1.1.2 Flexible Manufacturing System Layout Configurations.

The FMS layout is determined by the handling system used. The types of layout configurations commonly found in today's FMS's can be categorised as follows (Wilson,1985):

- In-line.
- Loop
- Ladder
- Open field
- Robot-centred cell

The configuration that is of interest is the loop configuration. The loop configuration is appropriate in the case of the system being designed as there are only two numerically controlled machines and one conveyor is sufficient to supply the required work pieces.

In the loop configuration parts usually flow in one direction around the loop with the capability to stop at any station. The load and unload stations are typically located at one end of the loop. A secondary handling system is also used at each work station to allow parts to move without obstruction around the loop.

1.1.3 Material Handling Equipment

The various types of material handling equipment that have been used to transfer parts between stations in an FMS include (Groover, 1987): roller conveyers, cart-on-track conveyers, and other types of conveyor systems: in-floor towline carts; AGVs; and robots. All of these handling systems constitute what is called the *primary material handling system* in the FMS which establishes the basic form of the layout configurations as discussed previously

The types of material handling equipment typically utilised for the five FMS layouts are shown in Table 1.1

Table 1-1 Layer configurations with systems.

Layout configuration	Material handling systems
In-line	Conveyor or shuttle system
Loop	Conveyor system
Ladder	Conveyor system, AGVs
Open field	AGVs, in-floor towline carts
Robot centred cell	Industrial robots

The automation of the parts storage area is one more step in the automation of manufacturing. Generally most of the loading and unloading of parts are handled by an operator. This process is both time consuming, prone to human errors and expensive, as an operator has to be paid to stand by the storage area and perform these duties.

1.1.1 Components of an FMS

There are three basic components of a flexible manufacturing system (Groover, 1987):

- *Processing stations.* These work stations are typically CNC machine tools that perform machining operations on part families. However, other types of processing equipment such as inspecting stations, assembly stations, and sheet metal presses are being incorporated in flexible manufacturing systems.

- *Material handling and storage.* Types of automated material handling equipment used to transport the work parts and subassemblies between the processing stations, sometimes incorporating storage into the function, include AGVs, AS/RS, conveyers and robots.

- *Computer control system.* Computer control is used to co-ordinate the activities of the processing stations and the material handling system in the FMS.

One additional component in the FMS is human labour. Human beings are needed to manage and monitor the operations of the FMS. Other functions typically performed by people are:

- loading raw materials into the system
- unloading finished parts (or assemblies) from the system
- changing and setting tools
- equipment maintenance and repair
- NC part programming
- operating the computer system.

A flexible manufacturing cell (Figure 1.1) consists of several flexible manufacturing modules organised according to particular product requirements. The cell can be based on a group of existing individual machine tools supported by local controllers and an inspection station. An industrial robot is used for work piece transfer. The plant layout is dictated by robot specifications. The cell hardware is completed by the addition of intelligent conveyers for the input, output and rejection of components. Components are fed into the cell and transported by the robot from work station to work station. The pattern of operation can vary in complexity. Robot specification can again be a limiting factor. The addition of an inspection station allows rejects to be identified and tolerance drifting or machine malfunctions to be indicated. This type of cell can be justified on the basis of zero product variety but ease of configuration and low capital cost. The cell is controlled by a single microcomputer. The extension of the software specification will allow a cell of this type to deal with a small variety of components. The system can be regarded as a self contained manufacturing unit or the information developed on its performance can be fed back for production systems management.

Figure 1-1 A typical flexible manufacturing cell

A flexible manufacturing group is a combination of flexible manufacturing modules and cells located in the same manufacturing area and joined by a material handling system, such as an automated guided vehicle (AGV).

A flexible production system consists of flexible manufacturing groups that connect various manufacturing areas, such as fabrication, machining, and assembly.

A flexible manufacturing line is a series of dedicated machines connected by AGVs, robots, conveyers, or some other type of automated transfer device.

The conventional belief is that flexible manufacturing systems are best used in medium volume and with a medium number of different parts. Cummins Engine Company claims a high degree of success and cost savings using FMS in high volumes (Vonderembse,1987).

1. INTRODUCTION

1.1 Background

The use of modern flexible automation technology has made it possible to design manufacturing systems that are profoundly influencing attitudes towards batch manufacturing. The effect of major economic and technological change is most dramatically evident in small batch manufacturing.

These developments and their interaction with the structure and operation of companies have far reaching repercussions for industry. The rapidly changing climate of international competition causes companies to give priority to the main issues that concern them. The manufacturing cost of a product has to be reduced in the face of world wide competition. The developments in manufacturing systems technology are now yielding solutions that make it possible to make inroads into this crucial factor.

The reduction of work in progress is now seen as one of the major objectives and produces early benefits when companies seek to innovate (Kulwiec, 1985). The continued use of high levels of skilled and semi-skilled labour cannot be justified in manufacturing. Costs and response time have to be reduced.

A flexible manufacturing system (FMS) actually refers to a number of systems that differ in the degree of mechanisation, automated transfer, and computer control (Chase and Aquilano, 1992). Five systems are defined and shown how they usually relate to the annual production using a number of different parts. These systems are the flexible manufacturing: module, cell, group, production system, and line.

A flexible manufacturing module is a computer numerically controlled (CNC) machine supported with a parts inventory, a tool changer, and a pallet changer. The flexible manufacturing module is the first building block of an FMS. It is based on the use of a single, CNC machine tool, supported by work piece transfer and storage equipment. Components are loaded and unloaded into the component magazine. This magazine will hold enough work for at least one shift. The station can thus operate in an unsupervised mode without direct manning for one shift. The CNC controller has to be capable of storing a number of part programs, subject to the complexity of the palletised fixtures. In addition, software is required for the estimation of useful tool life, tool replacement and tool breakage detection. All parts of the installation have to be under computer control and management reporting is sometimes required.

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ABSTRACT

The requirement of the project was to design an automatic storage and retrieval system (AS/RS) to be incorporated into a flexible manufacturing cell (FMC) at the University of the Witwatersrand. The flexible manufacturing cell currently being developed in the Industrial engineering department consists of a CNC milling machine and a CNC turning centre supported by an automated materials handling system, and an integrated computer control system. The automated materials handling system consists of a loop conveyor, parts transfer device, tool changing robot and the AS/RS. All the devices of the materials handling system have been constructed from low cost items readily available or alternatively have been manufactured at the University. The research philosophy adopted was to produce a low cost FMC, using local technology and expertise, to produce a system that is both economically feasible and relatively simple to implement.

The AS/RS is computer controlled consisting of three axis, driven by direct current motors. The AS/RS has a storage matrix of sixteen pallets (four by four) and is able to operate autonomously. The controlling software was written in turbo Pascal and designed to allow interface with the other material handling devices. The software allows for future incorporation of scheduling rules such as first in first out, shortest operating time or a schedule desired by the user. The AS/RS also allows the system to generate managerial reports on the status of the system as well as feedback to the FMC supervisory computer.

The design was carried out with the same philosophy used in the FMC i.e. to use low cost items to provide an economically feasible design that is both flexible yet simple to incorporate within a FMC.

In conclusion the AS/RS performs the required pick and place function with sufficient accuracy to ensure that parts are correctly positioned. The controlling program of the AS/RS functions correctly in terms of controlling the AS/RS. The AS/RS is fully autonomous in all operations.

The AS/RS has the following specifications :

	Value	Units
Accuracy	3.67	mm
Repeatability	7.2	mm
Resolution	0.00977	mm
Average pick & place time	41.6	s
X Axis travel	1000	mm
Y Axis travel	640	mm
Z Axis travel	420	mm
Lifting capacity	20	N
Gripping force	10	N
Degrees of freedom	3	

The design can be further improved by using stepper motors instead of direct current motors to provide a finer control in terms of velocity and position accuracy. Although the stepper motors need to have the same price for performance characteristics.

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

(Signature of candidate)

13th day of April 1997.

AN AUTOMATED STORAGE AND RETRIEVAL SYSTEM FOR USE IN A FLEXIBLE MANUFACTURING CELL.

Livio Fabio Corsaro

A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 1997.

Arm And Elbow Configuration

Figure 2.3 shows the arm and elbow or jointed arm configuration robot, where the body rotates vertically, while the arm has two joints, which have independent movements in the horizontal plane.

