Palestine Polytechnic University

College of Engineering & Technology
Mechanical Engineering Department

Graduation Project

Semi-Automatic Wrapping Machine For Pallets

Project Team
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Palestine Polytechnic University
Hebron-Palestine
College of Engineering & Technology
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According to the orientations of the supervisor on the project and the examined committee is by the agreement of a staffers all, sending in this project to the Mechanical engineering department are in the college of the engineering and the technology by the requirements of the department for the step of the bachelor's degree.

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Committee signature

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Abstract

"Semi-automatic Wrapping Machine For Pallets"

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&

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This project is to design and build a wrapping machine to wrap pallets with a stretch film (shrinkage) film which is a reprogrammable machine and it can do that in an automatic operation with a predetermined a number of revolute at upper and bottom of pallets or in manual operation where the user determines the path of the film carriage up and down. There is two independent drive motors are used for driving the film carriage and the turntable by using some of mechanisms.

Dedication

We dedicate this simple work:

To our parents

To our brothers

To our friends

To our nation

To any person works hardly…

Acknowledgement

First and for most we should offer our thanks, obedience and gratitude to Allah.

Our appreciation to:

Palestine Polytechnic University

College of Engineering & Technology

Mechanical Engineering Department

Our supervisor Dr. Ishaq Seder

Any one who helped us

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Introduction

CHAPTER ONE

INTRODUCTION

1.1 Overview

Stretch wrapping machine is generally used to package a palletised loads with a stretch-film.

This project intends to design and build a semi-automatic wrapping machine for pallets with stretch film, adjustment of the film tension by mechanical brake, with adjustable turntable rotation speed, its principle that the pallets will revolute around the z-axis, the wrapping material will have a linear motion in the z-direction. The project configuration is show in figure (1.1)

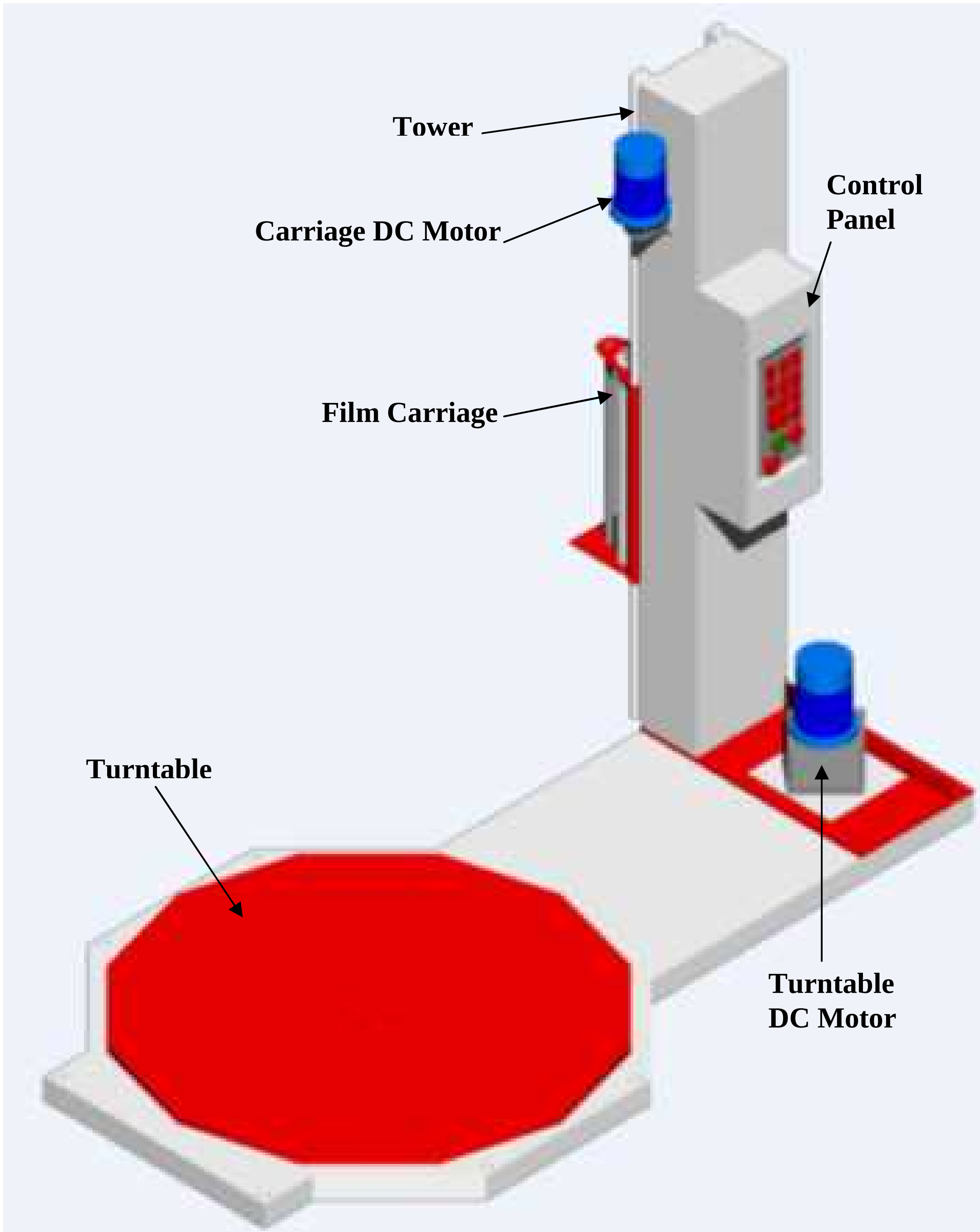


Fig (1.1): Machine configuration.

1.2 Importance of the project

After some research and recommendations from the pioneers, there seem that the local industries need for wrapping machine for pallets.

This is a good mechatronics engineering project, which contains some of the mechatronics engineering skills, such as a mechanical and electrical engineering skills and programming language that required for the student after graduation.

1.3 Time Plane

Table (1.1): The time plan of the project.

Time(week) / Tasks	1	2	3	4	5	6	7	8	9	11	12	13	14	15	16
Design															
Implementation															
Testing															
Writing documentation															

1.4 Project scope

This project contains of five chapters and organized as follows:

Chapter One: Introduction, It provides an overview about the wrapping machine and the scope of the project.

Chapter Two: Mechanical Design, Explanation and design of mechanical parts of the machine are specified in this chapter.

Chapter Three: Electrical Design, Presentation and interfacing of the electrical and electronic devices are designed in this chapter.

Chapter Four: Control, This chapter deals with the control system, computer process control and interfacing.

Chapter five: Conclusions and Economic Cost of the Project.

Appendices

Appendix A, The C Program.

Appendix B, Data Sheets.

Chapter Two

Mechanical Design

Chapter Two

Mechanical Design

2.1 The Mechanical Configuration.

The objectives of this chapter are to establish the configuration of the machine, and its design and select the mechanical elements composing the machine.

In mechanical design there are two design strategies: the first one is assuming that all dimensions, locations of connectors, and kinds of materials are unknown, then fixing some of them and see the best dimensions and locations after doing the analysis. The second strategy is seeing what is available of materials, dimensions and expects the best locations of connectors and supporters, then check for a desired factor of safety [1]. The second strategy is to be used.

The system is designed with the following configuration as shown in figure (1.1).

The mechanical system consists of two main parts; the first is turntable, which has the configuration and the components as shown in figure (2.1).

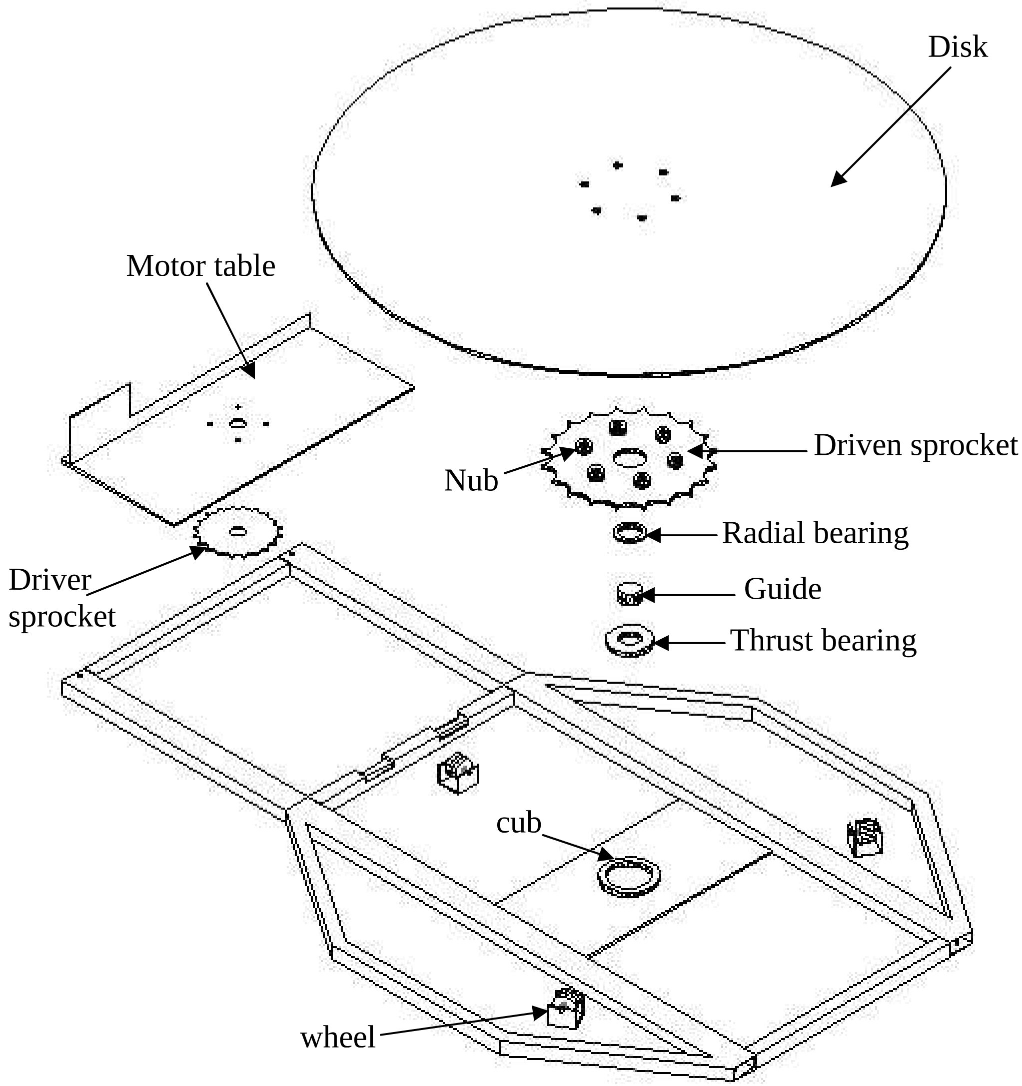


Figure (2.1): The configuration of the turntable.

2.1.1 Disk design

The disk as shown in the figure (2.2.a) has two identical circular plates with a radius of 80cm and a set of ribs (8 ribs) assembled as shown, the length of each rib is 73 cm.

By assuming each ribs (steel, where the yield strength (S_y) equal 380MPa) as a cantilever beam affected by a uniform distributed load (w) equal 2950 N/m, figure (2.2.b) show the shear and bending diagram for each ribs.

Note: The maximum load on the disk is 17228 N, so the load at each rib is 2153 N, where the load is distributed load so at one rib the load is 2950 N/m

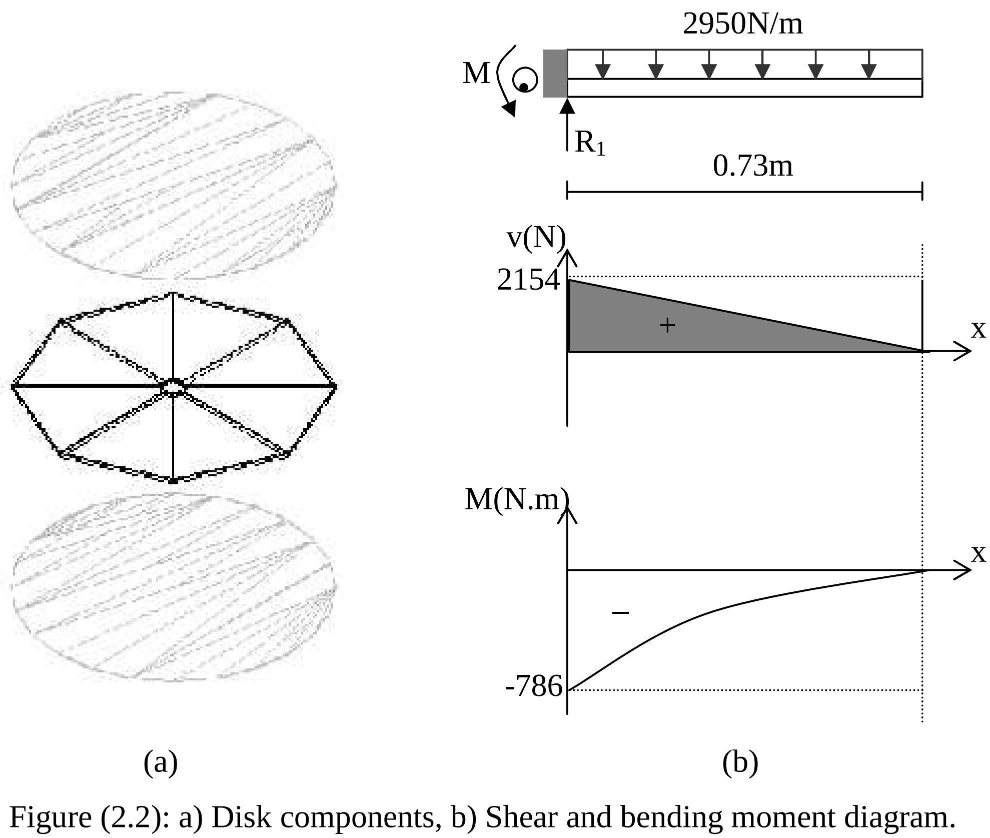


Figure (2.2): a) Disk components, b) Shear and bending moment diagram.

$$\sum F_y = 0 \rightarrow R_1 = 2950 \cdot l = 2154N$$

From the bending diagram the maximum moment will equal to:

$$|M_{max}| = 786 \text{ N.m}$$

σ_{max} is maximum stress and it is given by:

$$\pm_{\max} = \frac{|M_{\max}| \cdot c}{I} \qquad (2.1)$$

where

c: is the half thickness of the beam (rib).

M_{max}: is the maximum bending moment.

I: is the moment of area about x-axis and it is, for rectangular cross section, given by:

$$I = \frac{(b \cdot h^3)}{12} \qquad (2.2)$$

where

b: is the width of the beam and equal 20mm.

h: is the thickness and equal 2c = 30mm.

then,

$$\sigma_{max} = (786)(10*10^{-3})/(45*10^{-9}) = 175 \text{ Mpa} < Sy$$

So, its design in safe side.

2.1.2 Wheels design

The importance of the wheels that placed under the disk as shown previous figure (2.1), to carry (support) the disk and to balance the disk.

The type of the wheel pin material is (steel) and its cross section is a circular, which has a radius (r), which can be calculated by the following equation:

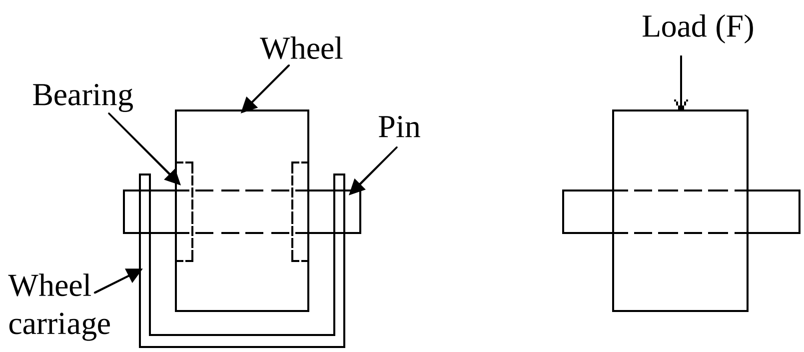


Figure (2.3): a) Wheel components. b) The effect load on the wheel.

The maximum shear stress τ_{max} for the circular cross section equal Sy/2 given by:

$$\tau_{max} = \frac{V}{A} \qquad (2.3)$$

where: *Sy* is the yielding stress of the steel and equal 535 Mpa [1].

then,

$$267.5*10^6 = \frac{(667*9.81/2)}{(\pi * r^2)}$$

$$\Rightarrow r = 2*10^{-3} m$$

2.2 The Tower

The second main part is the tower which has the configuration as shown in figure (2.4).

The function of the tower is to carry the film carriage, which distributes the wrapping material on the pallet where the film carriage slides in the vertical direction.

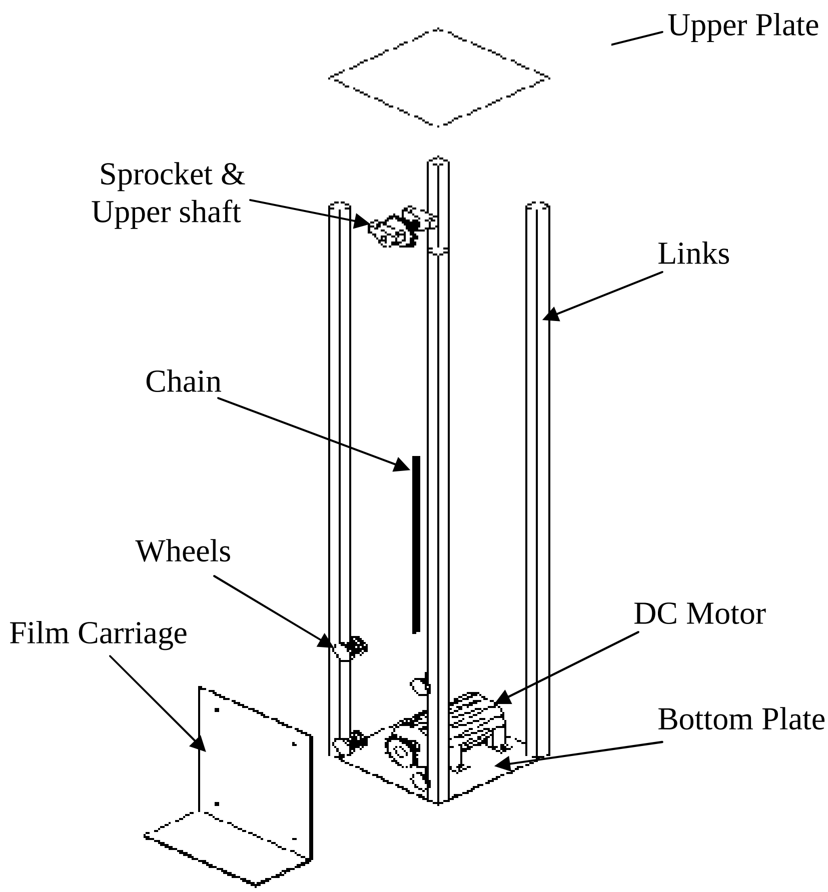


Figure (2.4): Tower Configuration.

2.2.1 Motor shaft design

The motor shaft is the shaft that transmits the motion to the sprocket that attached the film carriage by the chain and so the forces acting on it are the torque applied from the motor and the reaction bending moment resulting from the reaction force on the sprocket figure (2.5).

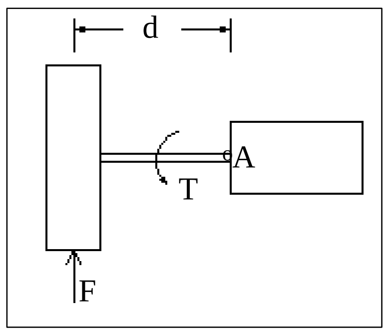


Figure (2.5): Motor shaft free body diagram.

Where

F: is the reaction force (the weight of the carriage and the load) and it is equal 490N.

M: is the resulting bending moment from the reaction force on the sprocket.

d: is the distance between the center of the sprocket and the beginning of shaft and it is equal 3cm.

then,

$$M = (490)(3 * 10^{-2}) = 14.75 N.m$$

by taking a critical point on the shaft which is at A, then the stresses at it, figure (2.6).

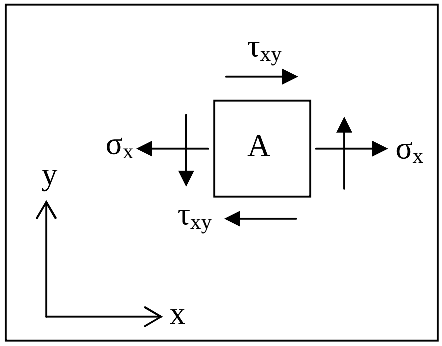


Figure (2.6): Stresses at point A.

then,

$$\tau_{xy} = {(T \cdot c)}/{J} \qquad (2.4)$$

Where

τ_{xy}: is the shearing stress.

c: is the radius of the shaft and equal 7mm.

