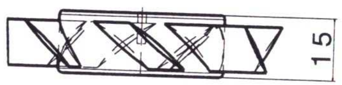
The Fan



Front view



Left view

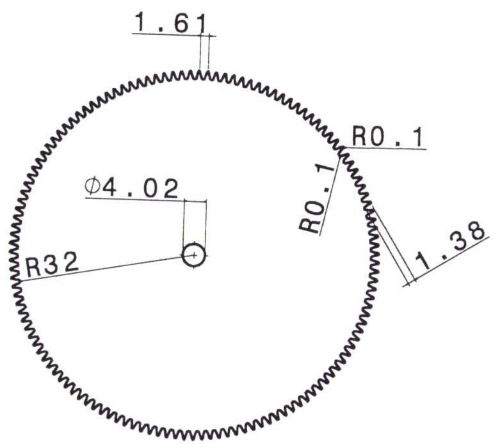


Top view

Isometric view

Scale 3:1
All Dimensions in mm

The Bigest Gear



Front view

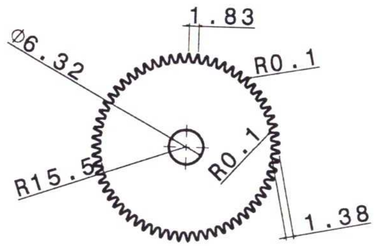
Left view

Top view

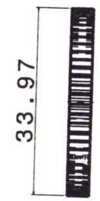
Scale 4:1
All Dimensions in mm

Isometric view

The Smallest Gear



Front view



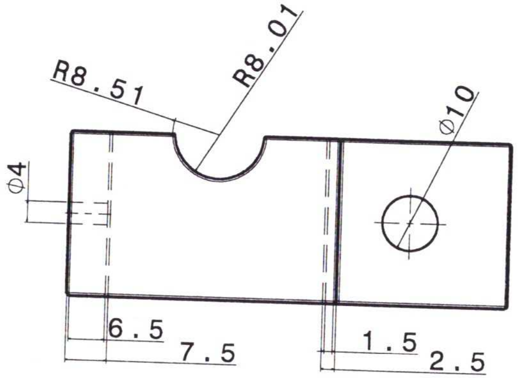
Left view

Top view

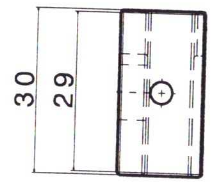
Isometric view

Scale 4:1
All Dimensions in mm

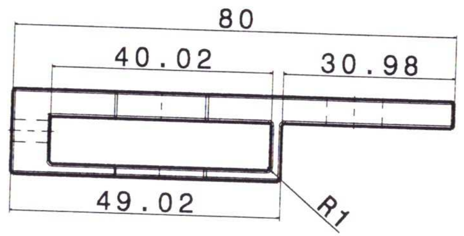
Potentiometer Base



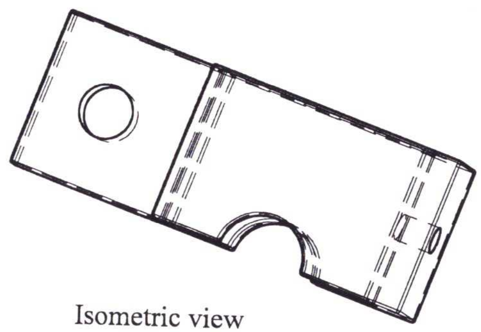
Front view



Left view

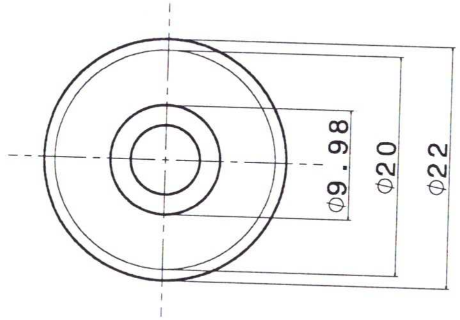


Top view

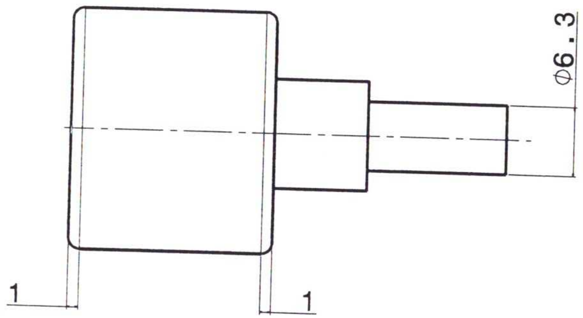

Isometric view

Scale 4:1
All Dimensions in mm

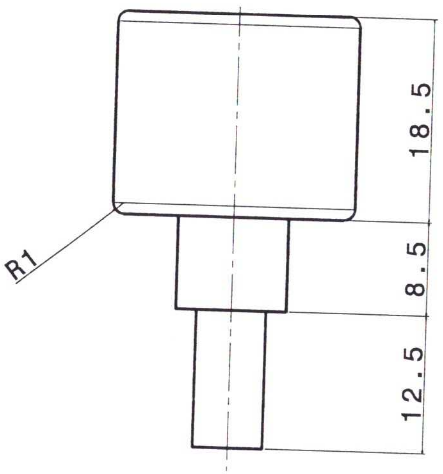
The Potentiometer



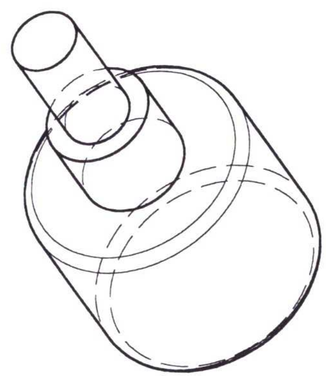
Front view



Left view



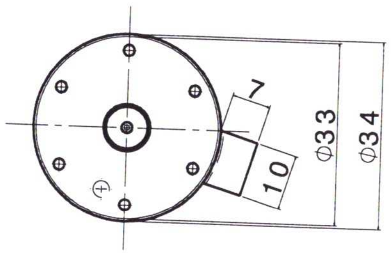
Top view



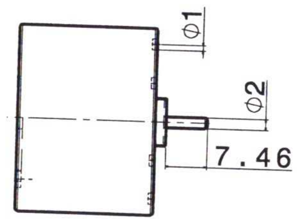
Isometric view

Scale 8:1
All Dimensions in mm

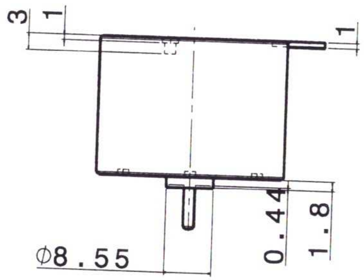
The Motor



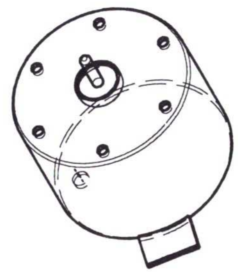
Front view



Left view

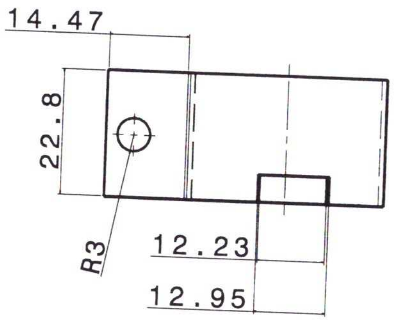


Top view

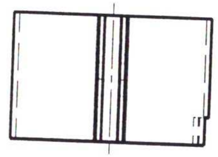

Isometric view

Scale 4:1
All Dimensions in mm

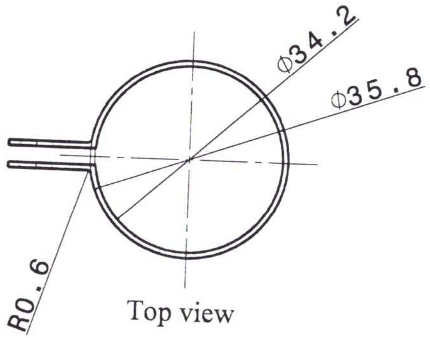
Motor Home



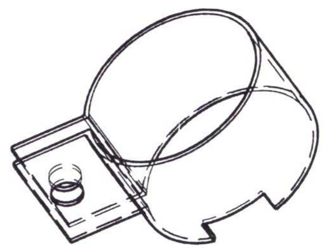
Front view



Left view



Top view



Isometric view

Scale 4:1
All Dimensions in mm

Appendix E

Project Program

```
/*****************************************************************
/*****************************************************************

#include <p18f4550.h>
#include "gamelcd_v3.h"
#include "timers.h"
#include <adc.h>
#include <pwm.h>

#pragma config FOSC = INTOSC_HS
#pragma config CPUDIV = OSC1_PLL2
#pragma config USBDIV = 2
#pragma config PLLDIV = 5

#pragma config WDT = OFF
#pragma config LVP = OFF



//*****************************************************************
//*****************************************************************

float uk=0.000000,m=0,uk_1=0,ek=0,ek_1=0,p=0,n=0,v=0,u=0,x,b=0,a=0;
short N=0;


//*****************************************************************
void main(void)
{

OSCCON=0xff;

TRISC=TRISC&0b11111011;
TRISB=255;

ADCON1=0x0A;