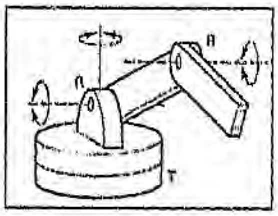


Figure 2-3 Arm and elbow configuration (Owen, 1980).

Cylindrical Configuration

The body rotates vertically, whilst the arm has both vertical and horizontal motions as can be seen in Figure 2.4.

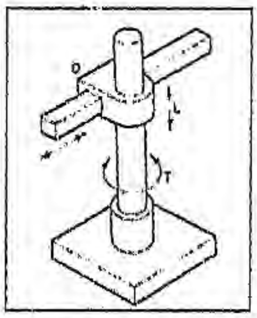


Figure 2-4 Cylindrical Configuration (Owen, 1980).

2.2.4 Alternative AS/RS Mechanisms

In addition to the AS/RS configurations discussed in section 2.2.3 there are presently six recognised configurations of robots (Owen, 1980): polar, arm and elbow, cylindrical, Cartesian, gantry and Selective Compliance Assembly Robot Arm (SCARA), that can be used as alternative configurations.

All the configurations have the following common applications:

- Arc welding.
- Fettling castings
- Handling at die casting machines.
- Loading and unloading machine tools.
- Gas welding.

Polar Configuration

In the polar configuration, as shown in Figure 2.2, the robot's body rotates vertically, while the arm rises or descends in the horizontal plane and extends radially.

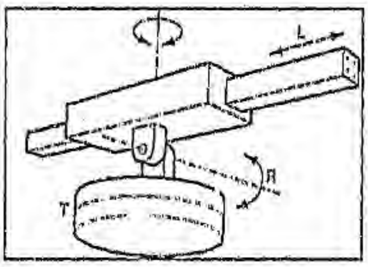


Figure 2-2 Polar configuration (Owen, 1980).

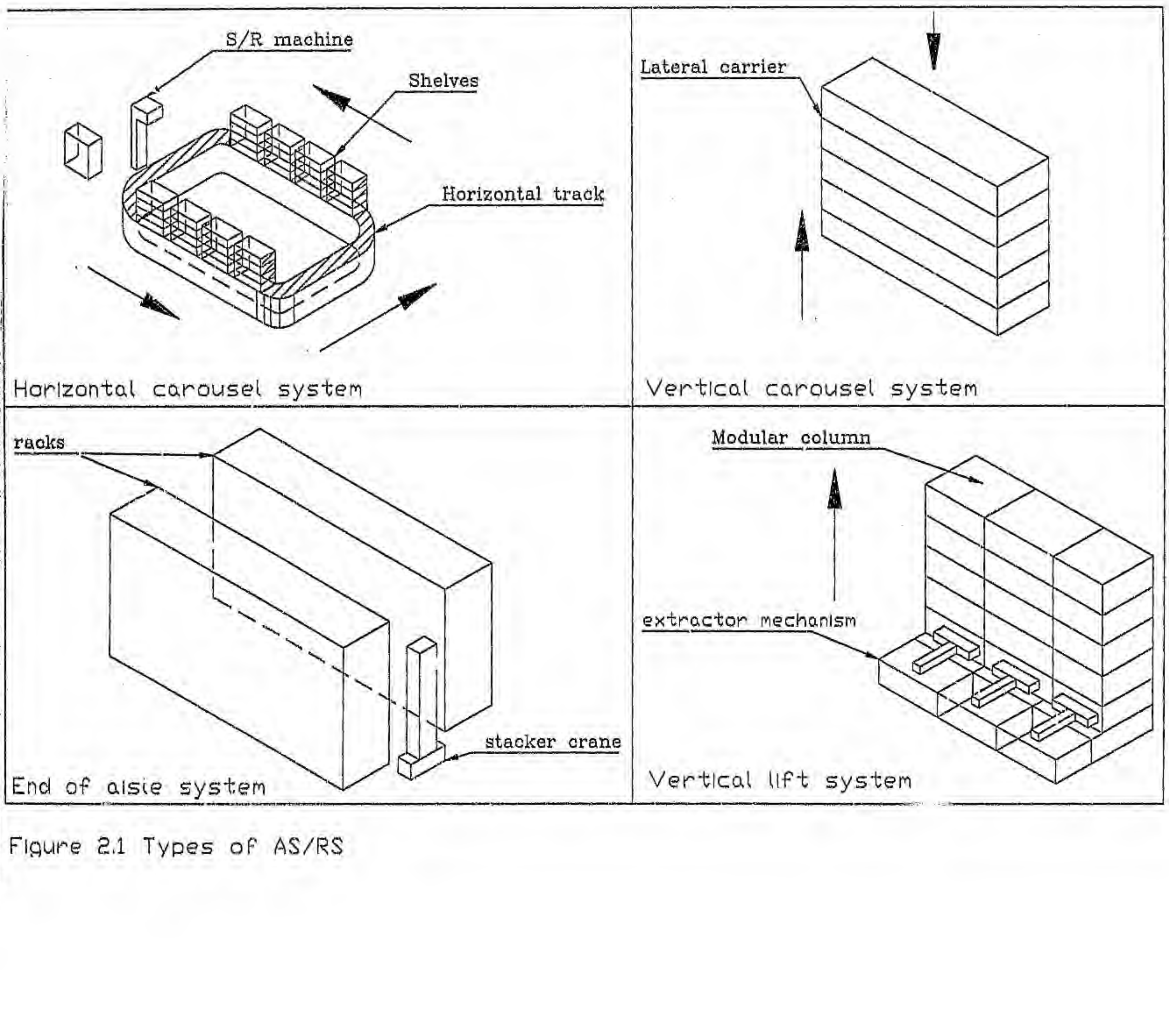


Figure 2.1 Types of AS/RS

Vertical Carousel system

Each free-standing unit (usually enclosed) contains a motor-driven mechanism that rotates lateral carriers on a continuous vertical track (see Figure 2.1). The carriers hold storage containers. The desired carrier is delivered to an access point, typically at waist level. This system has the benefits of efficient use of floor space; faster retrieval than horizontal carousels or end of aisle systems; and easy installation and expansion. Relocation and reconfiguration are also relatively easy.

The vertical carousel system is used in situations with low to moderate storage volume and moderate to high activity. It is mostly used in support areas for applications such as tool crib storage, buffer storage, receiving and finished goods. The average retrieval time on these systems is between 20 and 30 seconds.

End of Aisle system

Probably the best known type of AS/RS, this system consists of opposed racks on either side of an aisle (see Figure 2.1). Each aisle contains an extractor mechanism (stacker crane) mounted on a mast that moves the full length of the aisle on a track. The stacker crane travels vertically on the mast as well as laterally to pull containers to access points at the ends of the aisle. Systems with additional side access points are gaining popularity because these additional pickup and delivery points enhance throughput. System dimensions are affected by number of storage bins and size of the stored components. Retrieval time is affected by the number of bins per aisle.

Vertical lift systems.

This type of system is similar to a vertical carousel in exterior configuration; the interior configuration, however, is significantly different (see Figure 2.1). A vertical lift system consists of modular column storage units containing motor driven extractor mechanisms that move vertically to the location of the desired item, extract the tray on which the item is stored and deliver it to a waist level access port. Each system contains at least three modules. It is generally a build to "user's requirements" system, configured to meet exact needs.

The benefits of such a system are :

- Efficient use of floor space.
- The fastest retrieval time.
- Flexibility in system configuration.
- Number and location of access points and interior container spacing.
- Easy installation, expansion, relocation and reconfiguration.

The most effective application for this system is in virtually any storage volume or activity level. Vertical lift systems are used in areas such as tool crib, receiving area, buffer, maintenance crib, finished goods and kitting.

2.2.2 Determining Needs and Objectives

There is no universally "best" AS/RS; each offers certain advantages for certain applications. The key to selection, then, is a careful examination of the often complex relationship between storage volume needs and when and where stored material will actually be used. This relationship can change from one area to the next within the same facility.

Therefore, the starting point for choosing a system is a careful examination of an operation and its needs. The following is an outline for that examination. A set of criteria that, when matched against the features and benefits of various AS/RS, should indicate which systems are worth investigating further. The questions normally asked are as follows (Allen 1992):

- What is the general size and weight of the stored material ?
  In this case, it's pallets (including the work piece) having dimensions 150x100 mm weighing 2 Kg.