I: is the second moment of area about z-axis.

T: is the applied torque and equal 14.75 N.m.

then, for circular cross section

$$I = {(\pi \cdot c^4)}/{2}$$

$$= 37.7 * 10^{-10}\, m^4 \qquad (2.5)$$

then,

$$\tau_{xy} = 27.4 \text{ MPa}$$

the moment of area about for circular cross section, given by:

$$I = \left(\pi \cdot c^4\right) / 4 \qquad (2.6)$$

Depending on the equation (2.1)

$$\sigma_x = 54.6 MPa$$

the principle stresses are given in the relation

$$\sigma_{A,B} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^{\ 2}} \qquad (2.7)$$

$\sigma_y = 0$

then

$\sigma_A = 66$ MPa

$\sigma_B = -11.4$ MPa

The maximum shearing stress is given by:

$$\tau_{\max} = \left(\sigma_{\max} - \sigma_{\min}\right) / 2 \qquad (2.8)$$

where σ_{max} equal to σ_A

σ_{min} equal to σ_B

then,

$$\tau_{\max} = 38.7 MPA$$

noting that the shaft of the motor is made of steel with the yield stress S_y = 355MPa, and the shearing stress is given by:

$$S_{sy} = Sy/2 \qquad [1]$$

$$= 355/2 = 177.5MPa \qquad (2.9)$$

One important theory in mechanical design is maximum shear stress theory [1]:

$$n = \frac{S_{sy}}{2}_{max} \qquad (2.10)$$

where

n: is the factor of safety which <u>must be greater than one.</u>

S_y: is the yielding stress of the used material.

σ_{max}: is the maximum stress, MPa.

Using maximum shearing stress to find the factor of safety yields to:

$$n = 177.5/38.7 = 4.6$$

This indicates that the design is safe.

2.2.2 Upper shaft design

The tower includes a shaft, which is supported by self-aligning bearings at the ends, mounted upon the shaft is roller chain, which contributes a radial load. The assumed shear force and bending diagram is shown in figure (2.7).

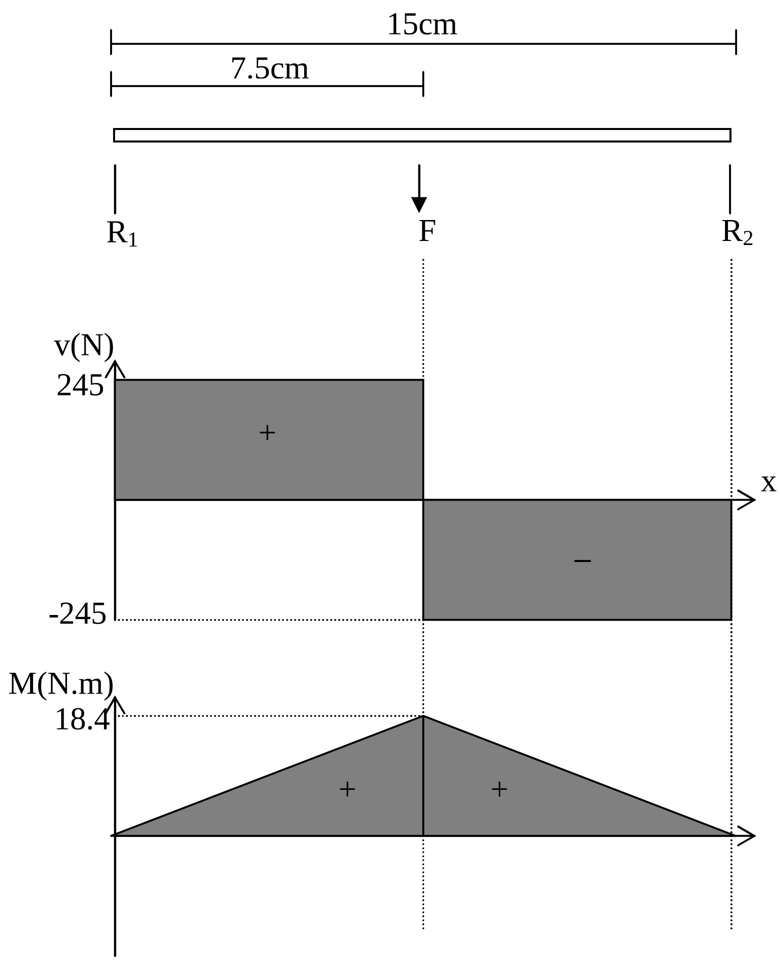
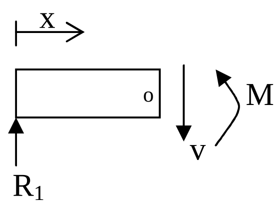


Figure (2.7): Bending and shear diagrams for the shaft.

By taking the cut at 0<x<7.5cm, then the free body diagram is:



$\Sigma F_y = 0 \rightarrow v = R_1 = 245$ N

$\Sigma M_o = \rightarrow M = R_1 * x$

So, the M_{max} at x = 0.075 m is equal to 18.4 N.m

From the bending diagram the maximum moment will equal to:

$$|M_{max}| = 18.4 \text{ N.m}$$

Depending on the equations (2.1) and (2.6), where the radius of the guide (r) equal c = 10mm (steel with the yield stress S_y = 355 MPa).

then,

$$\pm_{max} = \frac{(18.4)(10 * 10^{-3})}{0.49 * 10^{-12}}$$

$$= 0.4 \text{ MPa} < Sy$$

2.2.3 Upper plate design

As an approximation we can consider the upper plate as a beam to do the mechanical analyses, then the free body diagram of the plate will be as in figure (2.8). The dealing with this approximation will be easier as shown in the free body diagram. Where F (weight of the film carriage with the chain) equal 540N, the points A and B is the reactions of the bearings.

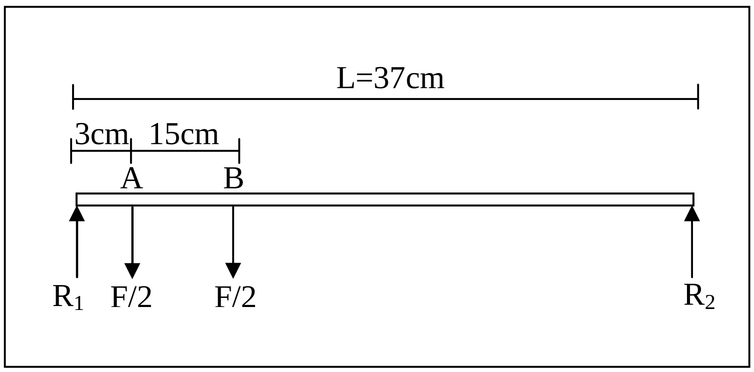


Figure (2.8): Free body diagram of the upper plate.

To find the shearing force and bending moment diagram, section must be taken before A and B, then reaction shear force V and bending moment M could be found and plotted overall the beam.

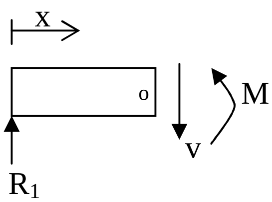
By applying Newton's second law:

$\Sigma F_y = 0 \rightarrow R_1 + R_2 - F = 0$

$\Sigma M_{R1} = 0 \rightarrow R_2*0.37 - (F/2)*0.03 - (F/2)*0.15 = 0$

then, R_1=408.6N, R_2=131.4N.

By taking the cut at $0<x<3$cm. Then the free body diagram is:



$\Sigma F_y = 0 \rightarrow v = R_1 = 408N$

$\Sigma M_o = 0 \rightarrow M = R_1 * x$ for $(3<x<18)$

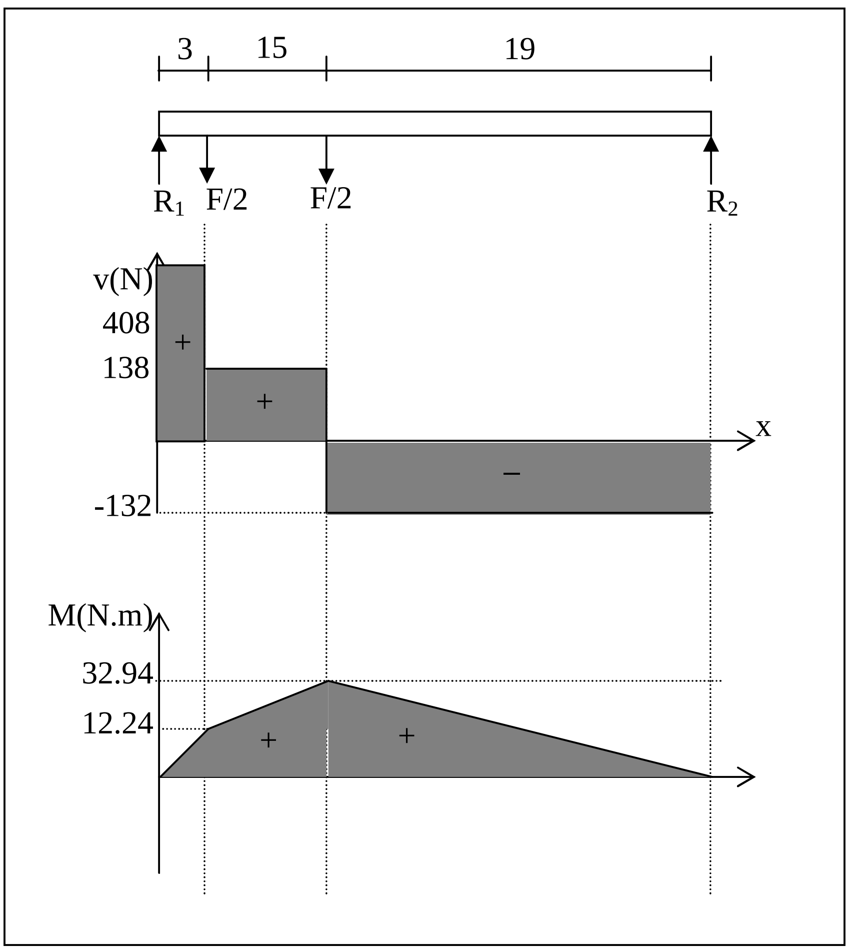


Figure (2.9): Shear and bending diagrams for upper plate.

From the bending diagram the maximum moment will be at x = 18:

$$|M_{max}| = 32.94 \text{ N.m}$$

Depending on the equations (2.1) and (2.2), where the width of the plate *b* equal 37cm and its thickness *h* equal 2c = 6mm.

then,

$$\sigma_{max} = (32.94).(3*10^{-3})/(6.7*10^{-9}) = 14.8\text{MPa} < S_y$$

2.2.4 Bottom plate design

Assuming this plate has dimensions (40cm * 80cm), then the free body diagram and the bending diagram of this plate will be as shown in figure (2.10). Where F is the weight of the tower with load and equal 980N (490N structure + 490N load).

By applying Newton's second law:

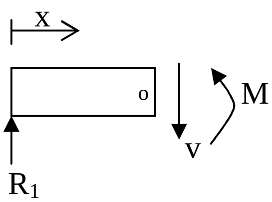
$\Sigma F_y = 0 \rightarrow R_1 + R_2 – (F/2) – (F/2) = 0$

$\Sigma M_{R1} = 0 \rightarrow R_2*0.8 – (F/2)*0.04 – (F/2)*0.41 = 0$

then,

$R_1 = 705N$, $R_2 = 275$ N.

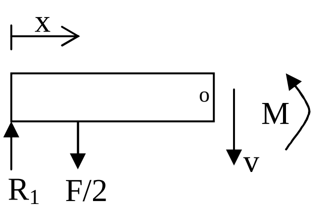
By taking the cut at (0<x<4cm). Then the free body diagram is:



$\Sigma F_y = 0 \rightarrow v = R_1 = 705N$

$\Sigma M_o = 0 \rightarrow M = R_1 * x = 705 * x$

By taking the cut at (0<x<41cm). Then the free body diagram is:



$\Sigma Fy = 0 \rightarrow v = R1 – (F/2) = 705 – 490 = 215$ N

$\Sigma Mo = 0 \rightarrow M = R1 * x_1 – (F/2) * x_2 = 107.75$ N.m

From the bending diagram the maximum moment will be at x_1 = 41cm and x_2 = 37cm:

$$|M_{max}| = 107.75 \text{ N.m}$$

Depending on equation (2.1)

$$\sigma_{max} = (107.75).(3*10^{-3})/(6.7*10^{-9}) = 48.3 \text{ MPa} < S_y$$

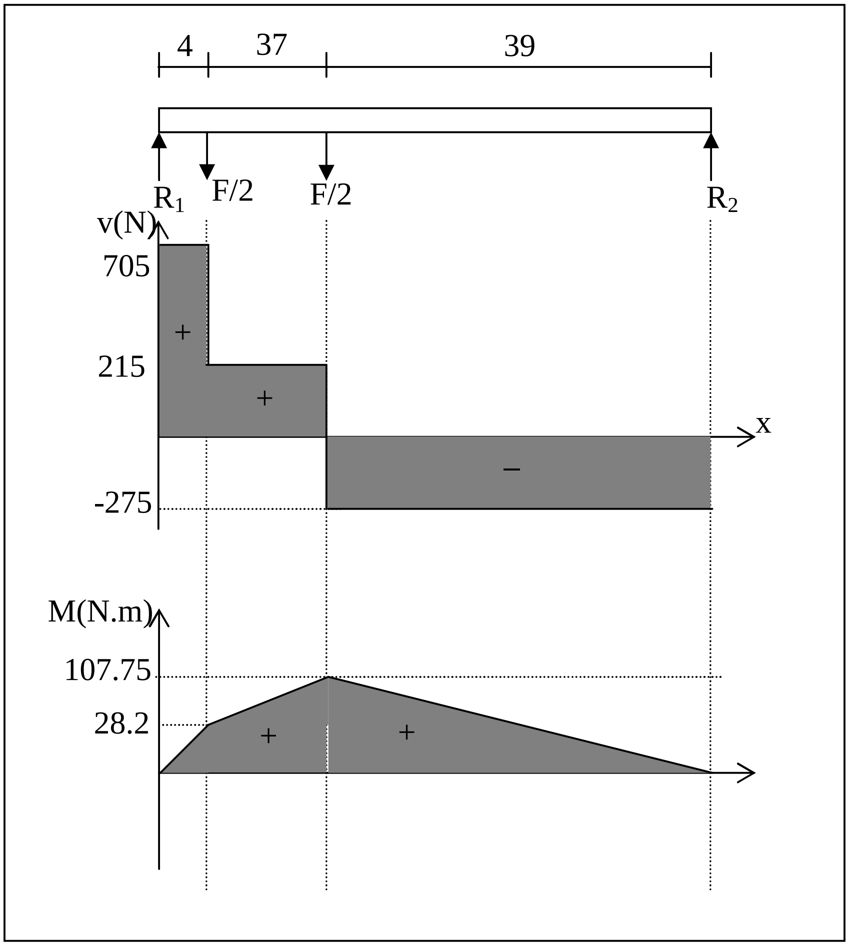


Figure (2.10): Shear and bending diagrams for the bottom plate.

2.2.4 Upper-and-bottom Connectors (links) design

There are four beam connectors between upper and bottom plates, where the load equal 540N (the weight of the film carriage, load and the upper plate) each beam have k/4 load. The material of the beams is steel and the cross section of the beam (hollow beam) 4*4cm with thickness 4mm. The stress on each rod will give by:

$$\sigma = F/A \qquad (2.12)$$

where

F: equal to k/4 = 540/4 = 135 N,

A: is the cross sectional area.

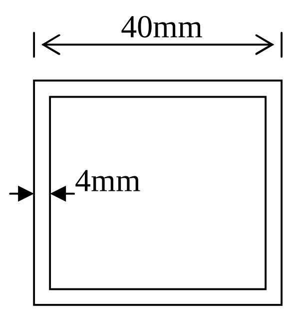


Figure (2.11): Beam cross section.

then,

$$\sigma = 2.34 \text{ KPa} << S_y$$

Generally, if F > $F_{cr,}$ the system will move away from its original position and settle in a new position, so it will be buckled. Clearly, a column which buckles under the specified load is not properly designed.

Where the column with both ends are fixed [1], then

$$F_{cr} = \frac{4\text{®}^2 EI}{l^2} \tag{2.13}$$

where l is the length of the column and equal 220cm.

Depending on equation (2.2), where b = h = 2cm, so $I = 213*10^{-9}m^4$

$$F_{cr} = \frac{4\text{®}^2 \left(213*10^{-9}\right)\left(4.9*10^{9}\right)}{2.2^2}$$

$$= 8.51*10^3\, N >> F$$

2.3 Time and speed analysis for the film carriage

By assuming the angular speed for the disk (turntable) 14 rpm and the disk radius 0.8m, so the required time to go from **a** → **a** as shown in figure (2.12) can be calculated as:

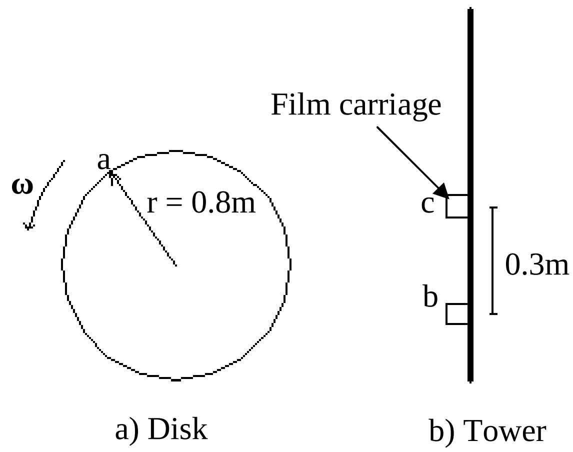


Figure (2.12): Time relation between disk and film carriage.

$$time = \frac{distance}{speed}$$

$$\Rightarrow time = \frac{2\pi . r}{\left(\frac{2\pi . n}{60} . r\right)} = \frac{2\pi * 0.8}{\left(\frac{2\pi * 14}{60} * 0.8\right)} = 4.3 second \qquad (2.14)$$

So, the calculated time for the disk is the same time that required to transfer the film carriage from **b** → **c**, figure (2.12.b).

The width of the stretch film roll is 50 cm, so the required speed for the film carriage to go from (**b** → **c**), and to get a film after wrapping as shown in figure (2.13.b) it can be calculated as the following:

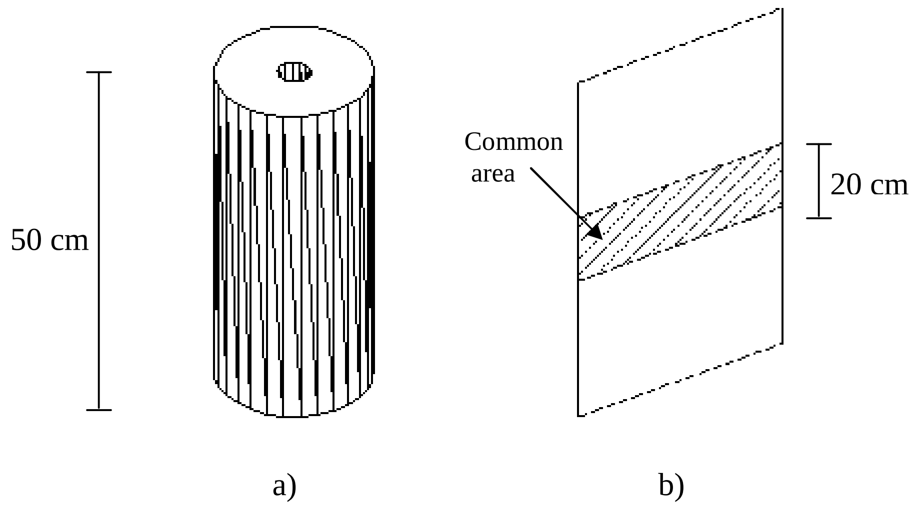


Figure (2.13): a) Stretch film roll. b) Film sample after wrapping.

$$speed = \frac{distance}{time}$$

$$\Rightarrow speed = \frac{0.3}{4.3} = 0.07 m/s$$

To calculate the angular velocity (ω) of the sprocket, it is given by the relation:

$$\mu = \frac{V}{r} \qquad (2.15)$$

Where V is the speed and equal 0.07 m/s, r is the sprocket radius and equal 7.75 cm then,

$$\omega = 0.9 \text{ rad/sec}$$

2.4 Design of mechanical elements

2.4.1 Roller Chain Drives Design

The advantages of finished steel roller chains are high efficiency (around 98 to 99 percent), no slippage, no initial tension required, long life, the ability to drive a number of shafts from a single source of power and chains may travel in either direction.