OpenADC(ADC_FOSC_64&ADC_RIGHT_JUST&ADC_2_TAD,ADC_CH0&ADC
_INT_OFF&ADC_VREFPLUS_VDD&ADC_VREFMINUS_VSS,0x0A);
OpenTimer2(TIMER_INT_OFF&T2_PS_1_1&T2_POST_1_1);
OpenTimer3(TIMER_INT_ON&T3_16BIT_RW&T3_SOURCE_INT&T3_PS_1_1&
T3_OSC1EN_OFF& T3_SYNC_EXT_OFF);

lcd_init();

INTCON=0b11000000;
PIE2bits.TMR3IE=1;
WriteTimer3(56536);

OpenPWM1(99);
```

```
SetDCPWM1(0);

//*****************************************************************

while(1)
{

uk_1=0;

while (1)
{


//a=(PORTB & 0b00001111);

//*****************************************************************

if
(PORTBbits.RB0==0&&PORTBbits.RB1==0&&PORTBbits.RB2==0&&PORTBbit
s.RB3==0)
{m=5;lcd_gotoyx(1,1);lcd_putrs("05");

a=0.06524*m+2.278;

//SetDCPWM1(400*a/9);
ek=a-p;
if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{ek=a-p;
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);
```

```
lcd_gotoyx(2,8);
lcd_puti(ek);


}
//SetDCPWM1(400*a/9);
//break;}

//*******************************************************************

else
if(PORTBbits.RB0==1&&PORTBbits.RB1==0&&PORTBbits.RB2==0&&PORTBb
its.RB3==0)
{m=10;lcd_gotoyx(1,1);lcd_putrs("10");

a=(0.06524*m+2.278);

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);


}
```

```
//*********************************************************************
else
if(PORTBbits.RB0==0&&PORTBbits.RB1==1&&PORTBbits.RB2==0&&PORTBb
its.RB3==0)
{m=15;lcd_gotoyx(1,1);lcd_putrs("15");

a=0.06524*m+2.278;
// SetDCPWM1(400*a/9);

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);


}

//*********************************************************************
else
if(PORTBbits.RB0==0&&PORTBbits.RB1==0&&PORTBbits.RB2==1&&PORTBb
its.RB3==0)
{m=20;lcd_gotoyx(1,1);lcd_putrs("20");

a=0.06524*m+2.278;

ek=a-p;
```

```
if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);


}

//************************************************************************

else
if(PORTBbits.RB0==1&&PORTBbits.RB1==0&&PORTBbits.RB2==1&&PORTBb
its.RB3==0)
{m=25;lcd_gotoyx(1,1);lcd_putrs("25");

a=0.06524*m+2.278;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
```

```
 uk=((22392*ek)-(22052*ek_1)-(uk_1));

 SetDCPWM1(400*uk/9);

 uk_1=uk;
 ek_1=ek;
 }

 lcd_gotoyx(2,1);
 lcd_puti(N);


 lcd_gotoyx(1,8);
 lcd_puti(a*10);


 lcd_gotoyx(2,8);
 lcd_puti(ek*10);


 }

//*****************************************************************