- Where are the highest levels of activity ? (Typically, 80 percent of activity deals with only 20 percent of the inventory).
  This needs to be investigated once the part families are known.

- Would centralised or localised storage be most effective ? (Factors to be considered are production support areas, shipping and receiving, warehousing, distribution).
  Localised storage is being used, because there are only two NC machines.

- What space is available for the system ?
  The space available is 1500x1500 mm.

2.2.3 Types of AS/RS

Horizontal carousel system

Each unit consists of shelving mounted on a continuous, motor driven, horizontal track. Items are typically stored in bins on the shelving (most commonly a wire basket design). Shelving rotates to deliver the desired bin to an access point, usually located at either end of the unit (see Figure 2.1).

The benefits of such a configuration are that it is relatively inexpensive, easy to install and expand, and has flexible shelf spacing. The most effective application is in low to moderate volume and activity situations. The average pick time for this system is 60 seconds.

An automated storage system represents a significant investment for the firm (depending on the size of the AS/RS), and it often necessitates a new and different way of doing business. The performance criteria by which automated storage systems can be measured are :

- Storage capacity.
- System throughput.
- Utilisation.
- Up time reliability.

AS/RS's are custom-made for each individual application, and they range from relatively small mechanised systems that are controlled manually to very large computer controlled systems that are fully integrated with factory and warehouse operations.

The degree of automation is dependant on the AS/RS used e.g. the function of retrieving or storing goods to the point of use may be mechanised but the actual transfer of the goods to a conveyor may be handled manually. The higher the degree of automation the higher the cost of the AS/RS however benefits such as accuracy, productivity and speed also increase.

The AS/RS usually consists of a series of storage aisles that are serviced by one or more storage/retrieval (S/R) machines, usually one S/R machine per aisle. The aisles have storage racks for holding the materials to be stored. The S/R machines are used to deliver materials to the storage racks and to retrieve materials from the racks. The AS/RS has one or more input/output stations where materials are delivered for entry into storage and where materials are picked up from the system. The input/output stations are often referred to as pickup and deposit (P&D) stations in the terminology of AS/RS. The P&D systems can be manually operated or interfaced to some form of automated handling system, such as a conveyor system or automated guided vehicle system (AGVs).

2.2.1 Storage Structure

One factor that is influencing system choice is a growing trend toward decentralising storage and making material more accessible at point of use locations. In many operations the use of satellite storage can increase both worker productivity and the efficiency of material flow. Computer interfacing can tie these satellite AS/RS to a central database, providing real-time inventory information for use by purchasing, order entry, production scheduling and other functions.

This trend favours vertical systems since it is usually impractical to take up production line floor space with horizontal storage. However, there are still many applications, particularly in warehousing and distribution operations, where end of aisle or horizontal carousel systems are the most cost effective.

2.2 Automatic Storage And Retrieval Systems

AS/RS's are devices whose primary function is to retrieve raw materials, parts or finished goods from a storage area and transport them to the point of use. The storage function is the reverse of the retrieval function.

Since AS/RS's were developed in the 1950s, the technology has advanced far beyond the original function of these systems; i.e. eliminating the walking that accounted for 70 percent of manual retrieval time. AS/RS have given industry the benefits of dramatically faster retrieval, condensed storage, increased productivity and the capability to interface with inventory control and material requirements planning (MRP) programs (Allen 1992). They have evolved into sophisticated systems, microprocessor-controlled and computer-interfaceable.

AS/RS's have also diversified, with different types of systems responding to different needs and applications. The four basic types of AS/RS technology available are: end-of-aisle, horizontal carousel, vertical carousel and vertical lift. While this variety offers the opportunity to match an AS/RS with a specific application more effectively, it also presents the dilemma of knowing exactly how to achieve that match.

Different companies have different reasons for installing an automated system for storing materials such as (Vonderembse, 1987):

- Increased storage capacity.
- Increased floor space utilisation.
- Improved safety in storage function.
- Recovered space for manufacturing facilities.
- Improved security and reduced pilferage.
- Reduced labour cost in storage operations.
- Increased labour productivity in storage operations.
- Improved control over inventories.
- Increased stock rotation.
- Improved customer service.

The primary reason for Wit's implementing an AS/RS within the FMC is ;
The FMC being developed at the university requires that the operations carried out are automated as far as possible. Thus the AS/RS forms an integral part in the automating of the materials handling function.

Secondary reasons are :

- Increased floor space utilisation.
- Recovered space for manufacturing facilities.
- Reduced labour cost in storage operations.
- Increased labour productivity in storage operations.
- Improved control over inventories.

In addition to these characteristics of the material, there are other factors to consider in analysing the system requirements. These other factors relate to the movement and handling conditions rather than the material itself. They include (Groover, 1987):

- The quantity of material to be moved.
- The rate of flow required.
- The scheduling of the moves.
- The route by which the materials are to be moved.

The quantity of material moved will influence the type of handling system that should be used. If large quantities of materials must be handled, a dedicated handling system should be considered. If the quantity is small, the handling equipment must be shared with other items moved.

The other point to consider is the type of environment that the FMC finds itself in. This is an important point as if any of the factors listed above are overlooked such as a high rate of use of the machine tool centres, the material handling system will have a high utilisation and could become the bottle neck of the system.

The storage area of the FMC should have sufficient capacity so as to absorb the fluctuations in work parts demand. The storage facility should also have enough storage areas to accommodate a part family.

2. LITERATURE SURVEY

Material handling is an important, yet sometimes overlooked aspect of automation. The cost of material handling forms a significant component of the total cost of production. Estimates of handling cost run as high as two-thirds of the total cost of production (Harrington, 1973). This fraction varies depending on the type and quantity of production and the degree of automation, as well as the efficiency of the material handling function. The purpose of material handling in a factory is to move raw materials, work in progress, finished parts, tools, and supplies from one location to another to facilitate the overall operations of manufacturing. The handling of materials must be performed safely and reliably.

2.1 Analysis For Material Handling Systems

The planning of a material system must begin with an analysis of the materials to be moved. Various materials require different mechanisms to transfer the materials from one location to another.

The following characteristics apply when classifying a material:

- physical form.
- movement in large quantities or as individual pieces.
- whether the components are in containers.

The design of the material handling equipment therefore relies heavily on the type of material, and the physical characteristics given in Table 2-1 should be considered.

Table 2-1 Table of physical characteristics of materials.

Category	Measures or descriptors
Size	Length, Width, And Height, Volume
Weight	Weight Per Piece, Weight Per Unit Volume
Shape	Long And Flat, Round, Square
Risk of damage	Fragile, Brittle, Sturdy
Safety risk	Explosive, Toxic, Corrosive
Condition	Hot, Wet, Dirty, Sticky
Physical form	Solid, Liquid, Gas

1.5 System at the University of the Witwatersrand.

The FMC currently being developed at the University of the Witwatersrand consists of the following items:

- a CNC milling machine.
- a CNC lathe.
- a conveyor.
- a parts transfer device for the milling machine.
- a tool changing robot.

The main emphasis of the FMC is to demonstrate the feasibility of flexible manufacturing on a small scale. All the components have been built and designed at the University and form part of an ongoing research project.

The purpose of this project is to design and build an AS/RS, responsible for the dispatching of the palletised work pieces. Depending on the jobs selected by the governing schedule rule the palletised parts will be fed onto the conveyor by the AS/RS. The palletised work pieces will then transported, on the conveyor, to the respective CNC machines.

A supervisory computer will monitor and control the entire operation while localised PC's will be responsible for the control of the parts transfer devices.

The advantages to be accrued from the implementation of a FMC in a job-shop environment are as follows (Hackman, 1990) :

- Increased productivity.
- Increased machine utilisation.
- Reduced work-progress.
- Reduced waste.
- Reduced man-power requirements.
- Automatic generation of managerial reports on the status of production.

Another example is the Rolls Royce factory where an FMC is being developed for the manufacture of turbine blades. It consists of seven grinding cells each served by an industrial robot. The cell is designed to manufacture five families of blades for the RB211 engine. The principal advantage sought in this application is to minimise change-over time. A novel feature in the process is the use of a zinc alloy encapsulation procedure for holding the work pieces. This is an unusual approach to component fixturing and makes it possible to use robot technology. This cell is designed to process 250 components per day. The principal in addition to productivity is the decrease in change-over time from one part family to the next.