2.4.1.1 Chain Geometry

The sprockets (of the turntable) teeth ratio is selected to be 1 to 2.7, so the number of the teeth of the driver sprocket (N_1) equal 15 and for the driven sprocket (N_2) equal 40. Figure (2.14) show the engagement of a chain and the sprocket.

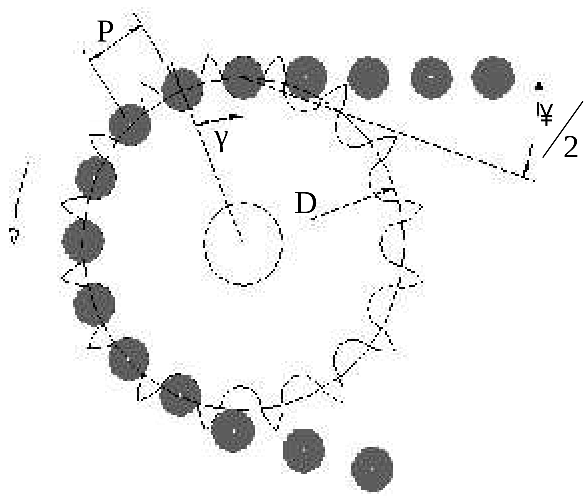


Figure (2.14): Engagement of a chain and the sprocket.

The distance between the centers of the sprockets (C) as shown in figure (2.15), for the turntable C = 1.6 meter and for the tower C = 2 meter. In general the center distance between the sprocket axis should be approximately 30 to 50 times the pitch of the chain. So,

$$P_{Tower} = \frac{200}{50} = 4cm$$

$$P_{Turntable} = \frac{160}{50} = 3.2cm$$

In general the minimum number of teeth in a sprocket should be 17 unless the drive is operating at a very low speed, under 100 rpm. So, the number of the teeth in a sprocket in the turntable 17 and in the tower 12.

The sprocket diameter can be calculated from the following equation [7]

$$\sin\frac{¥}{2} = \frac{P/2}{D/2}$$

Since, $¥ = 360°/N$

$$D = \frac{P}{\sin(180°/N)} \qquad (2.16)$$

Where

P: Chain pitch

γ: Pitch angle

D: The pitch diameter of the sprocket

N: Number of sprocket teeth

For the tower sprockets, where the pitch equal 4 cm, the number of teeth equal 12 and by applying equation (2.16), the diameter will be 15.5 cm.

For the turntable sprockets, where the pitch equal 3.2 cm, the number of teeth equal 17 and by applying equation (2.16), the diameter will be 17.4 cm.

The angle¥ / 2, through which the link swings as it enters contact, is called the angle of articulation. It can be seen that the magnitude of this angle is a function of the number of teeth.

Rotation of the link through this angle causes impact between the rollers and the sprocket teeth and also wears in the chain joint. Since the life of a properly selected drive is a function of the wear and the surface fatigue strength of the rollers, it is important to reduce the angle of articulation as much as possible.

The number of sprocket teeth also affects the velocity ratio during the rotation through the pitch angle γ. So the chain velocity V is defined as the number of feet coming off the sprocket in unit time. Thus the chain velocity in feet per minute is

$$V = \frac{Npn}{12} \qquad (2.17)$$

Where

N: number of sprocket teeth.

P: chain number, cm.

n: sprocket speed, $r/_{\min}$.

To calculate the length of the chain, it given by the relation:

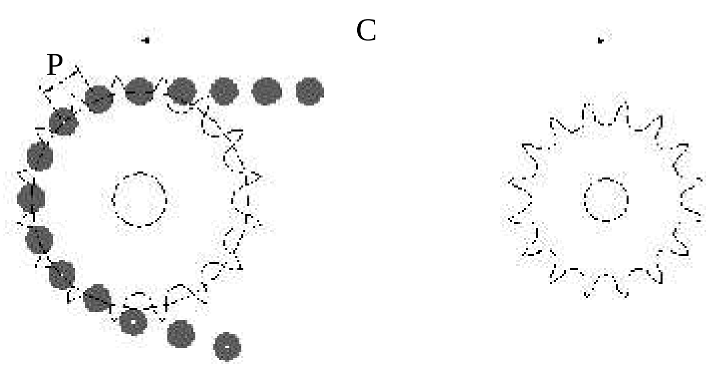


Figure (2.15): Symbols for chain length calculations

$$L_P = 2C/P + (N+n)/2 + (N-n)^2 / \left(4\text{®}\,^2 C/P\right) \qquad (2.18)$$

Where

L_P: Length of chain in pitches.

C: The distance between the centers of the sprockets (cm).

P: Pitch of the chain (cm).

N: Number of teeth of large sprocket.

n: Number of teeth of small sprocket.

For the tower, the center distance between the sprockets 200 cm, the pitch 4 cm, the number of the sprockets teeth 12. So, by applying equation (2.18) the chain length will be 112 pitches (448 cm).

For the turntable, the center distance between the sprockets 160 cm, the pitch 3.2 cm, the number of the teeth for the small sprocket 15, for the large sprocket 40 teeth. So, by applying equation (2.18) the chain length will be 127 pitches (409.7 cm).

Design guidelines for chain drives

The following are general recommendations for designing chain drives:

1. The minimum number of teeth in a sprocket should be 17 unless the drive is operating at a very low speed, under 100r/min.
2. The maximum speed ratio must be 7, although higher ratio is feasible. Two or more stages of reduction can be used to achieve higher ratios.
3. The center distance between the sprocket axis should be approximately 30 to 50 pitches (30 to 50 times the pitch of the chain).

4. The arc of contact of the chain on the smaller sprocket should be no smaller than 120^o.
5. The larger sprocket should normally have no more than 120 teeth.
6. The preferred arrangement for a chain drive is with the center line of the sprockets horizontal and with the tight side on top.
7. The chain length must be an integral multiple of the pitch, and an even number of pitches is recommended. The center distance should be made adjustable to accommodate the chain length and to take up for tolerance and wear. Excessive sag on the slack side should be avoided, especially on drives that are not horizontal. Convenient relation between center distance, chain length, number of teeth in the small sprocket, and number of teeth in the large sprocket, expressed in pitches, as in equation (2.18). The theoretical center distance assumes no sag in either the tight or the slack side of the chain, and thus it is a maximum.
8. The pitch diameter of a sprocket with N teeth for a chain with a pitch of P is as in equation (2.16).
9. The minimum sprocket diameter and therefore the minimum number of teeth in a sprocket are often limited by the size of the shaft on which it is mounted.

Chapter Three

Electrical Design

Chapter Three

Electrical Design

3.1 Introduction

This chapter contains an electrical design including the components used; also it includes the photo electric switch to determine the length of the pallet. The block diagram in figure (3.1) specifies the electrical procedure for controlling the system.

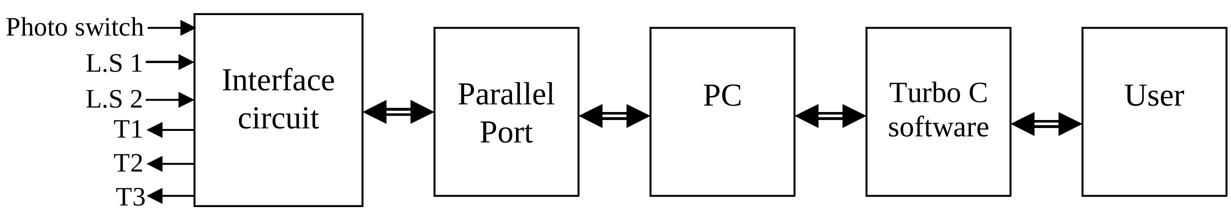


Figure (3.1): The block diagram of the system.

Where

L.S 1: limit switch to determine the number of disk revolutions.

L.S 2: limit switch to turn off the machine.

T1: transistor to turn on (forward) the tower motor.

T2: transistor to reverse the tower motor direction.

T3: transistor of turntable motor.

3.2 DC motor

3.2.1 Introduction to DC motor

A direct-current motor is a device for converting dc electrical energy into rotating mechanical energy. This process can be reversed, as in a dc generator, to convert mechanical to electrical power. Direct-current equipment lends itself to automatic processes, by giving automated machinery controllable, adjustable speeds, high starting torques, as well as responsive braking. The easy of control and high torque capability makes the DC motor attractive for many machinery applications. All motors, weather AC or DC power line, have several basic characteristics in common. They include:

1. A stator, which is the frame and other stationary components (provides the fixed Magnetic field could be a permanent magnet or an electromagnet).
2. A rotor or armature, which is the rotating shaft and its associated parts (many Coils of wire are wound on a cylindrical shaft).
3. Auxiliary equipment, such as a brush/commutator assembly for DC motors and a Starting circuit for AC motors.

3.2.2 Advantages of DC Motors (Reason for choose):

1) Excellent speed control for acceleration and deceleration with effective and simple torque control.

2) The fact that the power supply of a DC motor connects directly to the field of the motor allows for precise voltage control, which is necessary with speed and torque control applications.

3) DC motors perform better than AC motors on most traction equipment. They are also used for mobile equipment like carts; DC motors are conveniently portable and well suited to special applications, such as industrial tools and machinery that is not easily run from remote power sources.

3.2.3 DC motor characteristic

Motors that operate from DC power sources have many applications where speed control is desirable. They can be categorized into three major sectors series, shunt, or compound machines, depending on the method of connecting the armature and field windings. Permanent magnet DC motors are also used for certain applications.

3.3 Power calculations for the motors

A motor generally drives a load through some transmission system. While motor always rotates, the load may rotate or may undergo a translational motion.

3.3.1 Analysis of the required power of the turntable motor:

To calculate the load torque figure (3.2), it is given by the relation:

$$T_{Load} = \left(J_{Load} + J_{Disk}\right) \cdot \sim \qquad (3.1)$$

Where J_{Load} equal 480 kg.m^2 and J_{Disk} equal 48 kg.m^2
then,

$$T_{Load} = 774 N.m$$

So, to calculate the motor torque, it is given by the relation:

$$T_{motor} = \frac{T_{Load} \cdot a}{¦} \qquad (3.2)$$

Where

a is the transmission ratio and equal (1/150) and the efficiency equal 93%

then,

$$T_{motor} = 5.6 N.m$$

Then, to calculate the motor power, it is given by the relation:

$$P = \mu_m \cdot T_m \qquad (3.3)$$

Where the angular velocity of the motor ω_m equal 230 rad/sec, then

$$P = 1290 watt = 1.73 hp$$

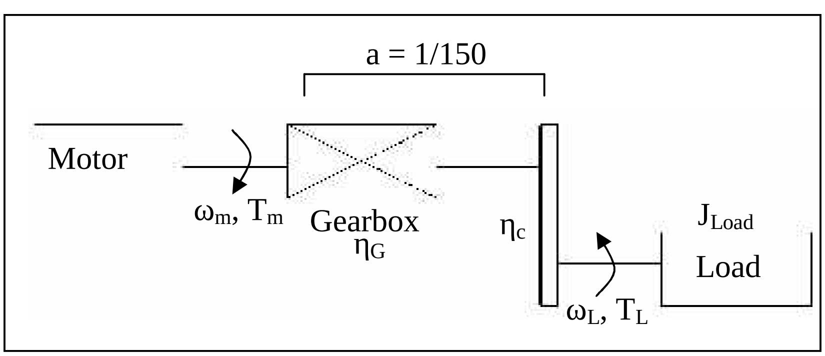


Figure (3.2): Load with rotational motion.

3.3.2 Analysis of the required power of the lifting motor (tower):

A motor driving a load, coupled to its shaft through a transmission system (sprocket) converting rotational motion to linear motion figure (3.3). The mass and velocity of load with translational motion be M (kg) and v (m/sec) respectively. To calculate the load torque, it is given by the relation:

$$T_l = \frac{F \cdot r \cdot a}{\eta_G} \qquad (3.4)$$

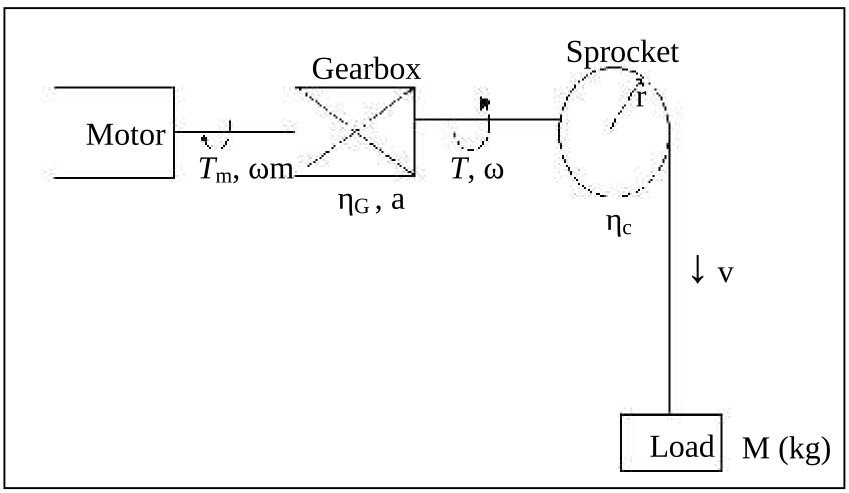


Figure (3.3): Load with translational motion.

In this case, friction between the sprocket and the chain is neglected.

By applying the previous equation to calculate the torque, where M = 50kg, r = 7.75cm, v = 0.07m/sec, ω_m 146.6(1/s), η_G = 94%, η_c = 98% and a = 1/130, then

$$T_l = \frac{(50*9.81)*0.0775*(0.01)}{(0.98*0.94)} \cong 0.41 N.m$$

Then to calculate the motor power, it is given by the equation (3.3), then

$$P = \mu_m \cdot T_l = 146.5*0.41 = 69.5 watt$$

3.4 Driving circuit

When using a computer or micro-controller as a controller, an interfacing circuit is needed to drive a motor, so that the motor power is supplied from power source different from the source of controller. This interfacing circuit can be implemented in a variety of technologies such as bipolar transistors, MOSFETS (Metal Oxide Semiconductor Field Effect Transistors), and if reversing of motor is needed this interfacing is known as H-bridge and is usually consists of four switches connected in the topology of an H as shown in figure (3.4).

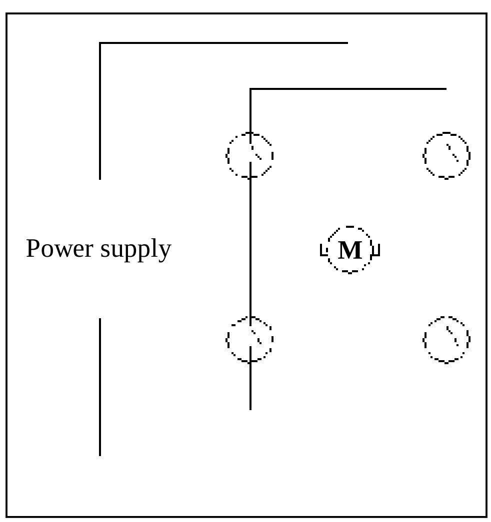


Figure (3.4): H-bridge using switches.

3.4.1 H-bridge

In an H-bridge, all the switches are opened and closed so as to put a voltage of one polarity across the motor for current to flow through it in one direction, or a voltage of the opposite direction, causing current to flow through the motor in opposite direction for reverse rotation.

Transistor is a bipolar junction; simply it is two PN junctions (two diodes). There are two possible combinations of two PN junctions, npn or pnp as shown in figure (3.5).

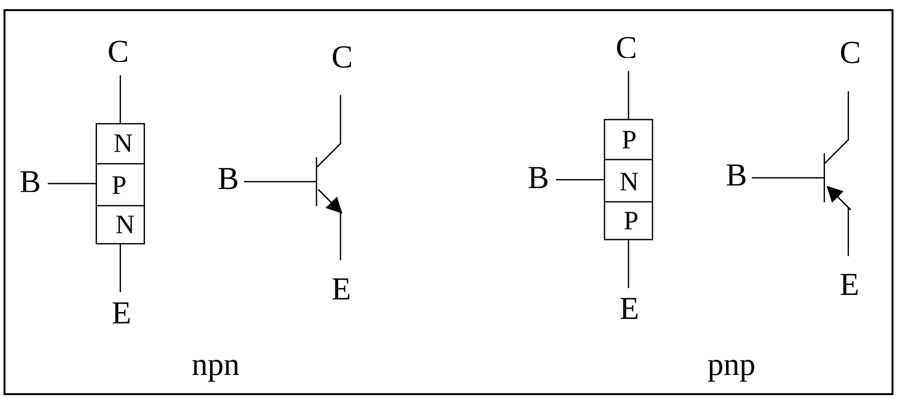


Figure (3.5): PNP and NPN transistors.

Beside the transistor works as switch, it could be used as linear amplifier to add gain to a circuit for amplifying small signal to match it with a higher power. Transistors can be classified either as signal-level devices or as power devices which capable of handling large currents and voltages. As shown in figure (3.5) a transistor has 3-

terminals (collector, base, and emitter). The ratio of the collector current to the base current is the current gain (β)

$$= {I_c}/{I_B}$$

Where:

I_C is the current pass through the collector.

I_B is the current applied to the base of the transistor.

Let's note that the voltage V_{CE} is the voltage drop between the collector and the emitter. When V_{CE} is small (approach zero) the transistor is work in saturation and then the transistor works as switch.

Now, to implement the H-bridge using npn transistor the circuit will be as shown in figure (3.6). Sometimes instead of using single transistor we could use what is called Darlington transistor which is small transistor combined to a large transistor, the result being equivalent to a large transistor with large amplification factor.

Now, to turn the motor in a direction, a signal is applied to the base of Q1, and Q4 and so the two transistors (switches) will pass I_c to the motor and then to the ground, and to turn the motor in other direction the signal is applied to the base of Q2 and Q3.

Noting that $I_c = I_a$ then the required $\beta = I_a/I_B$, and according to I_a and β the transistor is selected.

Generally, for inductive load such as a motor, when it is switched off, the energy present in the magnetic field induces a current on the winding. These are in reverse polarity with respect to the supply current. When a motor is switched off, a diode in parallel shorts these reverse induced current, so the diode creates a return path for the current. It should add diodes to catch the back voltage that is generated by the

motor's coil when the power is switched on and off. If the diodes are not used, the transistors will burn out.

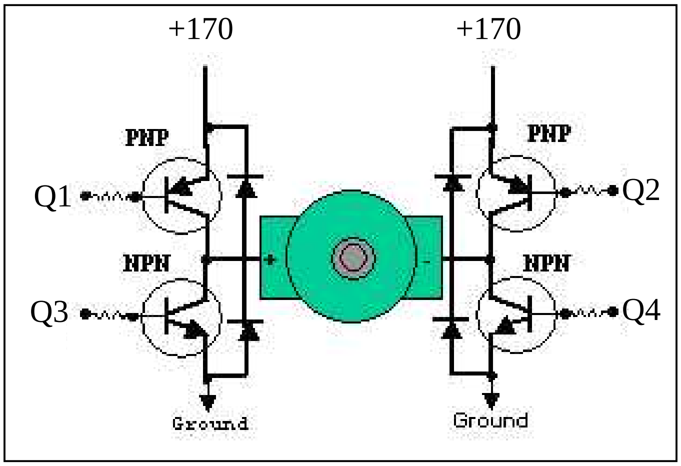


Figure (3.6): H-bridge using transistors.

According for table (3.1), the upper left and lower right transistors figure (3.6) turn on, then the power flows through the motor forward, i.e.: 1 to Q1, 0 to Q2, 0 to Q3 and 1 Q4.

Table (3.1): Truth table for the H-bridge.

Q1	**Q2**	**Q3**	**Q4**	**Function**
1	0	0	1	Forward
0	1	1	0	Reverse
1	1	0	0	Brake
0	0	1	1	Brake

Then for reverse, the upper right and lower left transistors figure turn on, then the power flows through the motor reverse, i.e.: 0 to Q1, 1 to Q2, 1 to Q3 and 0 to Q4.

If the two upper transistors turn on, the motor resists turning, so we effectively have a breaking mechanism. The same is true if both lower transistors turn on.

3.4.2 Isolation

It is known that the power supplies, sometimes, produces noises. Add to these noises the voltage spikes which generated when the brush of a motor slides past a section of the commutator, and electrical noises and changing magnetic fields (generated either internally or by external equipment). All these noises may affect the controller which consists of chips and their states may be changed. Because of this it is needed to separate the motor and its power from the logic components. To do this an optocuplar chip is used, which make complete separation of the motor and computer.