else
if(PORTBbits.RB0==0&&PORTBbits.RB1==1&&PORTBbits.RB2==1&&PORTBbits.RB3==0)
{m=30;lcd_gotoyx(1,1);lcd_putrs("30");

a=0.06524*m+2.278;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
```

```
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);

}

//**************************************************************************

else
if(PORTBbits.RB0==0&&PORTBbits.RB1==0&&PORTBbits.RB2==0&&PORTBb
its.RB3==1)
{m=35;lcd_gotoyx(1,1);lcd_putrs("35");

a=0.06524*m+2.278;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);
}
```

```
//**********************************************************************

else
if(PORTBbits.RB0==1&&PORTBbits.RB1==0&&PORTBbits.RB2==0&&PORTBbits.RB3==1)
{m=40;lcd_gotoyx(1,1);lcd_putrs("40");

a=0.06524*m+2.278;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);

}

//**********************************************************************

else
if(PORTBbits.RB0==0&&PORTBbits.RB1==1&&PORTBbits.RB2==0&&PORTBbits.RB3==1)
{m=45;lcd_gotoyx(1,1);lcd_putrs("45");
a=0.06524*m+2.278;

ek=a-p;
```

```
if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);

}

//*****************************************************************

else
if(PORTBbits.RB0==1&&PORTBbits.RB1==1&&PORTBbits.RB2==0&&PORTBb
its.RB3==0)
{m=50;lcd_gotoyx(1,1);lcd_putrs("50");
a=0.06524*m+2.278;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);
```

```
uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);

}

//*****************************************************************

else
if(PORTBbits.RB0==1&&PORTBbits.RB1==1&&PORTBbits.RB2==1&&PORTBb
its.RB3==0)
{m=55;lcd_gotoyx(1,1);lcd_putrs("55");

a=0.06524*m+2.278;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);
```

```
lcd_gotoyx(2,8);
lcd_puti(ek*10);

}

//*****************************************************************

else
if(PORTBbits.RB0==1&&PORTBbits.RB1==1&&PORTBbits.RB2==0&&PORTBb
its.RB3==1)
{m=60;lcd_gotoyx(1,1);lcd_putrs("60");

a=0.06524*m+2.278;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);

}

//*****************************************************************

else
if(PORTBbits.RB0==1&&PORTBbits.RB1==1&&PORTBbits.RB2==1&&PORTBb
its.RB3==1)
```

```
{m=65;lcd_gotoyx(1,1);lcd_putrs("65");

a=0.06524*m+2.27;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);

}

//***********************************************************************