Hessler (1988) suggests that one way of boosting productivity is the use of low cost automation, which falls in line with the research conducted at the University of the Witwatersrand. The use of low cost components, such as off the shelf pneumatic cylinders and hydraulic components, ensures that the cost of the device is justified in terms of the overall cost of the FMC.

If South Africa is to compete world wide within the manufacturing arena, it needs to increase the productivity of the small batch manufacturer. The implementation of inexpensive automation without sacrificing the flexibility of small batch manufacturing is one way of ensuring the competitiveness of SA.

1.2 Problem Statement

Design an automated storage and retrieval system. The device is to have autonomous operation and computer-based control. The placement of the palletised components should be sufficiently accurate to allow the successful placement of the pallet onto the conveyor belt. The controlling algorithm must be capable of allowing the user to specify which pallets are to dispatched and should be sufficiently flexible to allow the future storage of information such as: pallets already dispatched, mechanical failures, and system efficiency. The device is to form part of the FMC being developed at the University.

1.3 Project scope and limitations

The project encompasses various fields such as pneumatics, direct current (DC) motors, computer-based control and transducers. These will be brought together to provide a programmable device that can be called a true robot. The limitation is that the device will only have three degrees of freedom while more advanced robots usually have six degrees of freedom.

1.4 Work Strategy

1. Literature survey of various types of AS/RS and actuators.
2. Selection of AS/RS configuration and actuators.
3. Design of AS/RS based on actuators and configuration.
4. Build device based on design.
5. Write software in modular format.
6. Compile software and hardware into one unit.
7. Test and validate design.

In addition to the primary handling system, a *secondary handling system* is used in many FMS installations. The secondary handling system is located at each work station and is used to transfer work from the primary system to the work station. Its function is to position and locate the parts with sufficient accuracy and repeatability at the workstation for processing. The secondary system can also provide buffer storage of parts at the work stations.

Within the FMS there is an automatic storage and retrieval system (AS/RS) which supports the primary material handling system. The main function of the AS/RS is to provide and retrieve work parts to and from the system respectively. The AS/RS is an automated device able to perform the functions of picking and placing raw materials and finished goods from the storage area to the primary handling system. Material handling costs run as high as two thirds of the total cost of production (Harrington, 1973) and thus the use of AS/RS strives to minimise the amount of material handling within the system. Performance improvements from minimising material handling include:

- higher utilisation of machines.
- less spoilage of goods.
- lower production costs.
- increased productivity.

1.1.4 Examples of FMS in Industry

Systems based on the principles of FMS have been developed by various companies in Japan (Hartley, 1983). The three most dominant manufacturers being:

- Fanuc, the maker of numerical controllers, small CNC and EDM machines and robots.
- Murata, the maker of Robotrailers in Japan, as well as a variety of machinery including textile equipment.
- Yamazaki, a large maker of CNC machines.

In France Renault and Citroen are also using FMS to machine gearboxes for commercial vehicles, and prototype engine components respectively, while smaller systems have been set up in many other countries.

Fanuc is using a wide range of NC machines, from small lathes to large portal machining centres to produce a wide variety of parts for machine tools and robots. Murata has a system that started off with only seven machining centres producing parts from approximately 1m x 0.5m downwards. Yamazaki has produced a system based on two lines to produce large parts for machine tools. In all cases, there is a hierarchical computer control system. The common elements of all these systems are CNC machining centres, automatic pallet handlers, unmanned trolleys and buffer storage. The machine shops are operated for one or two shifts, and unmanned for at least the third shift.

Controllers.

The two main types of controllers available are as follows :

- Analogue.
- Digital.

Analogue controllers are discreet devices made up of components such as operational amplifiers, resistors and capacitors.

Digital controllers are used in two main methods : supervisory control and direct digital control. In the first instance the computer acts as the controller supplying the commands to the interface necessary to drive the DC motors. In direct digital control the microprocessor or computer directly controls the motor i.e. setting voltage and current requirements of the motor.

Control used in the project.

The control method used for the project is proportional control, where the axis velocities are set depending on the position of the axis. The velocity of the axis depends on primarily two criteria : position from home position and position from destination point.

The type of controller used is a digital one used in supervisory mode. The computer provides the algorithm while the electronic interface provides the direct drive of the DC motors. The algorithm is discussed in section *4.7.14 Procedure Xaxis.*

Control of DC motors.

There are two main methods by which to drive DC motors :

- Varying the voltage.
- Pulse width modulation.

Varying the voltage entails changing the supply voltage to the armature of the DC motor thereby causing a proportionate change on the motors output speed.

Pulse width modulation (PWM) entails pulsing the motor with a constant voltage amplitude, while varying the duty cycle of the pulsation to change the corresponding output speed of the motor.

Both methods provide good control of DC motors but PWM provides better speed control at low speeds (Marston, 1989).

There are a number of control techniques available to control DC motors. These are :

- Two position control.
- Proportional control.
- Integral control.
- Proportional plus integral control.
- Derivative control.
- Proportional integral derivative control (PID).

Two position control is used when the deviation of the required position with respect to the desired position (error) reaches a value, the motor is switched off or on depending on the value of the error.

Proportional control is where the change in the control signal is proportional to the error.

Integral control is where the change in the control signal is proportional to the integral of the error.

Derivative control depends on the rate at which an error is occurring to modify the control signal.

The advantages of using direct current (DC) motors are as follows (Pagem, Lhote, Kauffmann, Andre and Taillard, 1983):

- The energy required is easily available
- The robot is autonomous if run from batteries, and fixed robots can be run from domestic supplies.
- Electrical motors now available do not require step-down gears and so can be mounted onto the axis;
- Control is accurate, uniform, reliable and easy.
- There are no problems of leakage or pollution.

The weight factor is a disadvantage. The power-to-weight or torque-to-weight ratio of electric motors is lower than that of hydraulic motors. The weight of these motors cannot be reduced significantly since the frame is an active part of the magnetic circuit.

Direct current motors have the important advantage of providing torque that is virtually independent of the position and speed of the motor, depending only on the field coils and armatures. If the field coil is replaced by a magnet, torque is proportional to the current in the armature and speed depends only on supply voltage. The DC motor cannot be used in positional servo control without the following accessories (Pagem, Lhote, Kauffmann, Andre and Taillard, 1983).

- Tachometric generator;
- Positional sensor;
- Possibly step-gears or a mechanical system for transforming rotational into translational movement.
- Possibly a blocking system for the motor at rest if permanent supply to the motor is impractical due to problems of overheating.

Direct current motors are flexible in application and have good speed control, positional control and torque control. Performance standards are average despite the advances in the uses of magnetic cobalt materials, which are, however, expensive. Overheating is the main constraint.

Losses which occur in DC motors are :

- Winding losses.
- Brush contact losses.
- Iron losses.
- Friction losses.
- Short circuit currents.

The DC motor exhibits simple relationships between current, voltage, torque and speed. The application of a constant voltage to the terminals of a motor will result in the motor accelerating to attain a steady final speed (n). Under these conditions, the voltage (V) applied to the motor is opposed by the back emf (nK_E) and the resultant voltage drives the motor current (I) through the motor armature and brush resistance (R_s).

The equivalent circuit (Stuart,1989) of a DC motor is shown in Figure 2.9.

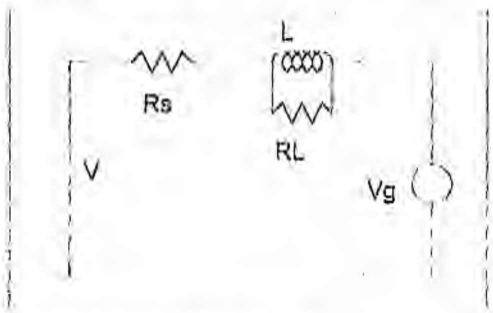


Figure 2-9 DC motor equivalent circuit.

The value of the winding inductance (L) is generally small and thus can be ignored, while the value of magnetic losses (R_L) is generally large thus a small current passes though R_L and can also be ignored.