3.4.2.1 Optocuplar

An optocuplar is usually divided into two parts: the input part and the output part. The input consists of an infrared light emitting diode (ILED). The output is usually a phototransistor for DC output, or phototriac for AC output. The link between the two parts is achieved by the infrared light emitted by the diode and received by the phototransistor or phototriac.

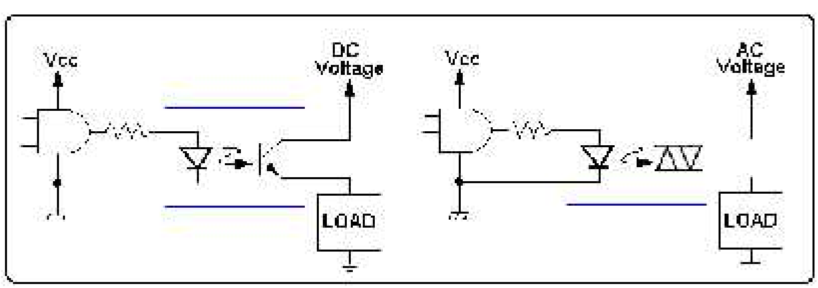


Figure (3.7): Typical connection of the optocuplar.

When forward current (I_F) is passed through the diode, it emits infrared radiation. The radiant energy is transmitted through an optical coupling medium and falls on the surface of the phototransistor or the phototriac. This causes the phototransistor or the phototriac to conduct the electrical current which passes to the load.

The input voltage and current are very small compared to the output voltage and current. This makes opt couplers very useful in interfacing circuits where a small electrical signal drives a large signal. It also provides protection for the control circuit from overloading and unexpected changes in the load circuit.

3.4.3 Protection elements

The incoming power to any system must be limited to ensure that the current through the lines is not above the rated value. Otherwise, the electrical or electronic equipment may be damaged. To limit the current level, fuse is installed. The fuse has an internal metallic conductor through which the current will pass. It will begin to melt if the current through the system exceeds the rated value printed on the casing, of course, if it melts through, the current path is broken and the load in its path is protected.

3.4.4 Photoelectric switch

The photoelectric switch used to determine the length of the pallet that when the film carriage reach the upper point of the pallet it will reverse the direction of the motor and when there is no load (pallet) the machine will not turn on, so it increases the safety of the machine, the position of the switch is shown in figure (3.8).

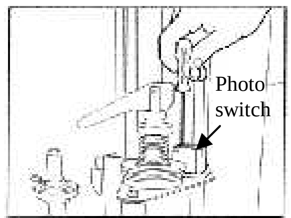


Figure (3.8): Photoelectric switch position.

3.5 Construction

The circuit which is used to interface the two motors with PC consists of all the components mentioned in section (3.4) is shown in figure (3.8).

Specifications for the used components:

PC817

Opt isolator with forward current 60mA, I_c = 60mA.

2Sc1815

Small transistor with I_c = 0.4A, β=120, frequency=200MHz.

BU806

High voltage and switching Darlington transistor with I_c = 8A, I_B = 2A**.**

The Darlington transistors are mounted to heat sinks to prevent overheating. Heat sinks come in many forms. In this application, a metal pracket with cooling fines is attached to each transistor.

For stable, reliable hardware there is no better choice for circuit construction than printed circuit board technology. The technique involves transferring a printed representation of the layout a chemically coated board.

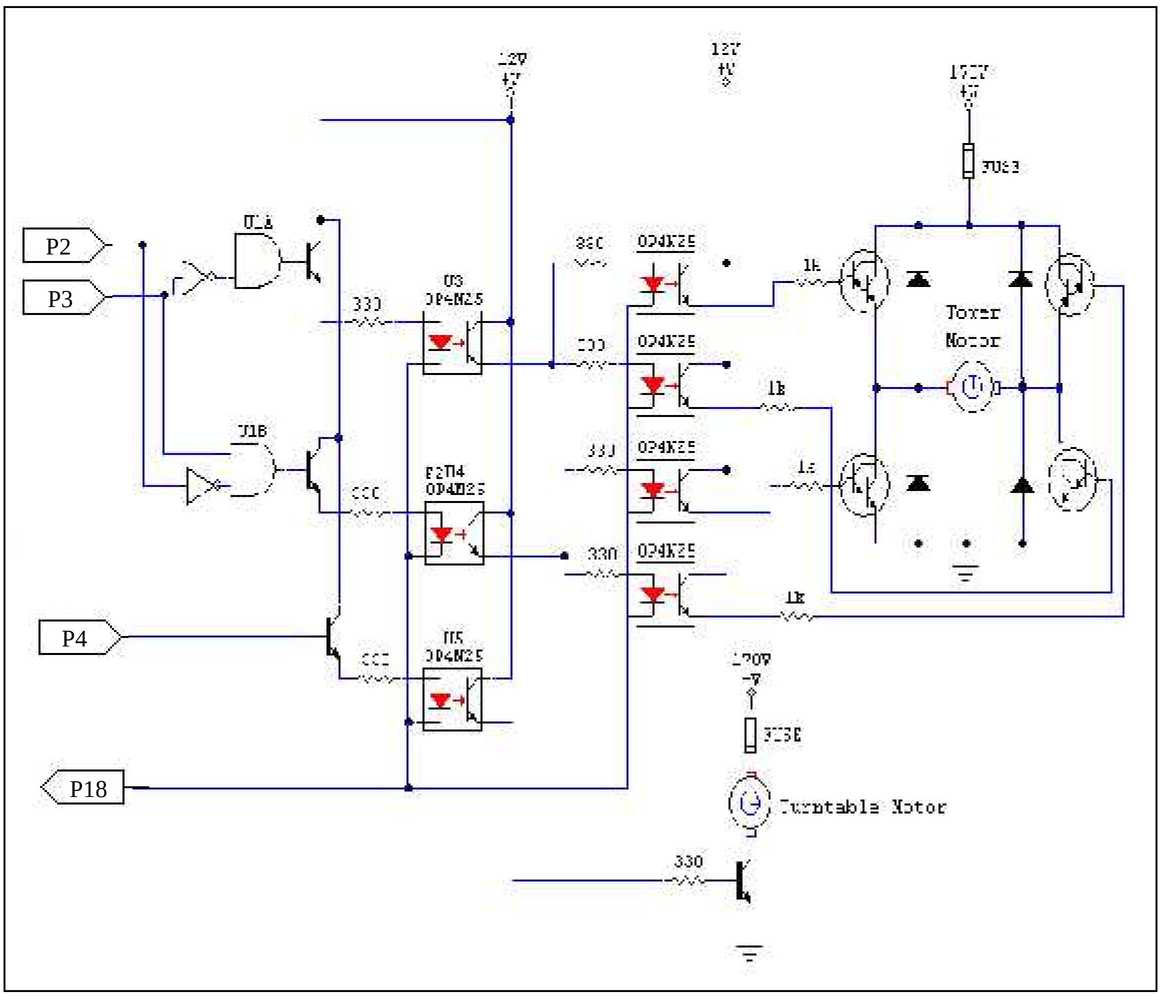


Figure (3.8): Interfacing circuit.

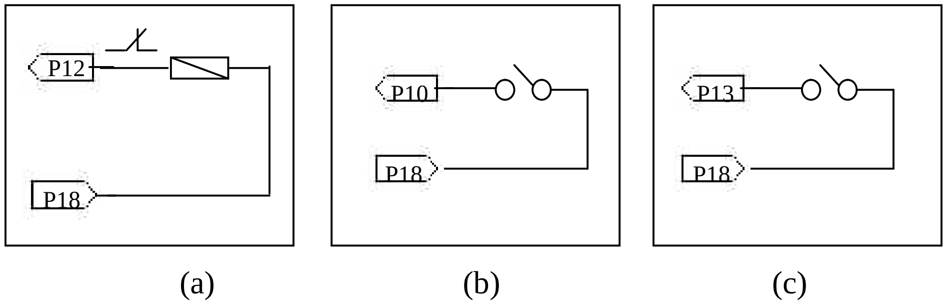


Figure (3.9): a) Photoelectric switch circuit.

b) Microswitch circuit for counting.

c) Microswitch to turn off the machine.

Chapter Four

Control

Chapter Four

Control

4.1.1 Control

The purpose of the control is to force or change the behavior to follow desired criteria.

4.1.1 Closed loop control system

Changing the current (changing the load on turn table motor) cause change in the angular velocity of the motor which cause asynchronous between the turntable motor and the tower motor, so we used a closed loop control to obtain accurate control of a process during the execution of an action, where feedback control is used where the variable that are being controlled are continuously measured by feedback, then compared to a reference (error calculation), and the action is modified according to a control law to overcome the error.

4.1.2 Physical modeling

A common actuator in control systems is the DC motor. It directly provides rotary motion, and coupled with wheels or drums and cables can provide translational motion. The electric circuit of the armature is shown in the following figure (4.1)

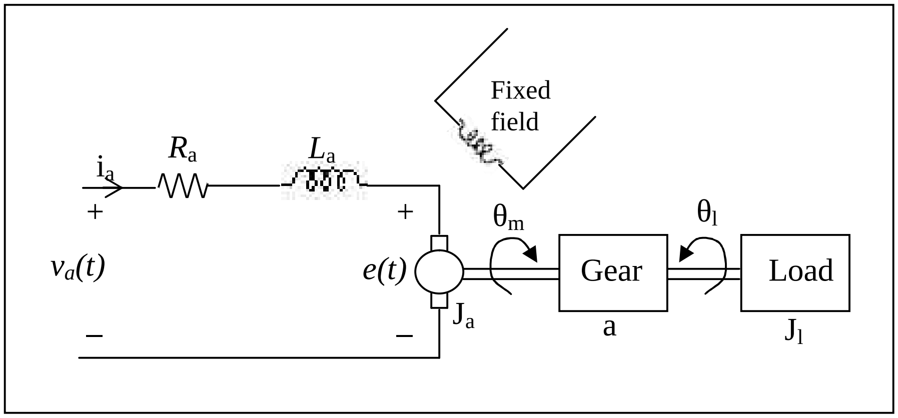


Figure (4.1): DC motor driving a rotational mechanical load.

In this model, the dynamics of the motor itself are idealized; for instant, the magnetic fielded is assumed to be constant. The resistance of the circuit is denoted by R_a and the inductance by L_a, the important thing with this model and basic laws of physics; it is possible to develop differential equations that describe the behavior of this electromechanical system.

4.1.2 Mathematical Derivation

The torque τ seen at the shaft of the motor is proportional to the current *i* which induced by the applied voltage,

$$\tau_m(t) = K_t i_a(t) \tag{4.1}$$

Where K_t, the armature constant, is related to physical properties of the motor, such as magnetic field strength, the number of turns of wire around the conductor coil, and so on. The back (induced) electromotive force, v_b is a voltage proportional to the angular velocity μ ,

$$v_b(t) = K_b \mu_m(t) \quad (4.2)$$

Where K_b , the emf constant, also depends on certain physical properties of the motor.

The mechanical part of the motor equations is derived using Newton's Law, which states that the inertia load (J) times the derivative of angular velocity equals the Sum of all the torques about the motor shaft. The result is this equation:

$$j \frac{d\mu}{dt} = \Sigma 2_i = -D\mu(t) + K_t i(t) \quad (4.3)$$

Where $D\mu_m(t)$: a linear approximation for viscous friction

Finally, the electrical part of the motor equations can be describe by,

$$e_a(t) = v_b(t) + L\frac{di}{dt} + R_a i_a(t) \quad (4.4)$$

or, solving for the applied voltage and substituting for the back emf,

$$e_a(t) = K_b \mu_m(t) + L_a \frac{di_a}{dt} + R_a i_a(t) \quad (4.5)$$

4.1.3 The system transfer function

Taking Laplace transform to equations (4.1), (4.2) and (4.4) yields:

$$T_m(s) = K_t I_a(s) \Rightarrow I_a(s) = \frac{1}{K_t} T_m(s) \qquad (4.6)$$

$$V_b(s) = K_b \mu(s) \qquad (4.7)$$

$$R_a I_a(s) + L_a s I_a(s) + V_b(s) = E_a(s) \qquad (4.8)$$

In order to find the transfer function, we substitute equ. (4.7) and (4.6) into (4.8), yields:

$$\frac{(R_a + L_a s)}{K_t} T_m(s) + K_b \mu(s) = E_a(s) \qquad (4.9)$$

In order to find $T_m(s)$ in term of¯$_m(s)$, and the system can be represents as shown in figure (4.2).

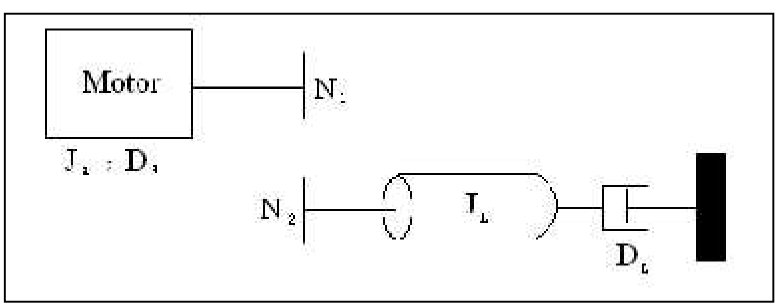


Figure (4.2): Dc motor driving a rotational load.

$$T_m(s) = (J_m s^2 + D_m s)\theta_m(s) \qquad (4.10)$$

Where:

J_m : The equivalent inertia at the armature

D_m : The equivalent viscous damping at the armature

Substituting equation (4.10) into (4.9) yields:

$$\frac{(R_a + L_a s)(J_m s^2 + D_m s)\theta_m(s)}{K_t} + K_b \theta_m(s) = E_a(s) \qquad (4.11)$$

By assuming the inductance, L_a is small compared to the armature resistance, Eq. (4.11) becomes

$$\left(\frac{R_a}{K_t}(J_m s + D_m) + K_b\right) s\theta_m(s) = E_a(s) \qquad (4.12)$$

After simplification, the desired transfer function, $\theta_m(s) / E_a(s)$ is found to be,

$$\frac{\theta_m(s)}{E_a(s)} = \frac{K_t / R_a J_m}{s[s + \frac{1}{J_m}(D_m + \frac{K_t K_b}{R_a})]}$$

4.1.4 Specific transfer function

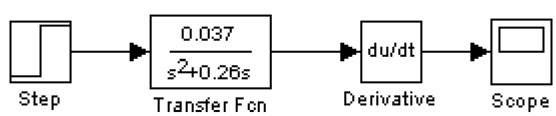
The dc motor shown previous has R_a = 6.3Ω, L_a = 14.9mH, K_b = 0.76, K_t = 0.59 K_m = 1.14, J_a = 2.5 kg.m^2, and D_m = 0.005 kg.m/sec. The motor is designed to operate with a rated input of 170 volt and has a rated power 1.73 hp at rated speed of 2200 rpm.

$$J_m = J_a + J_L\left(\frac{N_1}{N_2}\right)^2 \qquad (4.14)$$

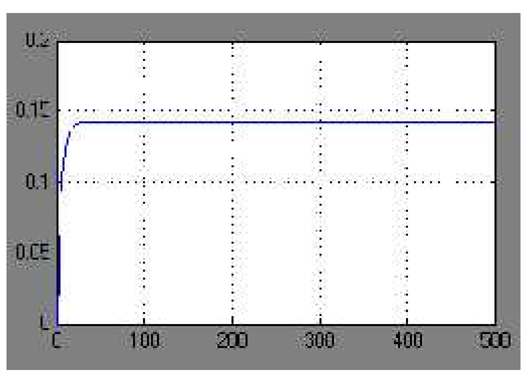
Where J_L = 528 kg.m^2, a = N_1/N_2 = 1/150, then J_m = 2.52 kg.m^2

Then, the specific transfer function is:

$$\frac{\bar{}_m(s)}{E_a(s)} = \frac{0.037}{s(s+0.27)}$$



(a)



(b)

Figure (4.3): a) Open loop system. b) Response of the system.

4.1.5 PI controller

The system response as in figure (4.3) represents the system when the load is constant, but if the load is variable it causes changing in motor speed. So, there is disturbance on the system. So, the PI controller will be used to treat this problem.

The PI controller used to improve the steady state error of control system; it can be implemented by using Op. Amp. as shown in figure (4.4)

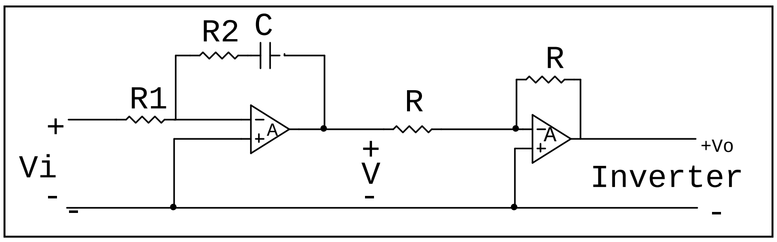


Figure (4.4): Physical realization of PI controller.

Figure (4.5) represents the closed loop system

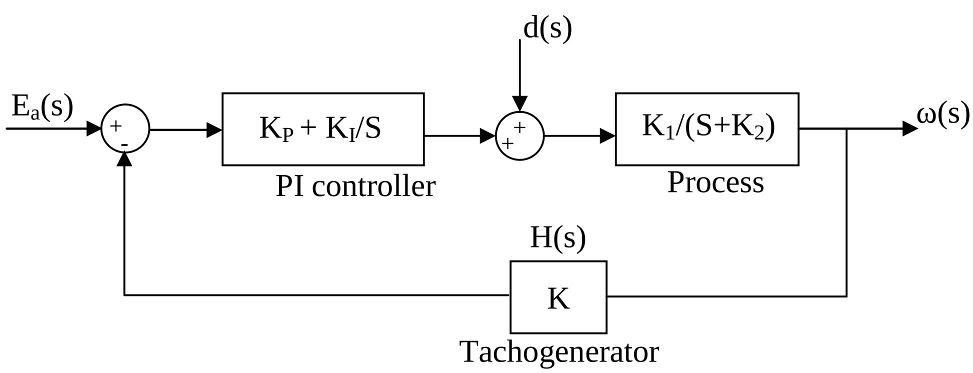


Figure (4.5): Closed loop system.

The transfer function of the closed loop is

$$\frac{\omega_m(s)}{E_a(s)} = \frac{0.037K_P S + 0.037K_I}{S^2 + (0.27 + 0.185K_P)S + 0.185K_I}$$

Where the desired percentage overshoot is 5% ($\xi = 0.7$) and settling time T_S equal 1 second, then natural frequency ω_n equal 5.7, then

$$2\xi\omega_n = 0.27 + 0.185K_P$$

$$\omega_n^2 = 0.185K_I$$

Then, $K_P = 41.8$ and $K_I = 175.6$

The physical realization of PI controller as shown in figure (4.4), given the following relations:

$$K_P = \frac{R_2}{R_1}$$

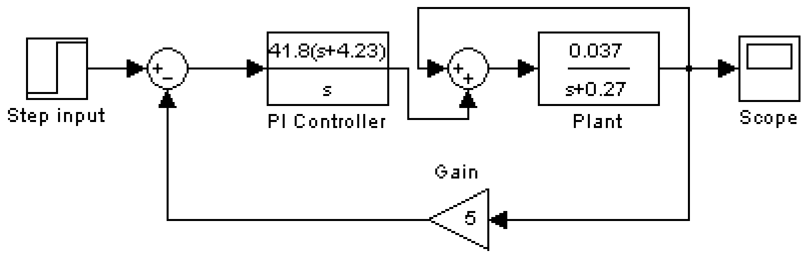
$$K_I = \frac{1}{(R_1 C)}$$

By assuming $C = 10\mu F$, then $R_1 = 569\Omega$, $R_2 = 23.8k\Omega$.

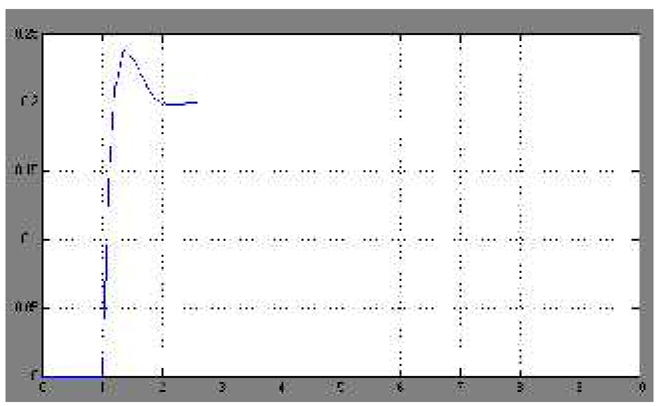
Then, the specific transfer function is

$$T(s) = \frac{1.55S + 6.5}{S^2 + 8S + 32.5}$$

The response of the closed loop system with PI controller is shown in figure (4.6)



(a)



(b)

Figure (4.6): a) Closed loop system with PI controller. b) Response of the system.