else
if(PORTBbits.RB0==0&&PORTBbits.RB1==0&&PORTBbits.RB2==1&&PORTBb
its.RB3==1)
{m=75;lcd_gotoyx(1,1);lcd_putrs("75");

a=0.06524*m+2.278;

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
```

```
uk_1=0;
}
else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

SetDCPWM1(400);

uk_1=uk;
ek_1=ek;
}

lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);

}

//*****************************************************************
else
if(PORTBbits.RB0==0&&PORTBbits.RB1==1&&PORTBbits.RB2==1&&PORTBb
its.RB3==1)
{m=70;lcd_gotoyx(1,1);lcd_putrs("70");

a=(0.06524*m+2.278);

ek=a-p;

if(ek<=0)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}
else
{
uk=(ek)-(ek_1)-(uk_1);

SetDCPWM1(400*uk/9);

uk_1=uk;
ek_1=ek;
}
```

```
lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(uk);

}

//***********************************************************

else
{m=0;lcd_gotoyx(1,1);lcd_putrs("00");
a=0.06524*m+2.278;
SetDCPWM1(0);}
}

//*********************************************************

//n=10*(PORTB & 0b00001111);lcd_gotoyx(1,1);lcd_puti(0.12*n);

//a=0.06524*m+2.278+1;

//SetDCPWM1(400*a/9);

//***************************************************************
//***************************************************************

//a=9;

/*if(ek<=0|m==0|a<=1)
{uk=0;
SetDCPWM1(0);
ek_1=0;
uk_1=0;
}

else
{
uk=((22392*ek)-(22052*ek_1)-(uk_1));

//SetDCPWM1(400*uk/9);

//uk_1=uk;
//ek_1=ek;
```

```
lcd_gotoyx(2,1);
lcd_puti(N);


lcd_gotoyx(1,8);
lcd_puti(a*10);


lcd_gotoyx(2,8);
lcd_puti(ek*10);

*/

}

CloseTimer3();

}

//*****************************************************************
//*****************************************************************

#pragma  interrupt TT
void TT(void)

{

if (PIR2bits.TMR3IF==1)

{

ConvertADC();
while(BusyADC()==1);
N=ReadADC();

p=N/110;

//ek=a-p;


//*****************************************************************

PIR2bits.TMR3IF=0;
WriteTimer3(56536);

}
}
```

```
//*********************************************************************
//*********************************************************************

#pragma code  CC=0x08
void CC(void)
{
_asm goto TT _endasm
}

#pragma code

/**********************************************************************
/**********************************************************************
```