If a voltage (V) is applied to the motor and a current (I) flows then :

$$V = IR_s + V_g$$

but $V_g = nK_E$

so

$$V = IR_s + nK_E \qquad (2\text{-}2)$$

Where :

I = Current (A)
R_s = Motor resistance (Ohms).
V_g = Back emf (Volts).
n = Motor speed (rpm)
K_E = Motor voltage constant

This is achieved by constructing the armature as a series of small sections connected in sequence to the segments of a commutator . Electrical connection is made to the commutator by means of two brushes. It can be seen from Figure 2-8 that if the armature rotates through 1/6 of a revolution clockwise, the current in coils 3 and 6 will have changed direction. As successive commutator segments pass the brushes, so the current flow in the coils connected to those segments changes direction. This commutation or switching effect results in a current flow in the armature which occupies a fixed position in space, independent of the armature rotation, and allows the armature to be regarded as a wound core with an axis of magnetisation fixed in space. This gives rise to the production of a constant torque output from the motor shaft.

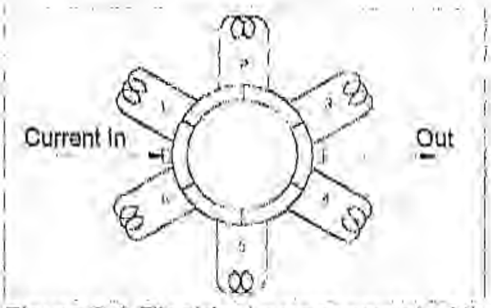


Figure 2-8 Electrical arrangement of the armature

The axis of magnetisation is determined by the position of the brushes and in order for the motor to have similar characteristics in both directions of rotation, the brush axis must be positioned such as to produce an axis of magnetisation which is at 90° to the stator field.

There are three main of types DC motor (Hannafin, 1986):

- Iron cored.
- Moving core.
- Brushless

DC motors are designed to convert electrical power into mechanical power and as a consequence of this, during periods of deceleration or if externally driven, will generate electrical power. However all the input power is not converted into mechanical power due to electrical resistance of the armature and other rotational losses. These losses give rise to heat generation within the motor.

If the motor is driven by an external load the motor will operate as a generator. As the shaft is rotated, a voltage will appear across the brush terminals. This voltage is called the *back emf* and is generated even when the motor is driven by an applied voltage. The output voltage is a linear function of the rotational speed of the motor, having a slope defined by the motor voltage constant, K_E (quoted in volts per 1000 rpm).

Motor losses can be divided into two areas : those which depend on the load and those which depend on speed.

In order to achieve maximum performance from the motor, the maximum number of conductors must be placed in the magnetic field, so as to obtain the greatest possible force. In practice this results in what is in effect a cylinder of wire, with the windings running parallel to the axis of the cylinder. A shaft is placed down this axis to act as a pivot, and this arrangement is called the motor armature. (Figure 2.7)

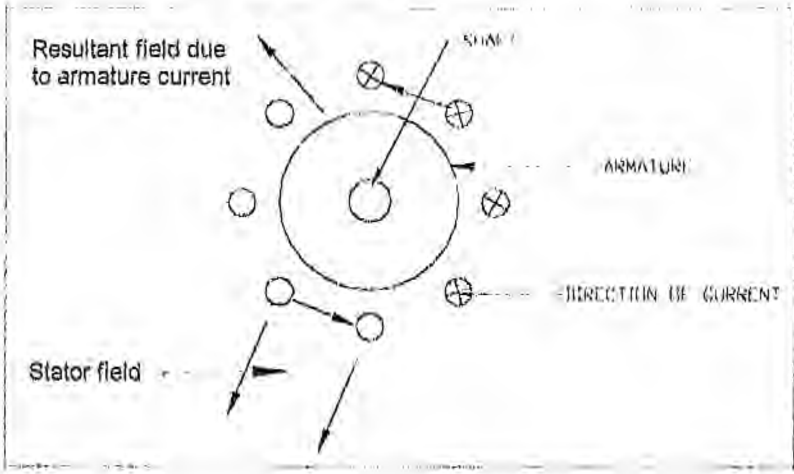


Figure 2-7 DC motor armature

It can be seen that as the armature rotates, so does the resultant magnetic field, and the armature will come to rest with its resultant field aligned with that of the stator field, unless some provision is made to constantly change the direction of the current in the individual armature coils.

The force bringing about rotation of the motor armature is the result of the interaction of two magnetic fields (the stator field and the armature field). In order to produce a constant torque from the motor, it is required that these two fields remain constant in magnitude and in relative orientation.

2.3.1 Direct Current Motors

The history of the direct current (DC) motor can be traced back to the time of Faraday who did extensive work with disk type machines.

This design was quickly improved upon, and by the end of the 19th century the design principles of DC motors had become well established.

At about that time, however, alternating current (AC) power supply systems came into general use and the popularity of the DC motor declined in favour of the less expensive AC induction motor. More recently, the particular characteristics of DC motors, notably high starting torque and controllability, have led to their application in a wide range of systems requiring accurate control of speed and position. This process has been helped by the development of sophisticated drive and computer control systems.

The main principles are based on the well known fact that when a current carrying conductor is placed in a magnetic field it experiences a force.

The force acting on the conductor is given by :

$$F = I \times B \qquad (2\text{-}1)$$

where :

B= magnetic flux density (Tesla, T)
I = current (A).

If this single conductor is replaced by a large number of conductors (i.e. a length of wire is wound into a coil), then the force per unit length is increased by the number of turns in the coil and this forms the basis of a DC motor.

The problem now is that of using this force to produce the continuous torque required in a practical motor.

2.3 Actuators Available for the AS/RS

An actuator is a device by which motion is generated, e.g. motors and pistons. The choice of actuator is influenced by factors such as: torque, speed, accuracy, reliability, maintenance, and weight (Biscoe, 1988).

The different kind of actuators relevant to this project will be discussed individually as well as their advantages and disadvantages. The actuators that are available for robots are the same for small scale AS/RS's. Robot actuators can be electrical, pneumatic, hydraulic or some combination of these.

Pneumatic systems are found in about 30 % of robots (Pagem, Lhote, Kauffmann, Andre and Taillard, 1983), although they are confined mainly to limited sequence devices. Pneumatic drives have the merit of being cheaper than other methods, and their inherent reliability means that maintenance costs can be kept down. Since machine shops typically have compressed air available this makes the pneumatic robot a common choice, as personnel on the shop floor are already familiar with compressed air tools. However, the system does not allow for easy control of either speed or position; two essential ingredients for any successful robot.

Electromechanical drives are used in some 20% (Pagem, Lhote, Kauffmann, Andre and Taillard, 1983) of robots. Typical forms are servomotors, stepping motors, pulse motors, linear solenoids and rotational solenoids.
The most popular form of drive system is hydraulic, because of :

- compactness,
- high levels of force and power
- accurate control.

Given a specific pallet to retrieve the S/R machine must be controlled to ensure that the final destination point is indeed the correct one. There are several methods by which the S/R machine can verify the pallet. One method is to count the vertical and horizontal pallets moved and thus arrive at the correct position. For a successful pick operation a reflective sensor could be used to align the S/R machine with the pallet.

Computer controls and programmable controllers are used to determine the required location and guide the S/R machine to its destination. The computer's primary function is to maintain the records of items to be picked and generate managerial reports about system performance, inventory control and scheduling of jobs. A programmable logic controller (PLC) is normally used for the actual activation of the S/R machine. Computers can also be used to do the PLC's job by making use of specialised process control cards.

2.2.7 Additional Features

There are a number of extra features that can be added to the basic components in order to provide a higher degree of automation and in turn increase the system efficiency. These other features are (Groover 1987):

- Aisle transfer cars.
- Full/empty bin detectors.
- Sizing stations.
- Load identification stations.

Most AS/RS's have one S/R machine per aisle. In AS/RS where the activity is low the cost of having one S/R machine per aisle is not warranted and this is where aisle transfer cars come into effect. Aisle transfer cars are rigid structures that transport the S/R machine from one aisle to the next as the need arises.

A full/empty detector is another feature that serves to make the AS/RS more autonomous. The detector is an electronic sensor that serves to detect whether the pallet is indeed in the correct place or whether there is a pallet. If the pallet is not in the correct location a recovery algorithm is set in motion to rectify the situation or the AS/RS will indicate to the operator that there is an inconsistency within the storage area.

The primary task of a sizing station is to ensure that the pallets or work pieces fall within the specified limits of the storage facility. The sizing station monitors the pallets dimensions and mass of work pieces to check whether they are within the required specifications.