4.2 Computer Process Control

Computer process control is defined as the use of a stored program in digital computer to control an industrial process. For the computer to be used in process control; the computer must collect data from the operation. If the computer is utilized to control the process directly, data must be communicated to the process. The data flowing back and forth between the computer and the process can be classified into three types:

1. Continuous analog signal.

A continue variable is one that assume a continuum of values over time. The variable is uninterrupted as time proceeds; an example of it is force, temperature, pressure, velocity and so on.

2. Discrete binary data.

Which are the data that can either of two possible values, such as on or off, open or closed and so on.

3. Pulse data or discrete data that are not restricted to binary; in other word, more than two value are possible.

Pulse data are a train of pulse signal. This type is used in digital sensors such as optical encoder.

4.3 PC Interfacing

To interface the computer with the actuators and sensors, there are some interfacing ways such as:

1. Data Acquisition card (DAQ)

Data acquisition interface help measuring information presented by both digital and analog signals. Digital signals can come from a variety of sources such as switch closures, relay contacts or TTL compatible interfaces. With the proper interface they can be directly read and processed by computers.

Analog signals come from instruments or sensors hat convert things like pressure, position or temperature into voltage or current. Analog signals cannot be directly read or processed by computer. The analog signals must first be converted to a digital number. This process is called analog-to-digital conversion or A/D The complementary process, digital to analog conversion or D/A, change digital data into analog voltage or current signals. Many data acquisition interface have both A/D and D/A converters. This permits computerized measurement and control of industrial processes and laboratory experiment.

The most important factor when using a data acquisition interface is the sampling time, which is the time to hold the value. The Nyquist Theorem specifies that an input signal should be sampled at least twice as fast as the input's highest frequency component. For example to accurately measure a 1 KHz signal, the minimum A/D sampling time is 2 KHz. This avoids signal aliasing.

2. Parallel port

PC parallel port is normally used for connecting computer to printer. But it can be very useful I/O channel for connecting electrical circuit to PC. The port is very easy to use when understanding some basic notes. PC parallel port can be damaged quite easily if making mistakes in the circuits that connected to it. If the parallel port is integrated to the motherboard (like in many new computers) repairing damaged parallel port may be expensive (in many cases it is cheaper to replace the whole motherboard than repair the port).

PC parallel port is 25 pin D-shaped female connector in the back of the computer and contains three registers: data, status, and control registers. Data register is easily used to output data with only 8-output pins (data lines). Table (4.1)

Table (4.1): Data pins

Pin	Function
2	D_0
3	D_1
4	D_2
5	D_3
6	D_4
7	D_5
8	D_6
9	D_7

Those data pins are TTL level output pins. This means that they put out ideally 0V when they are in low logic level (0) and +5V when they are in high logic level (1). The value that written in the program must be as a binary number. Every bit of the binary number control one output bit. The following table describes the relation of the bits,

Table (4.2) Data pins with its values

Pin	2	3	4	5	6	7	8	9
Bit	D_0	D_1	D_2	D_3	D_4	D_5	D_6	D_7
Value	1	2	4	8	16	32	64	128

For example if we want to set pins 2 and 3 to logic 1 then we have to output value $1+2=3$. If we want to set on pin 3, 5, and 6 then you need to output value $2+8+16=26$. In this way we can calculate the value for any bit combination we want to output. In C-language the command which is used to output data is:

$outport(0x378, n);$

Where

n is the data we want to output,

$0x378$ is the address of data register in hexadecimal.

The status register could be used as input register but it has only 5 input pins, such that:

D_0: state not specified.

D_1: state not specified

D_2: state not specified

D_3: state of pin 15(ERROR) inverted

D_4: state of pin 13 (SELLECTED)

D_5: state of pin 12(PAPER OUT)

D_6: state of pin 10(ACK)

D_7: state of pin 11(BUSY) inverted

In C-language the command, which is used to input data, is:

$x = inportb(0x379)$

Where

x is the input value

$0x379$ is the address of status register.

It must be noted that pins 18,19,20,21,22,23,24 and 25 are all ground pins.

4.4 Construction

This machine can work in an automatic or manual operation. In automatic operation the turntable motor turn on, then count the number of required revolutes, then the motor of the tower go forward (up) until the film carriage reach the upper point of the pallet, then stop for a period of time to count the required revolutes for the turntable, then the motor of the tower reverse its direction (down) to return to its start point and then the machine will turned off by the limit switch. In manual operation the turntable turn on, then the user can operate the motor of the tower up and down as he want. The flowchart shown in figure (4.7) represents what is mentioned.

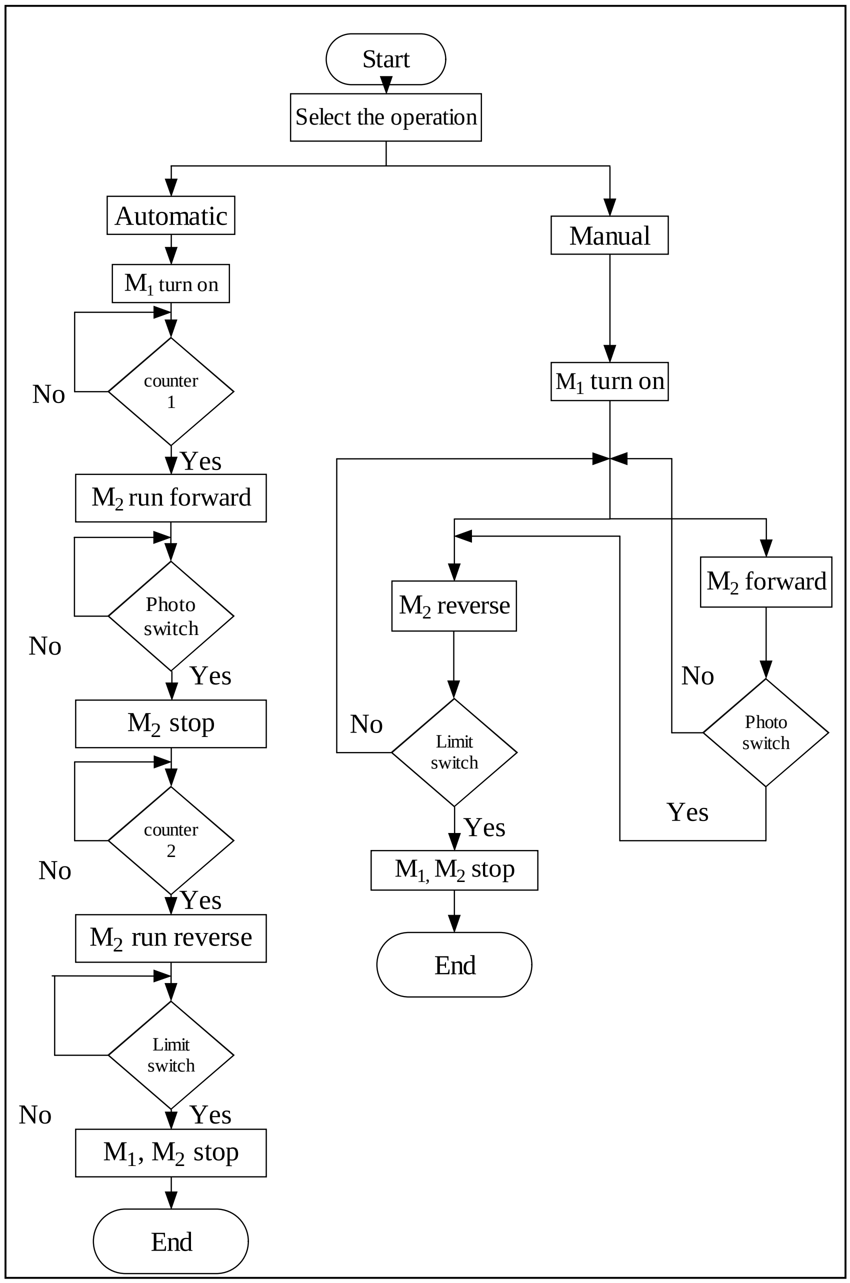


Figure (4.7): Program structure.

Chapter Five

Conclusions

Chapter Five

Conclusions
&
Economic Costs of the Project

5.1 Conclusion.

The machine which we have built is a semi-automatic wrapping machine for pallets, which can package the pallets in an automatic or manual operation.

It is easy and flexible way to use a computer as a controller, and parallel port as a method of interfacing sensors and actuators with the computer, but it has some limitations such as the low number of inputs and outputs pins, and the programmer must have programming skills to do what he wants.

In this project we built closed loop control system by using a tachogenerator and PI controller in order to reduce the settling time and rejection the disturbance which produced by the load changing.

5.2 Economic costs of the project

Table (5.1) show the economic costs of the project components.

Table (5.1): Economic costs.

Component	Quantity	Piece cost ($)	Total cost ($)
Motors	2	100	200
Small sprockets	3	5	15
Large sprockets	1	10	10
Disk	1	100	100
Chains	2	50	100
Beams	4	10	40
Thrust bearing	1	7	7
Radial bearing	9	3	27
Computer	1	50	50
Photoelectric switch	1	50	50
Plates	3	10	30
Micro switches	2	10	20
Tiflon (Acolon)	1 (rod)	8	8
Screws		5	5
Parallel port	1	3	3
Board	1	10	10
Ic's	10	1	10
Transistors	5	2	10
Total cost			**695$**

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10. www.alldatasheets.com
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Appendix A

The C Program

```
                    //************************include file***********
#include <iostream.h>
#include <conio.h>
#include <stdio.h>
#include <dos.h>
#include <stdlib.h>

//************************define******************
#define data 0x0378
#define status 0x0379
#define l10 0xBF
#define l12 0xdf
#define l13 0xEF
#define up_rotate 0x05
#define down_rotate 0x06
#define up 0x01
#define down 0x02
#define rotate 0x04
#define stop 0x00
#define dt 200
//************************function*****************
void menu(void);
void manual(void);
void automatic(void);
//************************ globale variable ***************
int input,input1,inputtemp;
int count_down,count_up;
//***********************main function ***************
void main(void)
{  count_down = 4;
         count_up = 4;
         outport(data,stop);
         menu();
}
//*********************** menu ******************
void menu(void)
{
         char select;
         do
         {
                  clrscr();
```

```
		cout<<"\n\n\n ";
		cout<<"Please press any key to continue processing\n";
		cout<<"		m : manual mode\n";
		cout<<"		a : automatic mode\n";
		cout<<"		e : exit program\n";
		select = getch();
		switch(select)
		{
			case 'm':manual();		break;
			case 'a':automatic();	break;
			default: exit(1);
		}
	}while((select == 'm')||(select == 'a'));
}
//**********************Automatice***************
void set_up_value(void);
void start_process(void);

void automatic(void)
{
	char select;
	do
	{
		clrscr();
		cout<<"\n\n\n ";
		cout<<"Please press any key to continue processing\n";
		cout<<"		s : set up value \n";
		cout<<"		c : continue start process\n";
		cout<<"		e : exit program\n";
		select = getch();
		switch(select)
		{
			case 's':set_up_value();		break;
			case 'c':start_process();	break;
			default: break;
		}
	}while((select == 'c')||(select == 's'));
}
//**********************start process***********
void start_process(void)
{
```

```
int count_down_temp,count_up_temp;

cout<<"\n\n\n";
cout<<"wrapping started......";

inputtemp = inp(status);
input = inputtemp | l10;

outport(data,rotate);
for(count_down_temp = 0;count_down_temp < count_down;)
{
	delay(dt);
	inputtemp = inp(status);
	input1 = (inputtemp | l10);
	if(input1 != input)
	{
		count_down_temp++;
		cout<<" "<<count_down_temp;
		input = input1;
	}
}
delay(dt);
outport(data,up_rotate);

inputtemp = inp(status);
delay(dt);
input = inputtemp | l12;

delay(dt);
do
{
	inputtemp = inp(status);
	delay(dt);
	input = inputtemp | l12;
}while(input == l12);
delay(dt);
inputtemp = inp(status);
input = inputtemp | l10;

outport(data,rotate);
for(count_up_temp = 0;count_up_temp < count_up;)
```

```
	{
		delay(dt);
		inputtemp = inp(status);
		input1 = inputtemp | l10;
		if ( input1 != input)
		{
			count_up_temp++;
			cout<<" "<<count_up_temp;
			input = input1;
		}
	}
	delay(dt);
	outport(data,down_rotate);
	delay(dt);
	do
	{
		inputtemp = inp(status);
		delay(dt);
		input = inputtemp | l13;
	}while(input == l13);
	outport(data,stop);

}
//************************set up value************
void set_up_value(void)
{
	clrscr();
	cout<<"input the set up value\n";
	cout<<"number of rotates bottum:";
	cin>>count_down;
	cout<<"number of rotates up:";
	cin>>count_up;
}

//************************manual ****************
void endprocess(void);
void up_function(void);
void processing(int rotate1,int up1,int down1,int *end,int *ch1,int *ch2);


void manual(void)
```

```
{
	int ch1,ch2;
	int rotate1=0,up1=0,down1=0,end=0;
	cout<<"Please press start key";
	do
	{
		if(kbhit())
		{
			ch1 = getch();
			if(ch1 == 0)
			{
				ch2 = getch();
				switch(ch2)
				{
					case 75: rotate1=0;up1=0;down1=0;end=0;break;
//stop the system
					case 77: rotate1=1;up1=0;down1=0;end=0;break;
					case 79: goto endprocess_function;
					case 72: //rotate1=1;
							inputtemp = inp(status);
							input = inputtemp | l12;
							if(input == l12) up1=1;
							else up1=0;
							down1=0;end=0; break;
					case 80: //rotate1=1;
							up1=0;
							inputtemp = inp(status);
							input = inputtemp | l13;
							if(input == l13)down1=1;
							else down1=0;
							end=0; break;
				}
			}
		}
		processing(rotate1,up1,down1,&end,&ch1,&ch2);
		delay(120);
	}while(1);
	endprocess_function: endprocess();
}
//***********************processing**************
void processing(int rotate1,int up1,int down1,int *end,int *ch1,int *ch2)
```

```
{
	if((*end == 0)&&(*ch1 == 0))
	{
		if((rotate1 == 0))//&&(up1 == 0)&&(down1 == 0))
			outport(data,stop);
		else if(/*(rotate1 == 1)&&*/(up1 == 0)&&(down1 == 0))
			outport(data,rotate);
		else if(/*(rotate1 == 1)&&*/(up1 == 1)/*&&(down1 == 0)*/)
			outport(data,up_rotate);
		else if(/*(rotate1 == 1)&&(up1 == 0)&&*/(down1 == 1))
			outport(data,down_rotate);

	*end = 1;
	}
	else if(*end == 1)
	{
		if((*ch2 == 72)||(*ch2 == 80))
		{
			outport(data,rotate);
		}
		*end = -1;
	}
}
//************************End Process function****
void endprocess(void)
{
	outport(data,down_rotate);
	do
	{
	inputtemp = inp(status);
	input = inputtemp | l13;

	}while(input == l13);
	outport(data,stop);
}

//************************ End *******************
```

Appendix B

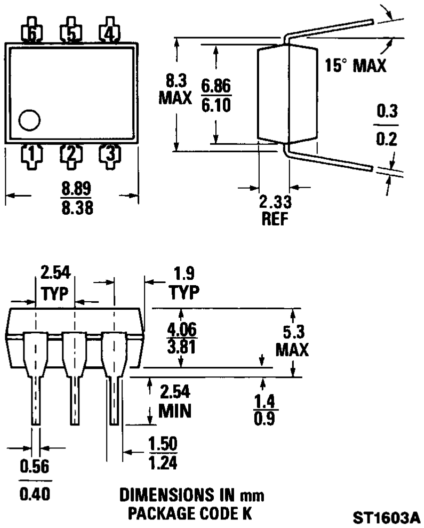
Datasheets

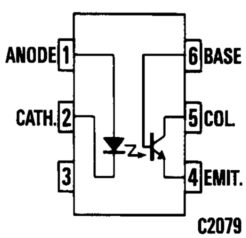
OPTOELECTRONICS

PHOTOTRANSISTOR OPTOCOUPLERS

4N25 4N27
4N26 4N28

PACKAGE DIMENSIONS





Equivalent Circuit

DESCRIPTION

The 4N25, 4N26, 4N27, and 4N28 series of optocouplers have an NPN silicon planar phototransistor optically coupled to a gallium arsenide diode.

FEATURES & APPLICATIONS

- AC line/digital logic isolator
- Digital logic/digital logic isolator
- Telephone/telegraph line receiver
- Twisted pair line receiver
- High frequency power supply feedback control
- Relay contact monitor
- Power supply monitor
- Small package size and low cost
- Excellent frequency response
- UL recognized—File E90700

ABSOLUTE MAXIMUM RATINGS

TOTAL PACKAGE

*Storage temperature .... −55°C to 150°C
*Operating temperature at junction .... −55°C to 100°C
*Lead temperature (soldering, 10 sec) .... 260°C
*Total package power dissipation at 25°C ambient (LED plus detector) .... 250 mW
*Derate linearly from 25°C .... 3.3 mW/°C

INPUT DIODE

*Forward DC current continuous .... 80 mA
*Reverse voltage .... 3.0 V
*Peak forward current
(300 μs, 2% duty cycle) .... 3.0 A
*Power dissipation at 25°C ambient .... 150 mW
*Derate linearly from 25°C .... 2.0 mW/°C

OUTPUT TRANSISTOR

*Collector emitter voltage (BV_{CEO}) .... 30 V
*Collector base voltage (BV_{CBO}) .... 70 V
*Emitter collector voltage (BV_{ECO}) .... 7 V
*Power dissipation at 25°C ambient .... 150 mW
*Derate linearly from 25°C .... 2.0 mW/°C

*Indicates JEDEC Registered Data.

ELECTRO-OPTICAL CHARACTERISTICS
(25°C Free Air Temperature Unless Otherwise Specified)

INDIVIDUAL COMPONENT CHARACTERISTICS

CHARACTERISTICS	SYMBOL	MIN.	TYP.	GUAR. MAX.	UNITS	TEST CONDITIONS
INPUT DIODE						
*Forward voltage	V_F		1.20	1.50	V	I_F=10 mA
Capacitance	C		150		pF	V_F=0 V, f=1 MHz
*Reverse leakage current			.05	100	μA	V_R=3.0 V, R_L=1.0 MΩ
DETECTOR						
DC forward current gain	h_{FE}		250			V_{CE}=5 V, I_C=500 μA
*Collector to emitter breakdown voltage	BV_{CEO}	30	65		V	I_C=1.0 mA, I_B=0
*Collector to base breakdown voltage	BV_{CBO}	70	165		V	I_C=100 μA, I_E=0
*Emitter to collector breakdown voltage	BV_{ECO}	7	14		V	I_E=100 μA, I_B=0
*Collector to emitter leakage current (4N25, 4N26, 4N27)	I_{CEO}		3.5	50	nA	V_{CE}=10 V Base Open
*Collector to emitter leakage current (4N28)				100	nA	
*Collector to base leakage current	I_{CBO}		0.1	20	nA	V_{CB}=10 V Emitter Open

TRANSFER CHARACTERISTICS

DC CHARACTERISTICS	SYMBOL	MIN.	TYP.	GUAR. MAX.	UNITS	TEST CONDITIONS
*Collector output current (a)	I_C				mA	V_{CE}=10 V, I_F=10 mA, I_B=0
(4N25, 4N26)		2.0	5.0	—		
(4N27, 4N28)		1.0	3.0	—		
*Collector-emitter saturation	$V_{CE(SAT)}$		0.2	0.5	V	I_C=2.0 mA, I_F=50 mA

TRANSFER CHARACTERISTICS

AC CHARACTERISTICS	SYMBOL	TYP.	UNITS	TEST CONDITIONS
Non-saturated Collector Delay time	t_d	0.5	μs	R_L=100 Ω, I_C=2 mA, V_{CC}=10 V
Rise time	t_r	2.5	μs	(Fig. 10 and 11)
Fall time	t_f	2.6	μs	
Non-saturated Collector Delay time	t_d	2.0	μs	R_L=1kΩ, I_C 2 mA, V_{CC}=10 V
Rise time	t_r	15	μs	(Fig. 10 and 11)
Fall time	t_f	15	μs	

*Indicates JEDEC Registered Data.

(a) Pulse Test: Pulse Width=300 μs, Duty Cycle ≤2.0%

(b) For this test LED pins 1 and 2 are common and Phototransistor pins 4, 5 and 6 are common.

(c) If adjusted to yield I_C=2 mA and i_c=0.7 mA RMS; Bandwidth referenced to 10 kHz.