Load identification stations serve the purpose of ensuring that the right pallet is placed at the right place at the right time. The need for load identification stations diminishes as the use of the human operator decreases.

Thus the S/R machine must have at least three degrees of freedom in order to accomplish a successful pick operation. The higher the degrees of freedom the more versatile and flexible the S/R machine is. However at the extreme of this flexibility is the robot, and as the flexibility increases so does the cost of the device. Adding extra degrees of freedom will not necessarily improve the system performance. In the successful execution of the task some of the degrees of freedom will have been made redundant.

The S/R machine must have the following characteristics to have a successful pick operation:

- Accuracy.
- Speed.
- Repeatability.
- Reliability.

The *storage modules* are the containers of the stored material. Examples of storage modules include pallets, steel wire baskets and containers, tote pans storage bins and special drawers. These modules are generally made to a standard base size that can be handled automatically by the shuttle of the S/R machine. The standard size of the pallet also permits it to be stored in a compartment that allows convenient entry and extraction of the load by the shuttle.

The *pick and deposit* stations are used to transfer loads to and from the AS/RS. They are generally located at the end of the aisles for access by the S/R machines and the external handling system that brings loads to the AS/RS and takes loads away. The pickup stations and deposit stations may be located at opposite ends of the storage aisle or combined at the same location. The pick and deposit stations may be designed so that they are compatible with both the S/R machine shuttle and the external handling system.

2.2.6 AS/RS controls

The principal control problem in AS/RS operation is the positioning of the S/R machine within an acceptable tolerance at the storage compartment in the structure for depositing or retrieving a specific load. The locations of materials stored in the system must be determined in order to direct the S/R machine to a particular storage compartment. Each compartment in the AS/RS is identified by a location number, which indicates aisle, horizontal position, and vertical position in the structure. A scheme based on alphanumeric codes can be used for this purpose. Using this location identification scheme, each unit of material or work piece that is stored is given an identification code and referenced to a particular location in the storage system. The record of these locations is called the item location file. Each time a storage transaction is completed, a record of the transaction must be entered into the item location file (Hackman and Rosenblatt, 1990).

2.2.5 Basic components of an AS/RS.

All AS/RS's consist of certain building blocks, used for nearly all of the AS/RS categories described in Section 2.2.3. These components are (Groover 1987):

- Storage structure.
- Storage/retrieval (S/R) machine.
- Storage modules (e.g. , pallets for unit loads).
- Pickup and deposit stations.

The *storage structure* is the framework within which the components are stored. The structure should have sufficient strength and rigidity so that the structure does not deflect significantly when loaded. The pallet holders should have the correct dimension to locate the pallets but at the same time have compliance so that the pallets can be inserted and removed without jamming.

The storage structure should also be designed optimally, i.e. the relationship between number of horizontal bins with respect to vertical bins should be a function of cost and efficiency of the system. The storage area should also be modularised as far as possible so as to allow the addition of extra storage space without incurring a large cost.

The *S/R machine* (sometimes called the crane) is used to accomplish a storage transaction, delivering loads from the input station into storage, or retrieving loads from storage and delivering them to the output station. To perform these transactions, the S/R machine must be capable of horizontal and vertical travel to align its carriage (which carries the load) with the storage compartment in the storage structure, and it must also pull the load from or push the load into the storage compartment.

The carriage (which forms part of the S/R machine) consists of some form of shuttle mechanism to deposit loads into and extract loads from their storage compartments. The design of the shuttle system must also permit the [illegible] be transferred from the S/R machine to the pick and place station or other [illegible]al handling interface with the AS/RS. The shuttle should have some form of gripper mechanism to grasp the required pallets.

Cartesian Configuration

In this configuration shown in Figure 2.5, the robot has three perpendicular linear motions.

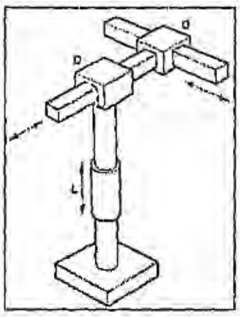


Figure 2-5 Cartesian configuration (Owen, 1980).

Gantry Configuration

With this type of configuration the robot has identical motions to the Cartesian configuration. The difference is that the gantry configuration has extra support thus providing a more rigid support and the ability to carry larger loads. It is used mainly for transferring larger loads and in assembly operations.

SCARA configuration

This type of configuration is similar to that of the arm and elbow configuration. The difference is that the joints normally operate in the horizontal plane and have a linear movement in the vertical plane, shown in Figure 2.6.

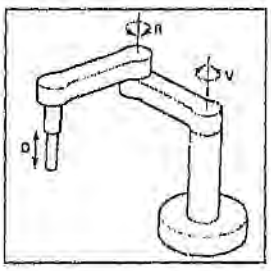


Figure 2-6 SCARA Configuration (Owen, 1980).

3.4 Preliminary design ideas

The first preliminary design consisted of a gantry configuration and makes use of ball screws driven by stepper motors to provide the positioning of the gripper.

The structure would consist of square tubing and have a trolley assembly that would run along rails within the structure, driven by the ball screws to position the gripper at the required location.

The second design consisted of a revolute configuration, making use of hydraulic rotary actuators for the various joints, thus in effect giving the largest degree of movement of the preliminary designs. The structure would resemble that of a human arm and the position of the various links would be monitored with rotary encoders.

The third preliminary idea makes use of a cylindrical configuration and hydraulic actuators. The rotary actuator is to be used to rotate the arm, the hydraulic cylinder is used to extend the arm and a second cylinder then gives the vertical axis of motion. The position of the various links would be monitored by rotary encoders.

Drawbacks of preliminary designs

The first preliminary idea has the following disadvantages:

- Stepper motors turn at a low speed, thus if ball screws are adopted to provide linear motion, the final velocity of the device is far too slow for use in industry.
- The supporting structure will be large and cumbersome.

The second preliminary design has the following drawbacks:

- Control algorithm that is far too complex for the required task and would lead to a robot that would have cost beyond the given budget.
- At least four rotary encoders would be needed together with stepper motors or alternatively six rotary encoders. The available personal computer (PC) card can only handle three rotary encoders thus two such cards would have been required.

The various principles available in the manufacture of a robot are tabulated below.

Table 3-1 Principles of drivers (Shigley 1986)

Criterion	**Hydraulics**	**Pneumatics**	**Electronics**	**Mechanical**
Energy carrier	Oil	Air	Electrons	Shafts, linkages, belts, chains, wheels.
Energy transmission	Pipes, hoses, bores	Pipes, hoses, bores	Cables.	Shafts, linkages, etc.
Conversion from or into mechanical Energy.	Pumps, cylinders, hydraulic motors	Compressors, cylinders and pneumatic motors	Generators, batteries, electric motors, magnets, etc.	
Important variables	Pressure Flow	Pressure Flow	Voltage, current	Force, torque, velocity, rotational speed
Power	Excellent, compact	Good, limited by pressure	Good	Good because energy conversion is not needed
Accuracy of motion	Excellent because oil is incompressible	Fair (air is compressible)	Differs considerably (slippage and stepping motors)	Excellent due to positive connection
Efficiency	Fair to good	Fair to good	Good	Good
Controllability	Excellent	Excellent	Excellent	Fair

Using the information in Table 3-1 it was decided to investigate the possibility of driving the primary axes with DC motor and ball screw combinations. This could lead to a design that has a high power factor with excellent controllability as well as a high degree of accuracy.

3.3 Criteria

The robot should satisfy the following criteria:

- Fast moving (2.5 m/min).
- Easily programmable.
- Low maintenance.
- Reliable.

It was decided to construct the robot using a combination of electronics, pneumatics and mechanical principles extracting the advantages of each system to maximise the design in terms of torque developed, positional accuracy and speed.

3. DESIGN PROCEDURE

The first step in the design was to choose a configuration that best suited the task at hand. The required operation of the device depends on the layout of the storage area A number of configurations for robots are available and one of these configurations, or a combination of them, can be used for the final configuration of the AS/RS device.

3.1 Requirements

- The AS/RS must have a storage capacity of at least sixteen pallets.
  The AS/RS must remove a loaded pallet from the storage matrix.
  The gripper must be able to locate and grasp the pallet.
  The AS/RS must be able to place the pallet onto a intermediate storage buffer area.
  The AS/RS must be able to store the pallet.
- The operations that make up a typical cycle are :
  1. Locate.
  2. Grip.
  3. Lift.
  4. Transfer.
  5. Insert.
  6. Release.
  7. Retract.
- The design must be flexible i.e. allow parameters to be changed.
- The AS/RS must be able to pick up components with a mass of at least 500 g
- The AS/RS must be able to pick up pallets having a maximum size of 100 x 150 mm.
- The AS/RS must have an accuracy of at least 3 mm.

3.2 Constraints

- Budget of R 10000
- Available technology.
- One year for implementation.
- Size of structure (1200x1000x1000 mm).
- Permissible weight of various robots segments (max. 1kg each).

2.5 *Sensors and Transducers*

A transducer is a device that converts one type of physical quantity (e.g., temperature, force, velocity, flow rate) into another type (commonly electrical voltage). The reason for making this conversion is that the converted signal can be used or evaluated more conveniently. Transducers are often called sensors as they are used to measure some physical quantity (Jamshidi, 1990).

There are two main types of transducers, namely analogue and digital. Analogue transducers produce a continuous analogue signal such as an electrical voltage. Digital transducers are measuring devices that produce a digital output signal. Digital transducers are becoming more popular due to the fact that they are easy to interface with stand-alone measuring devices.

2.5.1 Types of Transducers

There are a variety of transducers available but the types of most interest are those that measure displacement, velocity, and acceleration (Engelberger, 1980). Force is important when considering grippers although in the case of this project, force measurement is not required.

Transducers used to measure displacement, velocity and acceleration are :

- Potentiometers
- Absolute rotary encoder.
- Incremental rotary encoder
- Linear-variable-differential transformer
- Tachometers.

There are other sensors that can be used such as limit switches to detect the absence or presence of objects as well as vision systems to identify objects in the working envelope.

2.4 Control Systems

2.4.1 Programmable Logic Controllers.

A programmable logic controller (PLC) is defined by the National Electrical Manufacturers Association (NEMA) as (Groover 1987):

"A digitally operating electronic apparatus that uses a programmable memory for the internal storage of instructions for implementing specific functions such as logic, sequencing, timing, counting, and arithmetic capabilities to control, through digital or analogue input/output modules, various types of machine or processes".

A PLC has almost the same structure as a computer, however, it has been specially designed so as to interface with external devices such as relays and other hardware.

The advantages of using a PLC are as follows

- Programming a PLC is easier than wiring a relay control panel.
- A PLC can be reprogrammed. Conventional controls must be rewired and are often scrapped instead.
- PLCs take less floor space than relay control panels.
- Maintenance of a PLC is easier, and reliability is greater.
- A PLC can be connected to the plant computer systems more easily than relays can.

2.4.2 The Computer

The computer is an easily programmable device with mass storage, video display, keyboard and interfaces to peripheral devices such as printers and plotters. The computer however is limited in its capabilities to drive external devices such as relays and valves.

There are various ways to overcome this problem especially with the availability of computer-based control cards.

2.3.5 End Effectors

The end effectors are generally used as manipulators or as tools to perform some operation. The end effector must be capable of carrying out an operation without damaging the object it is manipulating.

There are many ways of grasping an object and these are listed below (Owen, 1980):

- Mechanical grippers.
- Hooking onto a part.
- Lifting and transferring a part on a thin platform or spatula.
- Scooping or ladling.
- Electromagnets.
- Adhesives.
- Quick disconnect bayonet sockets.

There are also a variety of configurations such as two fingers, three finger grippers, vacuum cups and human hand configuration.

2.3.4 Hydraulic Systems

Although there are hydraulic systems that are powered by water they have problems, such as oxidation, the growth of mould and poor lubrication. The most useful hydraulic fluids are mineral oils. These fluids also have excellent heat dissipation properties, and therefore contribute to safe running temperatures.

The pressure can reach up to several thousand KPa in some robots, but the common pressure is about 10 MPa (Pagem, Lhote, Kauffmann, Andre and Taillard, 1983).

The main problems to be resolved are:

- To transport the oil to the various joints of the robot.
- Leakage from the connecting pipes.
- Adequate fluid filtration, as small particles block servo valves and erode flow controllers.

There are a number of hydraulic actuators available that can be used at the joints to provide linear or rotational movement.

- Linear pistons
- Linear movement transformation pistons that use a rack and pinion system to translate linear motion to rotational motion.
- True rotary pistons or flapper pistons.
- Rotary motors
- Motors with axial pistons shafts and inclined plate.
- Motors with axial pistons and inclined barrel
- Motors with radial pistons.

2.3.3 Pneumatic Actuators

Compressed air can be found in any workshop at a low pressure, usually not exceeding 1000 KPa (Pagem, Lhote, Kauffmann, Andre and Taillard, 1983). It is simple to use and is conveyed through small and flexible pipes. Air actuators have the following characteristics:

- Because the fluid is non-corroding problems of air tightness are not important, so that hard wearing, low cost components can be used.
- The power to weight ratio lies between those of electrical and hydraulic systems. Operation is largely unaffected by extremes of temperature.
- Maintenance is easily carried out.
- Little special training of the user is required.

Pneumatics do have disadvantages. These systems have little lubrication thus friction can be a considerable problem. The air always has some amount of water vapour that leads to condensation and thus could cause damage to the actuators.

The main characteristic of a gas is its compressibility and this can be used to resist overloading. However in terms of positional control this is a distinct disadvantage.

There are a variety of actuators namely:

- Linear pistons
- Rotary pistons such as a rack and pinion system.
- Multi stage pistons that allow several positions to be attained;
- Impact or percussion pistons for riveting or marking operations.
- Cable pistons without shafts for long strokes.
- Curved pistons without shafts for lateral output.
- Membrane or bellow pistons for long strokes.
- Simple pistons that swell and shorten as the internal pressure increases.
- Motors.
- Volumetric motors.
- Turbines.

The following items are used to control or supply the pneumatic devices with air, or pressure.

- Valve distributor. This is a distributor with three apertures and two positions.
- Spool distributor. A mobile spool moves across ports varying the amount they are opened and hence controlling the movement of air between the ports.

Series and parallel motor connections

With a bipolar drive, alternative possibilities exist for the motor connections except when the motor has only four leads. An 8-lead motor can be connected with the two halves of each winding either in series or in parallel (Stuart, 1989); with a 6 lead motor, there is the option of using either one half-winding or both half windings in series. The alternative connection schemes produce different torque speed characteristics and also affect the current rating of the motor (see Figure 2.11).

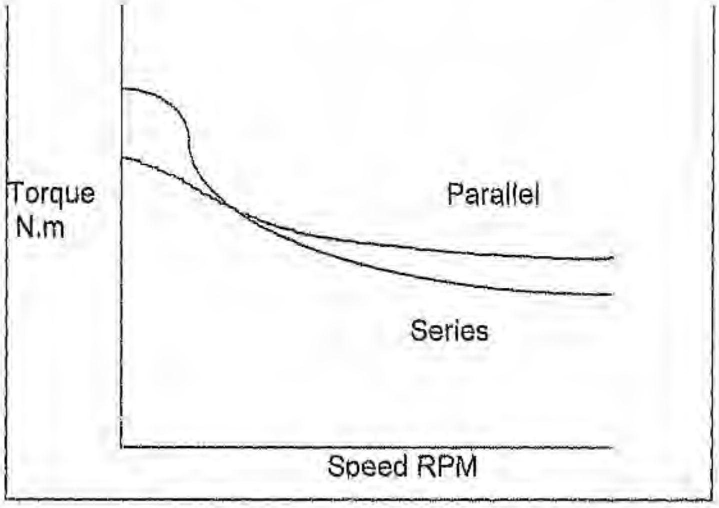


Figure 2-11 Torque curves for series and parallel connection.

As a rule (Hannifin, 1985), parallel is the preferred connection method as it produces a flatter torque curve and greater shaft power. Series is useful when high torque is required at low speeds, and it allows the motor to produce full torque from a lower current drive.

Number of motor leads

Most stepper motor manufacturers are now tending to standardise on 8-lead motors (Figure 2.10). These offer the best combination in terms of motor performance and flexibility. However, motors with other numbers of leads are also available and are evaluated below (Marston, 1989).