ELECTRO-OPTICAL CHARACTERISTICS
(25°C Free Air Temperature Unless Otherwise Specified) (Cont'd)

TRANSFER CHARACTERISTICS (Cont'd)

AC CHARACTERISTICS	SYMBOL	MIN.	TYP.	GUAR. MAX.	UNITS	TEST CONDITIONS
Saturated t_{on} (from 5 V to 0.8 V)	t_{on} (SAT)		5		μs	R_L=2kΩ, I_F=15 mA, V_{CC}=5 V
t_{off} (from SAT to 2.0 V)	t_{off} (SAT)		25		μs	R_B=Open (Fig. 10)
Saturated t_{on} (from 5 V to 0.8 V)	t_{on} (SAT)		5		μs	R_L=2kΩ, I_F=20 mA, V_{CC}=5 V
t_{off} (from SAT to 2.0 V)	t_{off} (SAT)		18		μs	R_B=100kΩ (Fig. 10)
Non-saturated Base—Collector photo diode Rise time	t_r		175		ns	R_L=1kΩ, V_{CB}=10 V
Fall time	t_f		175		ns	
Isolation voltage (b)						$I_{I-O} \leq 1\ \mu A$
(4N25, 4N26, 4N27, 4N28)	V_{ISO}	5300	—	—	V	RMS, t=1 minute
*(4N26, 4N27)		1500	—	—	V	Peak
*(4N28)		500	—	—	V	Peak
Isolation resistance (b)			10^{11}		Ω	V=500 VDC
Isolation capacitance (b)			1.3		pF	V=0, f=1.0 MHz
Bandwidth (c) (also see note 2)	B_W		300		kHz	I_C=2.0 mA, R_L=100 Ω (Fig. 12)

*Indicates JEDEC Registered Data.

(a) Pulse Test: Pulse Width=300 μs, Duty Cycle ≤2.0%

(b) For this test LED pins 1 and 2 are common and Phototransistor pins 4, 5 and 6 are common.

(c) If adjusted to yield I_C=2 mA and i_c=0.7 mA RMS; Bandwidth referenced to 10 kHz.

TYPICAL ELECTRO-OPTICAL CHARACTERISTIC CURVES
(25°C Free Air Temperature Unless Otherwise Specified)

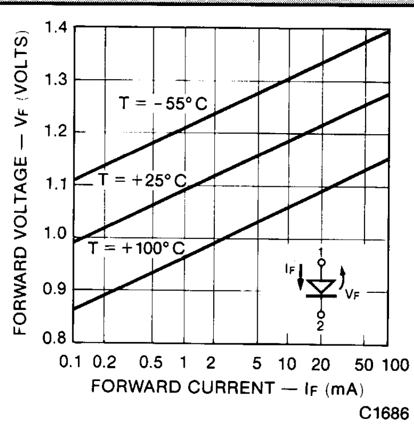


Fig. 1. Forward Voltage vs. Current

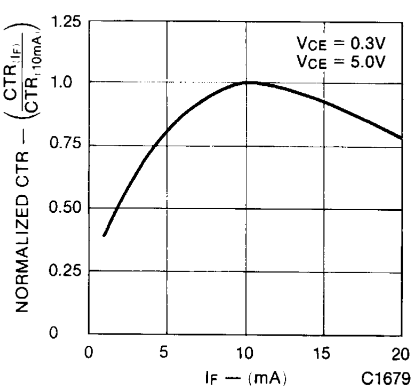


Fig. 2. Normalized CTR vs. Forward Current

TYPICAL ELECTRO-OPTICAL CHARACTERISTIC CURVES

(25°C Free Air Temperature Unless Otherwise Specified) (Cont'd)

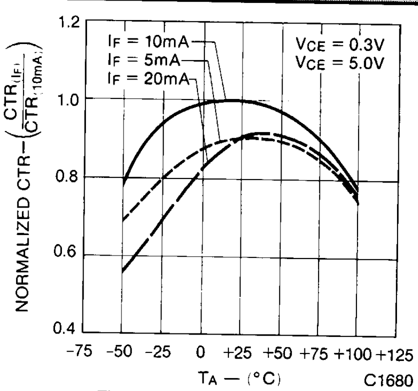


Fig. 3. Normalized CTR vs. Temperature

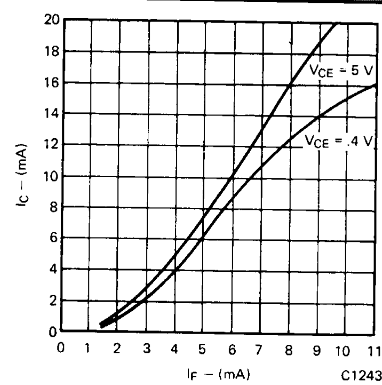


Fig. 4. Collector Current vs. Forward Current

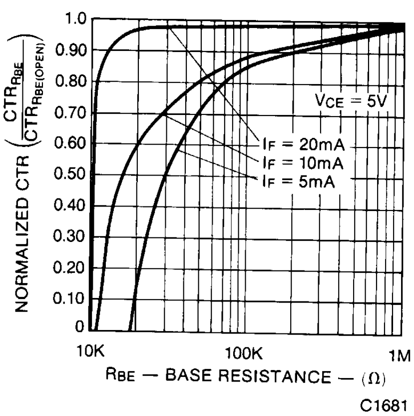


Fig. 5. CTR vs. RBE (Unsaturated)

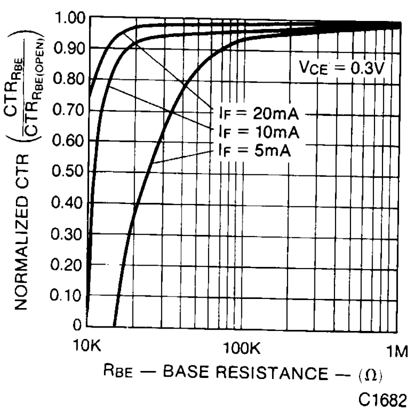


Fig. 6. CTR vs. RBE (Saturated)

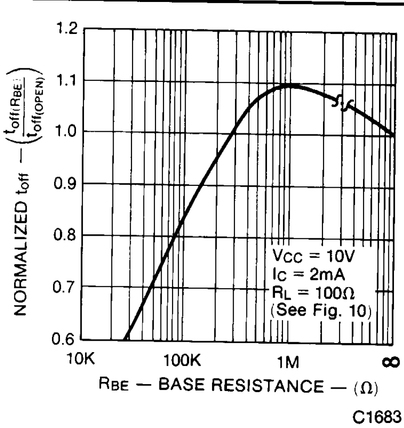


Fig. 7. Normalized T_{OFF} vs. RBE

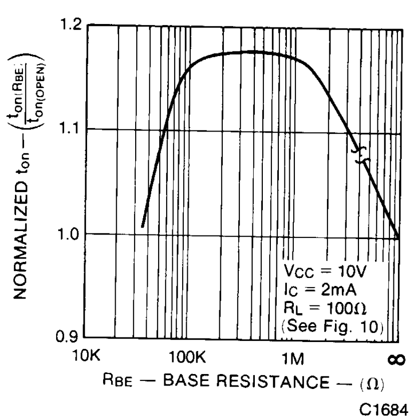


Fig. 8. Normalized T_{ON} vs. RBE

TYPICAL ELECTRO-OPTICAL CHARACTERISTIC CURVES
(25°C Free Air Temperature Unless Otherwise Specified) (Cont'd)

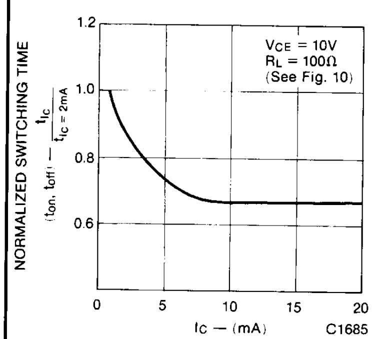


Fig. 9. Switching Time vs. IC

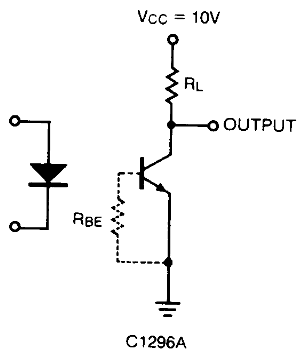


Fig. 10. Switching Time Test Circuit

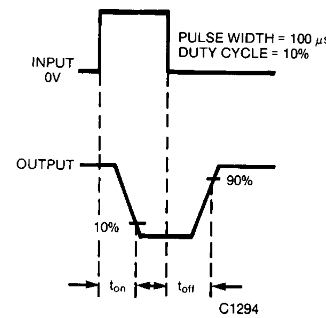


Fig. 11. Switching Time Waveforms

OPERATING SCHEMATICS

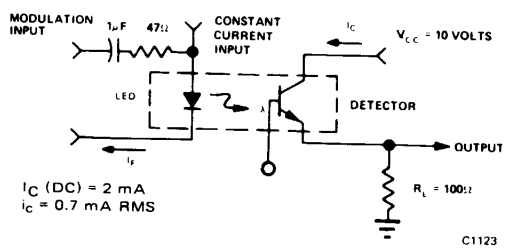


Fig. 12. Modulation Circuit Used to Obtain Output vs. Frequency Plot

NOTES

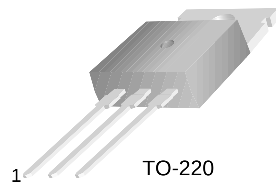
1. *The current transfer ratio (I_C/I_F) is the ratio of the detector collector current to the LED input current with V_{CE} at 10 volts.*
2. *The frequency at which i_c is 3dB down from the 10 kHz value.*
3. *Rise time (t_r) is the time required for the collector current to increase from 10% of its final value to 90%. Fall time (t_f) is the time required for the collector current to decrease from 90% of its initial value to 10%.*

FAIRCHILD
SEMICONDUCTOR ™

BU806/807

High Voltage & Fast Switching Darlington Transistor

- Using In Horizontal Output Stages of 110° Crt Video Displays
- BUILT-IN SPEED-UP Diode Between Base and Emitter



TO-220

1.Base 2.Collector 3.Emitter

NPN Epitaxial Silicon Darlington Transistor

Absolute Maximum Ratings T_C=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage		
	: BU806	400	V
	: BU807	330	V
V_{CEO}	Collector-Emitter Voltage		
	: BU806	200	V
	: BU807	150	V
V_{EBO}	Emitter-Base Voltage	6	V
I_C	Collector Current (DC)	8	A
I_{CP}	*Collector Current (Pulse)	15	A
I_B	Base Current	2	A
P_C	Collector Dissipation (T_C=25°C)	60	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 55 ~150	°C

Electrical Characteristics T_C=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
V_{CEO} (sus)	* Collector-Emitter Sustaining Voltage				
	: BU806	I_C = 100mA, I_B = 0	200		V
	: BU807		150		V
I_{CES}	Collector Cut-off Current				
	: BU806	V_{CE} = 400V, V_{BE} = 0		100	µA
	: BU807	V_{CE} = 330V, V_{BE} = 0		100	µA
I_{CEV}	Collector Cut-off Current				
	: BU806	V_{CE} = 400V, V_{BE} = -6V		100	µA
	: BU807	V_{CE} = 330V, V_{BE} = -6V		100	µA
I_{EBO}	Emitter Cut-off Current	V_{BE} = 6V, I_C = 0		3	mA
V_{CE}(sat)	* Collector-Emitter Saturation Voltage	I_C = 5A, I_B = 50mA		1.5	V
V_{BE}(sat)	* Base-Emitter Saturation Voltage	I_C = 5A, I_B = 50mA		2.4	V
V_F	* Damper Diode Forward Voltage	I_F = 4A		2	V

* Pulsed: pulsed duration = 300µs, duty cycle = 1.5%

Typical Characteristics

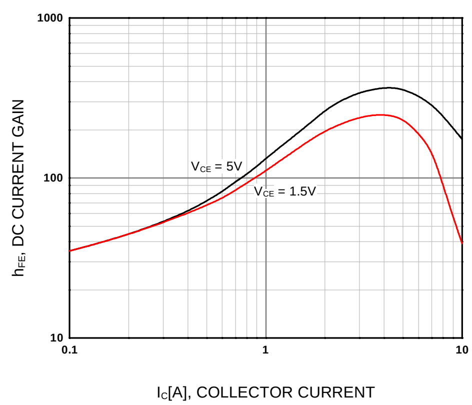


Figure 1. DC current Gain

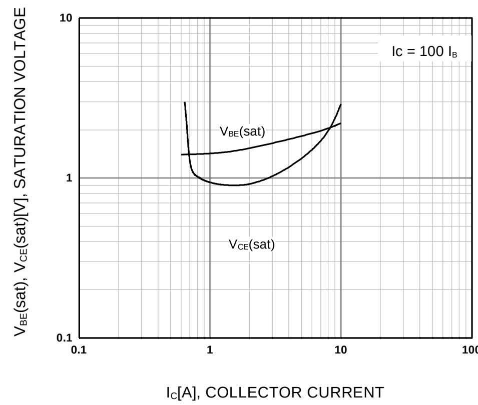


Figure 2. Collector-Emitter Saturation Voltage Base-Emitter Saturation Voltage

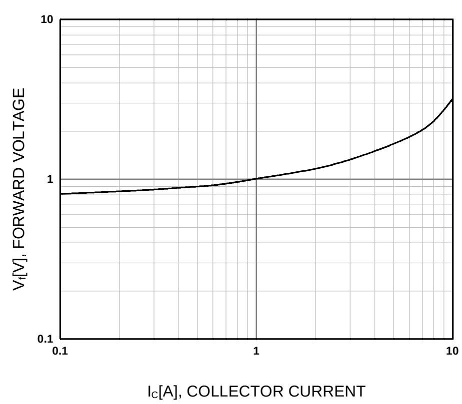


Figure 3. Damper Diode

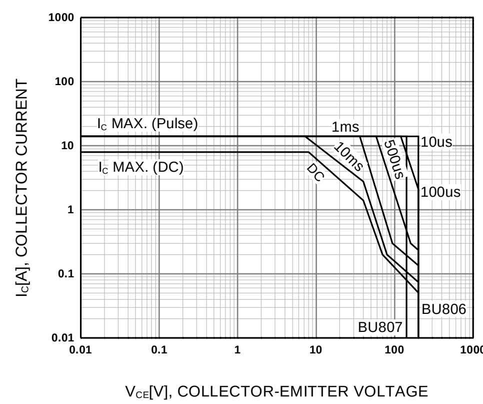


Figure 4. Safe Operating Area

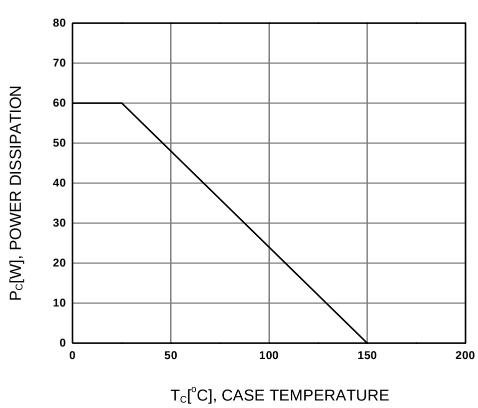
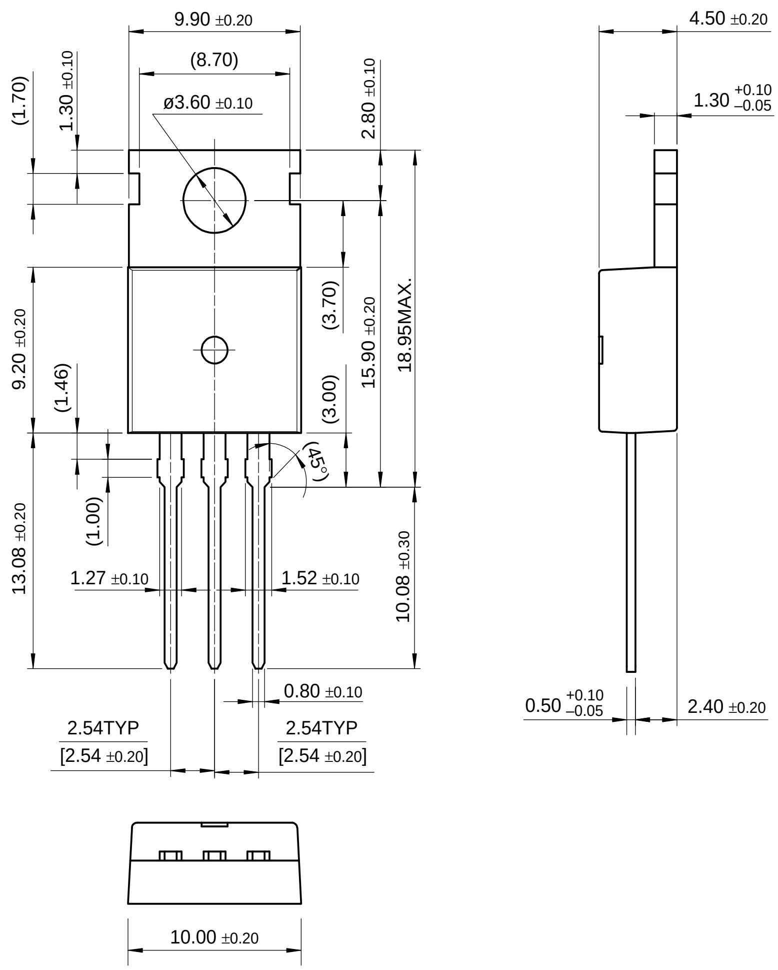


Figure 5. Power Derating

Package Demensions

TO-220



Dimensions in Millimeters

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PRODUCT STATUS DEFINITIONS

Definition of Terms

Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

National Semiconductor

August 2000

TL082
Wide Bandwidth Dual JFET Input Operational Amplifier

General Description

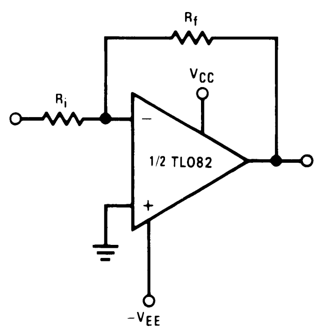
These devices are low cost, high speed, dual JFET input operational amplifiers with an internally trimmed input offset voltage (BI-FET II™ technology). They require low supply current yet maintain a large gain bandwidth product and fast slew rate. In addition, well matched high voltage JFET input devices provide very low input bias and offset currents. The TL082 is pin compatible with the standard LM1558 allowing designers to immediately upgrade the overall performance of existing LM1558 and most LM358 designs.

These amplifiers may be used in applications such as high speed integrators, fast D/A converters, sample and hold circuits and many other circuits requiring low input offset voltage, low input bias current, high input impedance, high slew rate and wide bandwidth. The devices also exhibit low noise and offset voltage drift.

Features

- Internally trimmed offset voltage: 15 mV
- Low input bias current: 50 pA
- Low input noise voltage: 16nV/√Hz
- Low input noise current: 0.01 pA/√Hz
- Wide gain bandwidth: 4 MHz
- High slew rate: 13 V/µs
- Low supply current: 3.6 mA
- High input impedance: $10^{12}\Omega$
- Low total harmonic distortion: ≤0.02%
- Low 1/f noise corner: 50 Hz
- Fast settling time to 0.01%: 2 µs

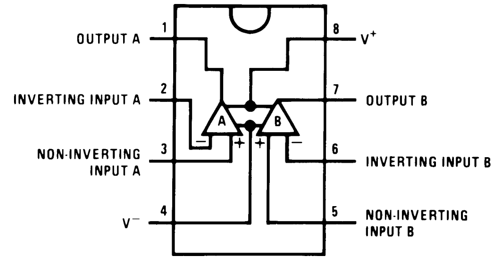
Typical Connection



DS008357-1

Connection Diagram

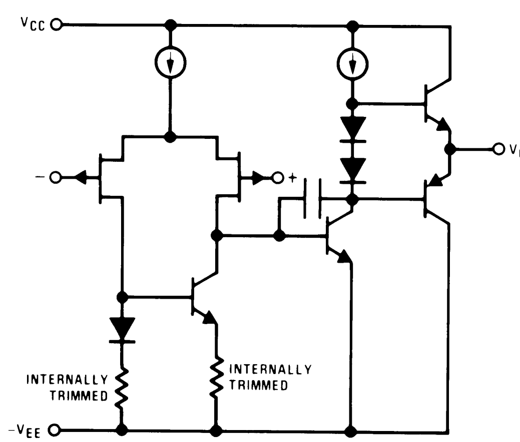
DIP/SO Package (Top View)



DS008357-3

Order Number TL082CM or TL082CP
See NS Package Number M08A or N08E

Simplified Schematic



DS008357-2

BI-FET II™ is a trademark of National Semiconductor Corp.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	±18V
Power Dissipation	(Note 2)
Operating Temperature Range	0˚C to +70˚C
$T_{j(MAX)}$	150˚C
Differential Input Voltage	±30V
Input Voltage Range (Note 3)	±15V
Output Short Circuit Duration	Continuous
Storage Temperature Range	−65˚C to +150˚C
Lead Temp. (Soldering, 10 seconds)	260˚C

ESD rating to be determined.

Note 1: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

DC Electrical Characteristics (Note 5)

Symbol	Parameter	Conditions	TL082C			Units
			Min	Typ	Max	
V_{OS}	Input Offset Voltage	R_S = 10 kΩ, T_A = 25˚C		5	15	mV
		Over Temperature			20	mV
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	R_S = 10 kΩ		10		µV/˚C
I_{OS}	Input Offset Current	T_j = 25˚C, (Notes 5, 6)		25	200	pA
		$T_j \leq$ 70˚C			4	nA
I_B	Input Bias Current	T_j = 25˚C, (Notes 5, 6)		50	400	pA
		$T_j \leq$ 70˚C			8	nA
R_{IN}	Input Resistance	T_j = 25˚C		10^{12}		Ω
A_{VOL}	Large Signal Voltage Gain	V_S = ±15V, T_A = 25˚C	25	100		V/mV
		V_O = ±10V, R_L = 2 kΩ				
		Over Temperature	15			V/mV
V_O	Output Voltage Swing	V_S = ±15V, R_L = 10 kΩ	±12	±13.5		V
V_{CM}	Input Common-Mode Voltage Range	V_S = ±15V	±11	+15		V
				−12		V
CMRR	Common-Mode Rejection Ratio	$R_S \leq$ 10 kΩ	70	100		dB
PSRR	Supply Voltage Rejection Ratio	(Note 7)	70	100		dB
I_S	Supply Current			3.6	5.6	mA

AC Electrical Characteristics (Note 5)

Symbol	Parameter	Conditions	TL082C			Units
			Min	Typ	Max	
	Amplifier to Amplifier Coupling	T_A = 25˚C, f = 1Hz-20 kHz (Input Referred)		−120		dB
SR	Slew Rate	V_S = ±15V, T_A = 25˚C	8	13		V/µs
GBW	Gain Bandwidth Product	V_S = ±15V, T_A = 25˚C		4		MHz
e_n	Equivalent Input Noise Voltage	T_A = 25˚C, R_S = 100Ω, f = 1000 Hz		25		nV/√Hz
i_n	Equivalent Input Noise Current	T_j = 25˚C, f = 1000 Hz		0.01		pA/√Hz
THD	Total Harmonic Distortion	A_V = +10, R_L = 10k, V_O = 20 Vp − p, BW = 20 Hz−20 kHz		<0.02		%

Note 2: For operating at elevated temperature, the device must be derated based on a thermal resistance of 115˚C/W junction to ambient for the N package.

Note 3: Unless otherwise specified the absolute maximum negative input voltage is equal to the negative power supply voltage.

Note 4: The power dissipation limit, however, cannot be exceeded.

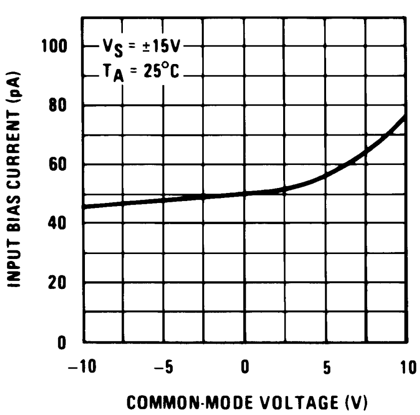
Note 5: These specifications apply for V_S = ±15V and 0˚C ≤T_A ≤ +70˚C. V_{OS}, I_B and I_{OS} are measured at V_{CM} = 0.

Note 6: The input bias currents are junction leakage currents which approximately double for every 10˚C increase in the junction temperature, T_j. Due to the limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junction temperature rises above the ambient temperature as a result of internal power dissipation, P_D. $T_j = T_A + \theta_{jA} P_D$ where θ_{jA} is the thermal resistance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.

Note 7: Supply voltage rejection ratio is measured for both supply magnitudes increasing or decreasing simultaneously in accordance with common practice. V_S = ±6V to ±15V.

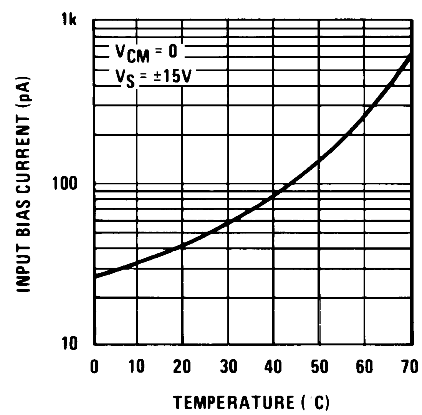
Typical Performance Characteristics

Input Bias Current



DS008357-18

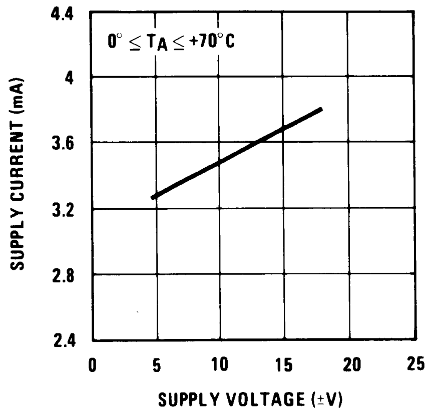
Input Bias Current



DS008357-19

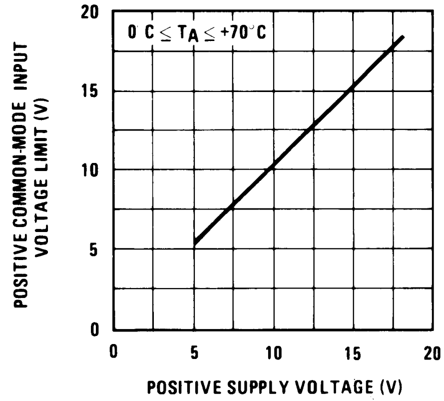
Typical Performance Characteristics (Continued)

Supply Current



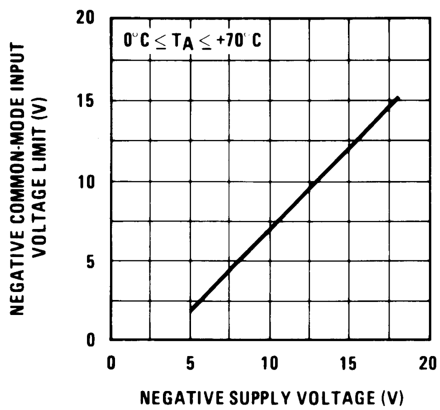
DS008357-20

Positive Common-Mode Input Voltage Limit



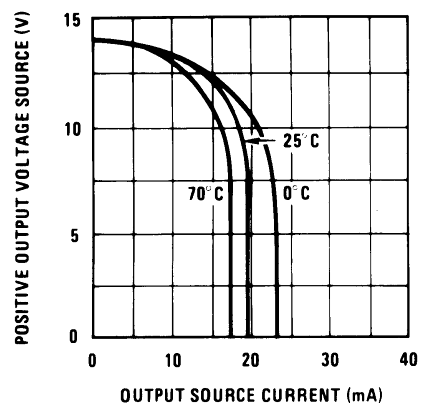
DS008357-21

Negative Common-Mode Input Voltage Limit



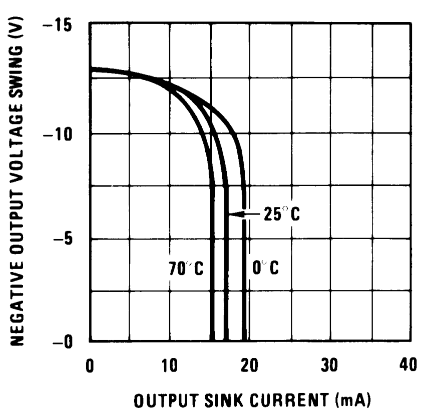
DS008357-22

Positive Current Limit



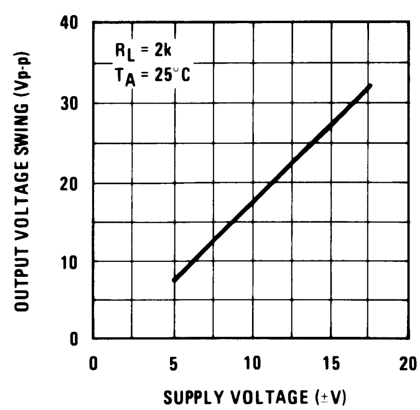
DS008357-23

Negative Current Limit



DS008357-24

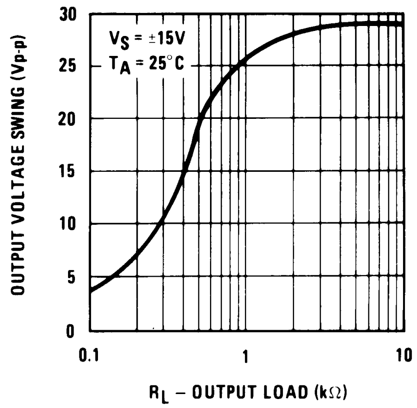
Voltage Swing



DS008357-25

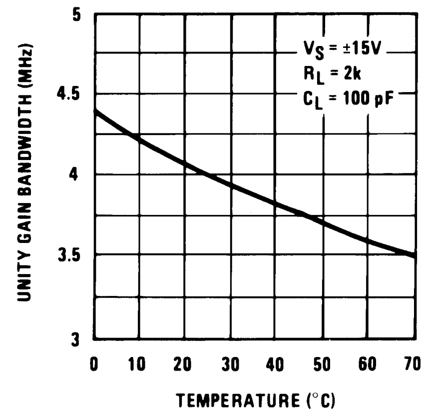
Typical Performance Characteristics (Continued)

Output Voltage Swing



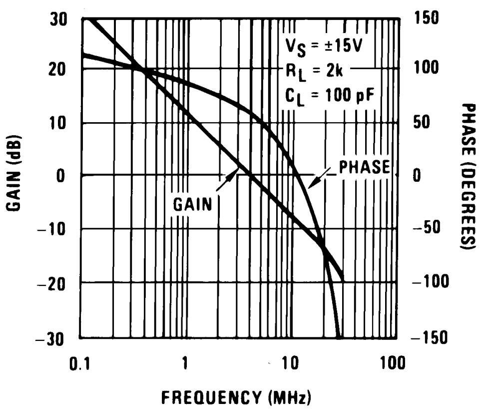
DS008357-26

Gain Bandwidth



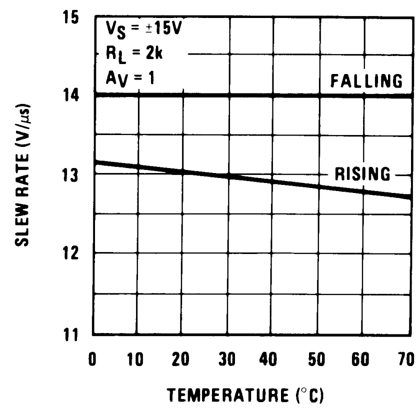
DS008357-27

Bode Plot



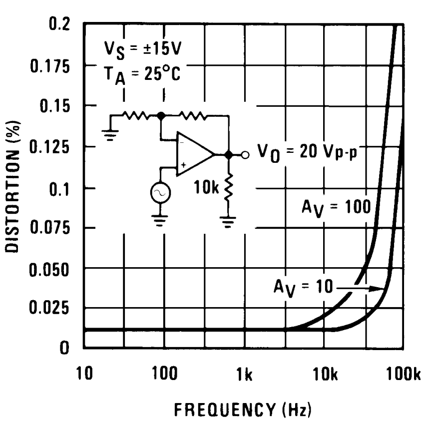
DS008357-28

Slew Rate



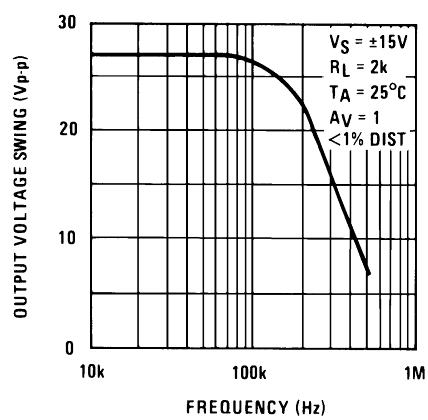
DS008357-29

Distortion vs Frequency



DS008357-30

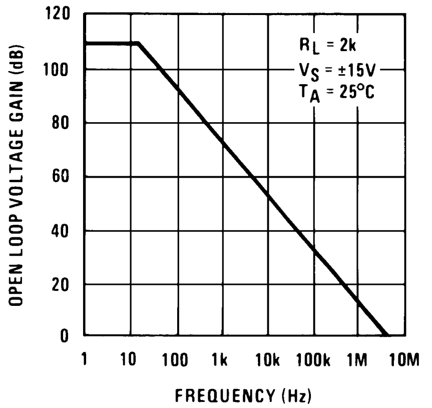
Undistorted Output Voltage Swing



DS008357-31

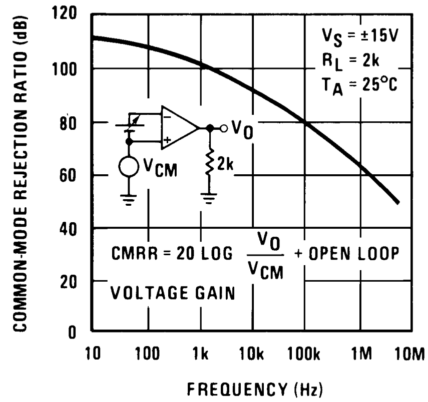
Typical Performance Characteristics (Continued)

Open Loop Frequency Response



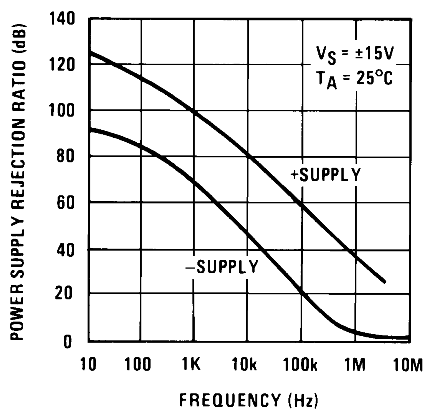
DS008357-32

Common-Mode Rejection Ratio



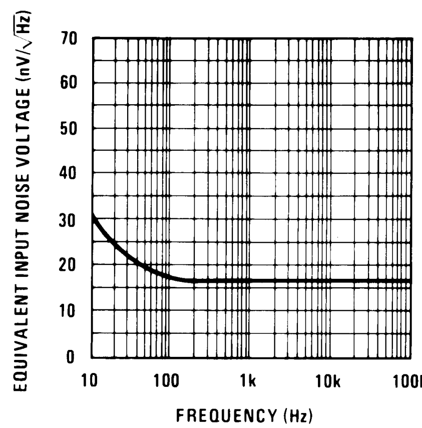
DS008357-33

Power Supply Rejection Ratio



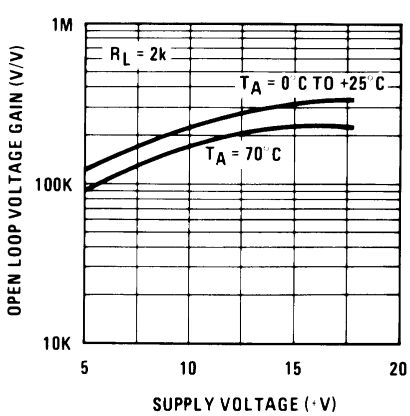
DS008357-34

Equivalent Input Noise Voltage



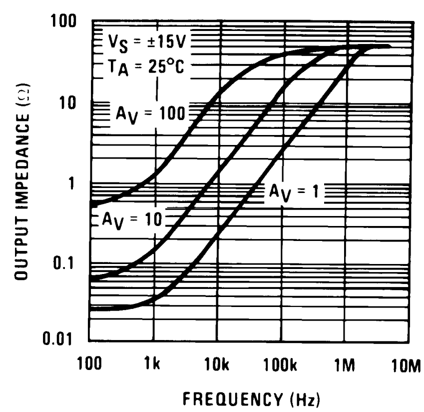
DS008357-35

Open Loop Voltage Gain (V/V)



DS008357-36

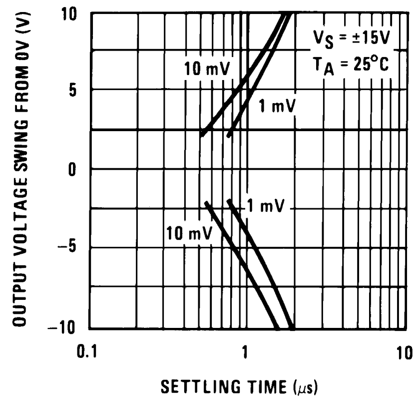
Output Impedance



DS008357-37

Typical Performance Characteristics (Continued)

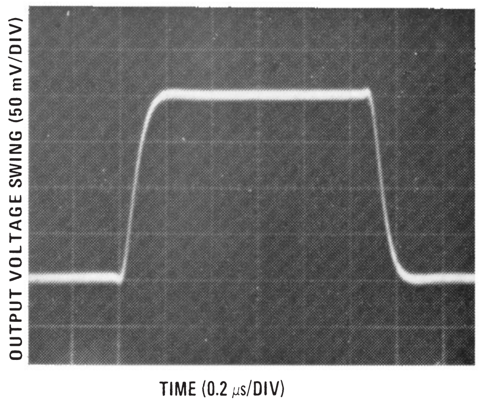
Inverter Setting Time



DS008357-38

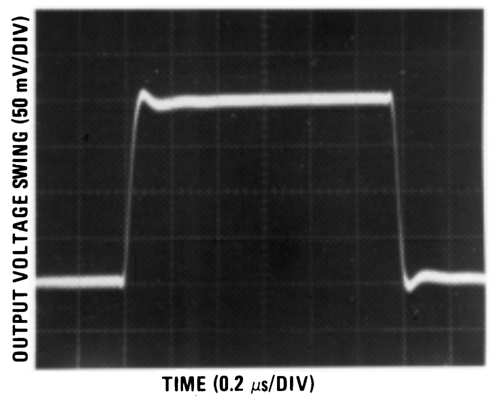
Pulse Response

Small Signal Inverting



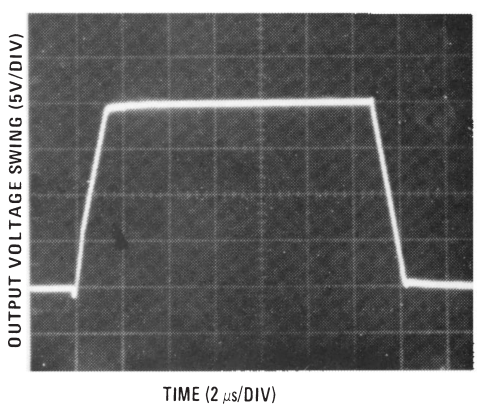
DS008357-6

Small Signal Non-Inverting



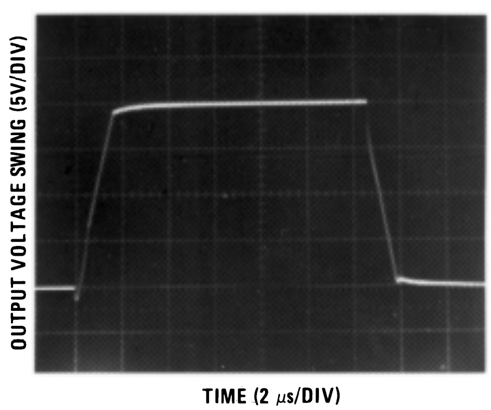
DS008357-7

Large Signal Inverting



DS008357-8

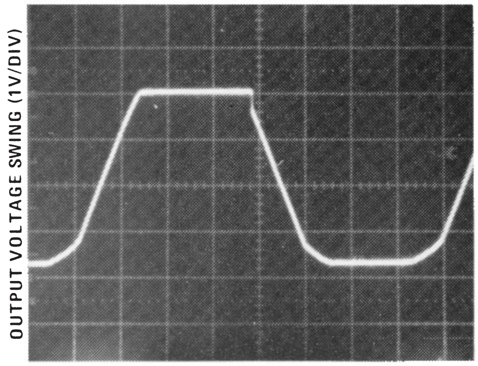
Large Signal Non-Inverting



DS008357-9

Pulse Response (Continued)

Current Limit (R_L = 100Ω)



DS008357-10

Application Hints

These devices are op amps with an internally trimmed input offset voltage and JFET input devices (BI-FET II). These JFETs have large reverse breakdown voltages from gate to source and drain eliminating the need for clamps across the inputs. Therefore, large differential input voltages can easily be accommodated without a large increase in input current. The maximum differential input voltage is independent of the supply voltages. However, neither of the input voltages should be allowed to exceed the negative supply as this will cause large currents to flow which can result in a destroyed unit.

Exceeding the negative common-mode limit on either input will cause a reversal of the phase to the output and force the amplifier output to the corresponding high or low state. Exceeding the negative common-mode limit on both inputs will force the amplifier output to a high state. In neither case does a latch occur since raising the input back within the common-mode range again puts the input stage and thus the amplifier in a normal operating mode.

Exceeding the positive common-mode limit on a single input will not change the phase of the output; however, if both inputs exceed the limit, the output of the amplifier will be forced to a high state.

The amplifiers will operate with a common-mode input voltage equal to the positive supply; however, the gain bandwidth and slew rate may be decreased in this condition. When the negative common-mode voltage swings to within 3V of the negative supply, an increase in input offset voltage may occur.

Each amplifier is individually biased by a zener reference which allows normal circuit operation on ±6V power supplies. Supply voltages less than these may result in lower gain bandwidth and slew rate.

The amplifiers will drive a 2 kΩ load resistance to ±10V over the full temperature range of 0˚C to +70˚C. If the amplifier is forced to drive heavier load currents, however, an increase in input offset voltage may occur on the negative voltage swing and finally reach an active current limit on both positive and negative swings.

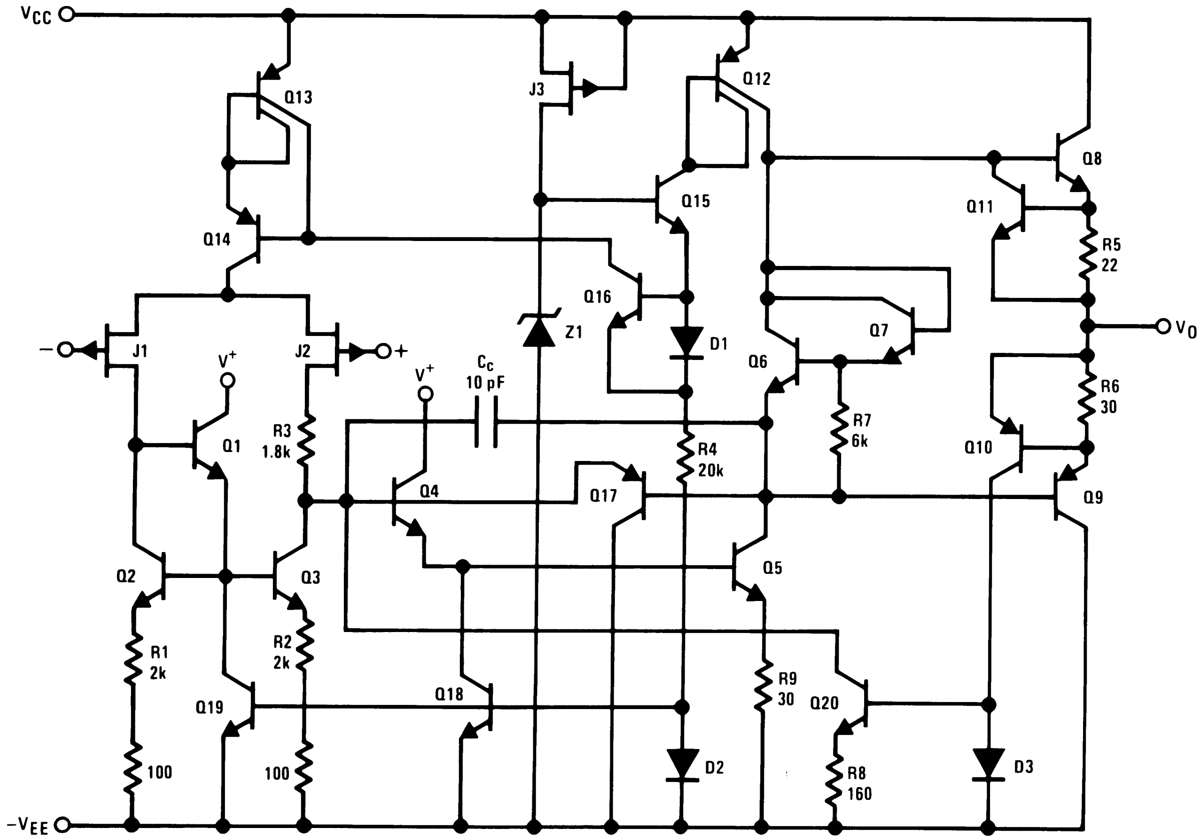
Precautions should be taken to ensure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Because these amplifiers are JFET rather than MOSFET input op amps they do not require special handling.

As with most amplifiers, care should be taken with lead dress, component placement and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize “pick-up” and maximize the frequency of the feedback pole by minimizing the capacitance from the input to ground.

A feedback pole is created when the feedback around any amplifier is resistive. The parallel resistance and capacitance from the input of the device (usually the inverting input) to AC ground set the frequency of the pole. In many instances the frequency of this pole is much greater than the expected 3 dB frequency of the closed loop gain and consequently there is negligible effect on stability margin. However, if the feedback pole is less than approximately 6 times the expected 3 dB frequency a lead capacitor should be placed from the output to the input of the op amp. The value of the added capacitor should be such that the RC time constant of this capacitor and the resistance it parallels is greater than or equal to the original feedback pole time constant.

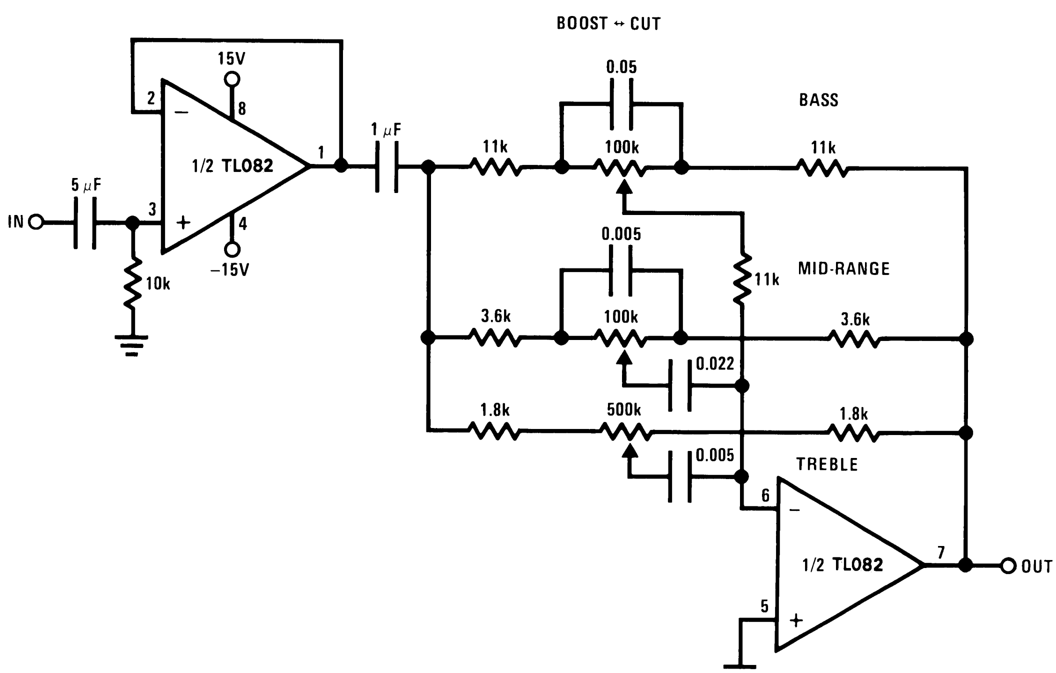
Detailed Schematic



DS008357-11

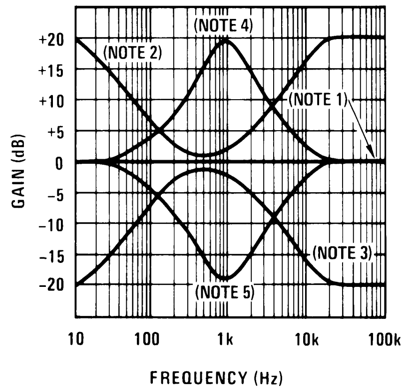
Typical Applications

Three-Band Active Tone Control



DS008357-12

Typical Applications (Continued)



DS008357-13

- All potentiometers are linear taper
- Use the LF347 Quad for stereo applications

Note 8: All controls flat.

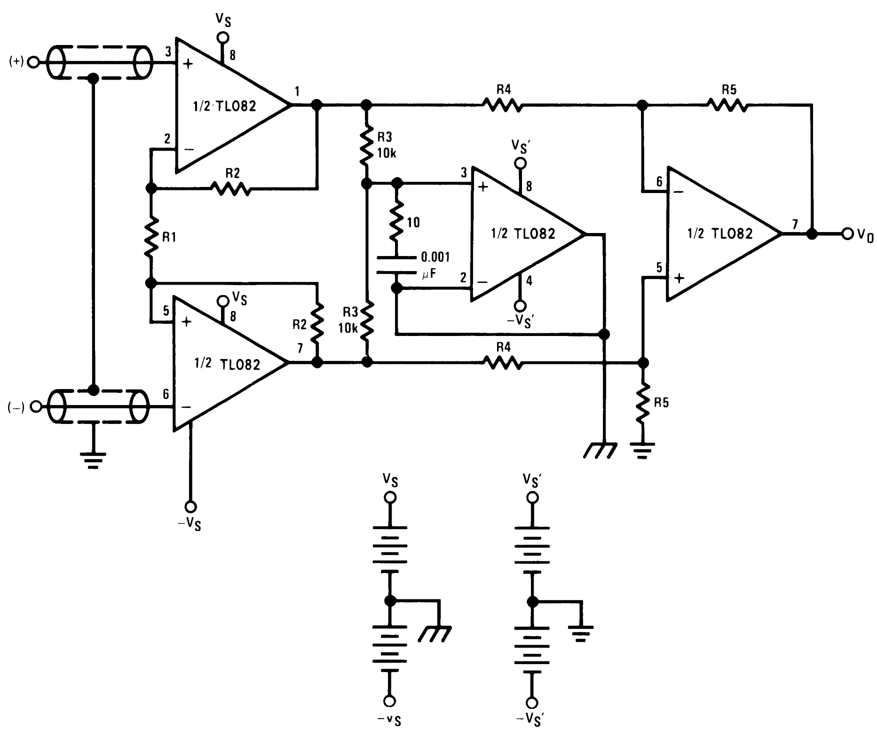
Note 9: Bass and treble boost, mid flat.

Note 10: Bass and treble cut, mid flat.

Note 11: Mid boost, bass and treble flat.

Note 12: Mid cut, bass and treble flat.

Improved CMRR Instrumentation Amplifier



DS008357-14

$$A_V = \left(\frac{2R2}{R1} + 1\right)\frac{R5}{R4}$$

⊥ and ⏚ are separate isolated grounds

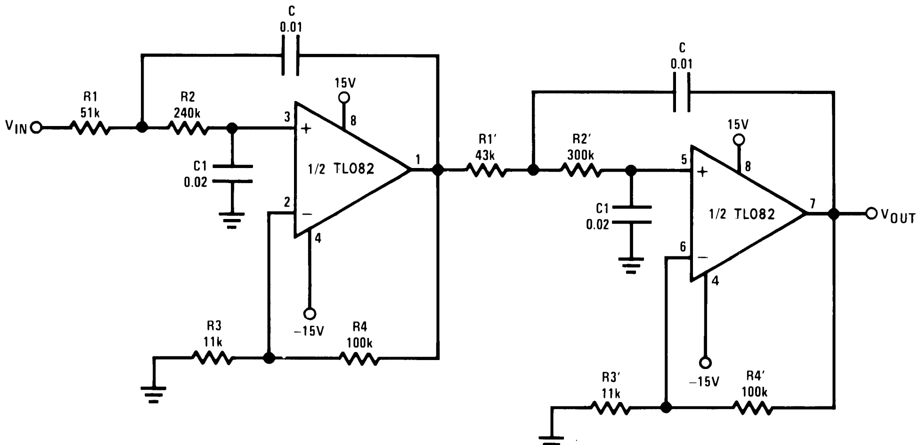
Matching of R2's, R4's and R5's control CMRR

With A_{VT} = 1400, resistor matching = 0.01%: CMRR = 136 dB

- Very high input impedance
- Super high CMRR

Typical Applications (Continued)

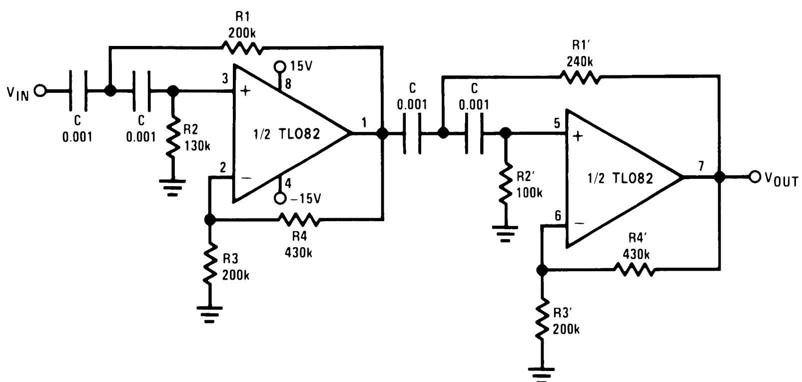
Fourth Order Low Pass Butterworth Filter



DS008357-15

- Corner frequency (f_c) $= \sqrt{\frac{1}{R1R2CC1}} \bullet \frac{1}{2\pi} = \sqrt{\frac{1}{R1'R2'CC1}} \bullet \frac{1}{2\pi}$
- Passband gain (H_O) = (1 + R4/R3) (1 + R4′/R3′)
- First stage Q = 1.31
- Second stage Q = 0.541
- Circuit shown uses nearest 5% tolerance resistor values for a filter with a corner frequency of 100 Hz and a passband gain of 100
- Offset nulling necessary for accurate DC performance

Fourth Order High Pass Butterworth Filter

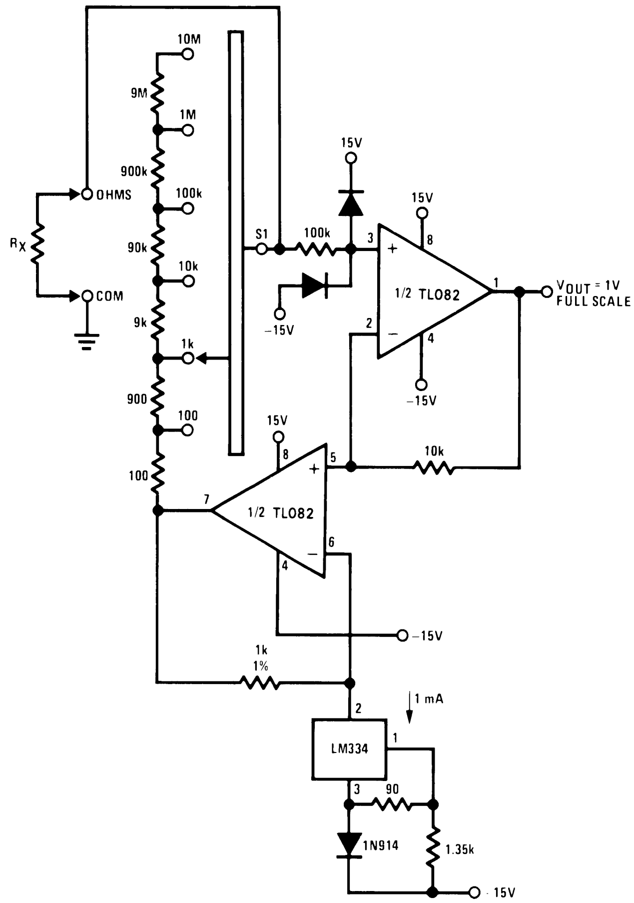


DS008357-16

- Corner frequency (f_c) $= \sqrt{\frac{1}{R1R2C^2}} \bullet \frac{1}{2\pi} = \sqrt{\frac{1}{R1'R2'C^2}} \bullet \frac{1}{2\pi}$
- Passband gain (H_O) = (1 + R4/R3) (1 + R4′/R3′)
- First stage Q = 1.31
- Second stage Q = 0.541
- Circuit shown uses closest 5% tolerance resistor values for a filter with a corner frequency of 1 kHz and a passband gain of 10

Typical Applications (Continued)

Ohms to Volts Converter

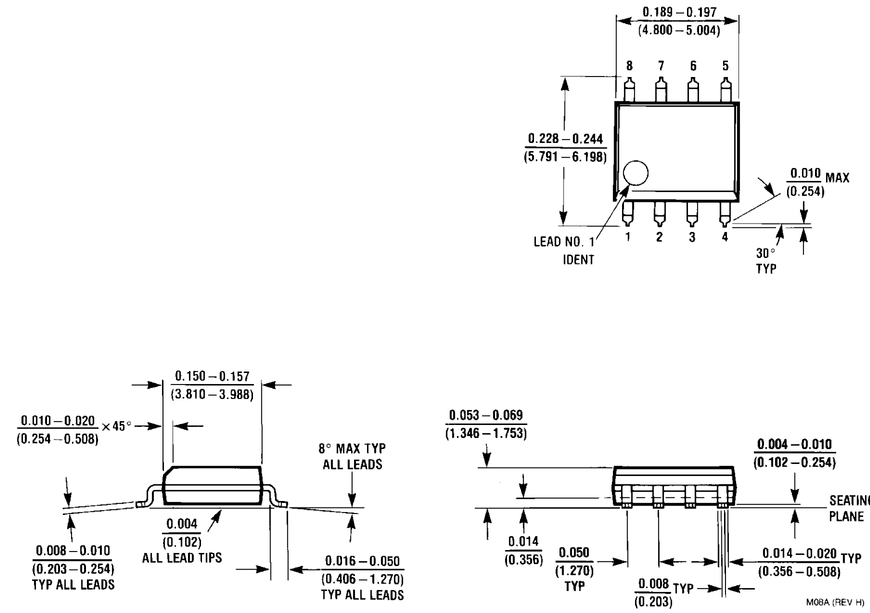


DS008357-17

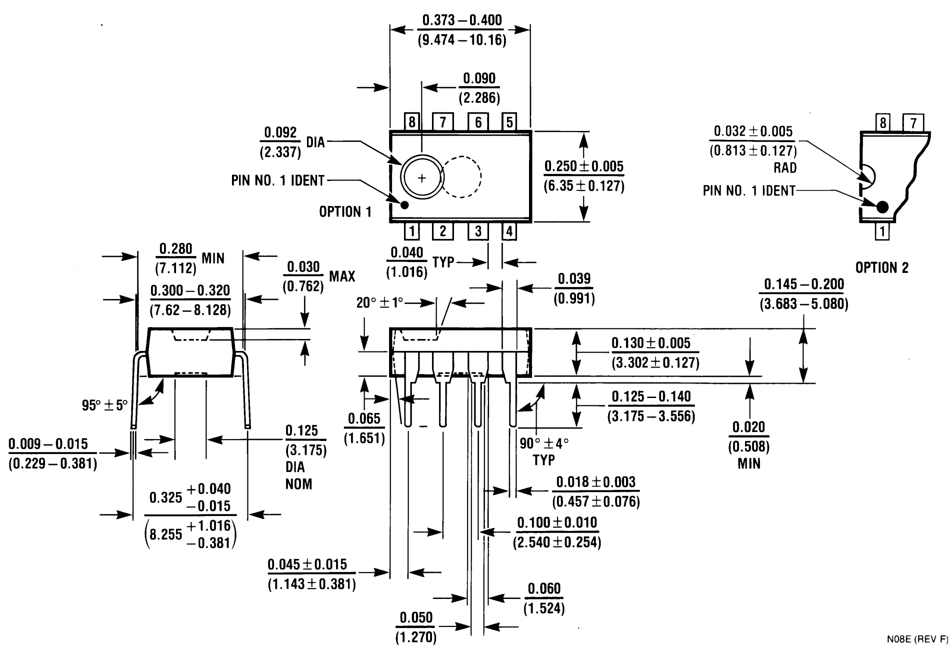
$$V_O = \frac{1V}{R_{LADDER}} \times R_X$$

Where R_{LADDER} is the resistance from switch S1 pole to pin 7 of the TL082CP.

Physical Dimensions inches (millimeters) unless otherwise noted



Order Number TL082CM
NS Package M08A



Order Number TL082CP
NS Package N08E

Notes

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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