- Four lead motors are simple to connect and should in theory be a little less expensive than their counterparts with extra leads. There is no option of making series or parallel connections to get a different torque characteristic, and this type of motor cannot be used on a unipolar drive.

- Five lead motor's are rare and have similar characteristics to the 6 lead motor except that they have one common line.

- Six lead motors are decreasing in popularity, their main drawback is the inability to connect the coils in parallel as can be done with an 8-lead motor. However, it should be remembered that a 6-lead motor with the windings in series is equivalent to a parallel-connected motor with half the current rating. Therefore a high current 6-lead motor can give a useful performance connected in series.

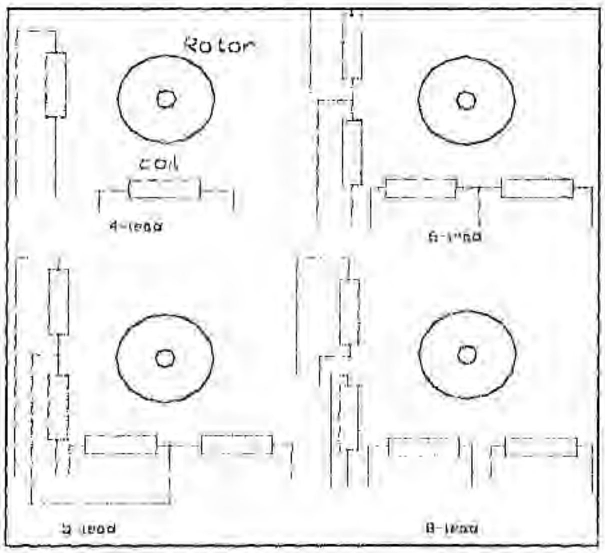


Figure 2-10 Motor lead connection.

2.3.2 Stepping Motors.

Stepping motors allow a digital electrical signal to be converted directly into an incremental angular positioning movement. The stepping motor is synchronous, so there is a correlation between the input command and the resulting position. There are undeniable disadvantages of this type of system: acceleration and deceleration are discontinuous, and performance standards are limited. Torque varies with the position of the rotor. The faults can be overcome and even completely rectified by adapting the power supply to suit the motor, and other design improvements can be made.

There are three categories of stepping motor (Pagem, Lhote, Kauffmann, Andre and Taillard, 1983):

- Motors with permanent magnet rotors.
- Motors with variable reluctance.
- Hybrid motors that combine the properties of the other two types.

A number of stepper motor characteristics determine the final torque and performance of the stepper motor, namely :

Motor current rating

The current rating of a stepper motor is based primarily on the permissible temperature rise of the case (Hannifin, 1985). Operation at the rated current will produce the full rated torque of the motor at low speeds. Most motors are available with alternative windings having different current ratings, which means that each winding has a different number of turns and therefore a different inductance. It is important to make sure that the best winding is chosen for the application.

A motor with a low current rating has a large number of turns and therefore a high inductance. Although this motor can be driven from a low-current drive, the high inductance causes the current (and therefore the torque) to drop off rapidly as speed is increased. Such a motor is therefore suitable only for low-speed operation. Conversely a high-current motor has fewer turns and therefore needs a higher drive current, but the lower inductance results in a much flatter torque curve as speed is increased.

The gripper as shown in Figure 3.9, has been designed with a step machined in its jaws to prevent the pallet from slipping out when being moved.

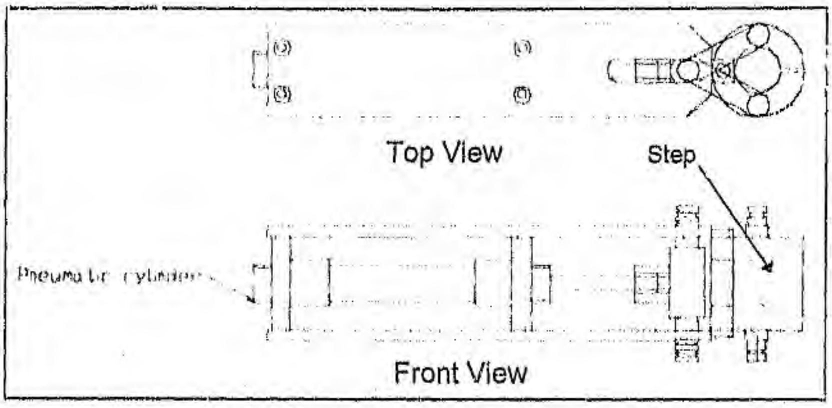


Figure 3.9 Gripper.

3.7.2 Gripper Final Design

The chosen gripper is a pneumatically actuated device designed to grasp a locator on the pallet. The gripper has a small pneumatic cylinder that extends when the gripper needs to be closed and retracts when the gripper needs to be opened. Figure 3.7 shows the AS/RS grasping the pallet.

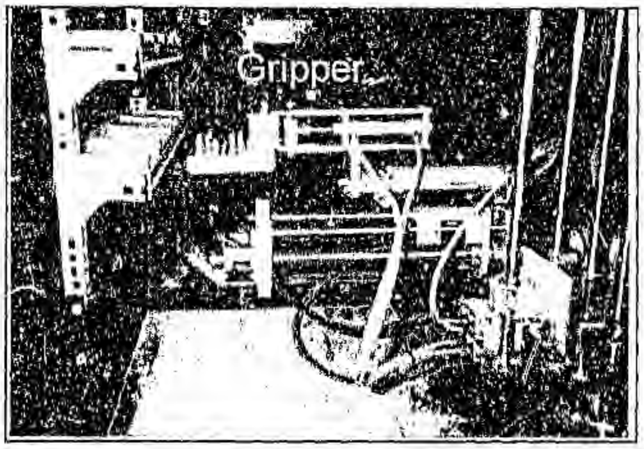


Figure 3.7 Gripper grasping the pallet.

The two jaws open radially and pivot about a point. The gripper has been designed to grasp a locating element on the pallet (see Figure 3.8) and to prevent rotation of the pallet in the horizontal plane.

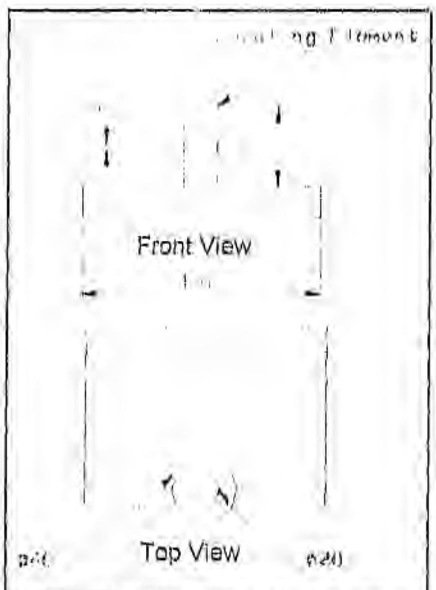


Figure 3.8 Pallet with locating element.

Figure 3.6 shows the second preliminary gripper design using square jaws as the grasping mechanism. The jaws would be moving parallel, and thus locating the pallet within the jaws. Friction or a locating groove would be the force that would prevent the pallet from slipping out.

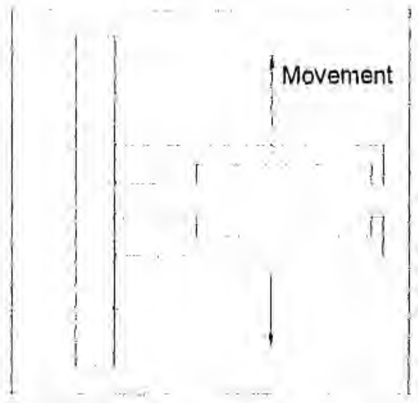


Figure 3.6 Square jaw gripper.

The disadvantage with this configuration is two-fold :

- The gripper would be large and cumbersome.
- The mechanism to ensure that the jaws travel parallel is complicated and unnecessary for such a low level task as that required to pick the pallet.

3.7 The gripper

The main function of the gripper is to securely grasp the pallet. The gripper should be maintenance free and lightweight.

3.7.1 Preliminary design

A number of gripper configurations exist and they all depend on the pallet shape. The gripper can be designed to resemble a pair of forks as shown in Figure 3.5, which are inserted under the pallet and then lift the pallet off the shelf to the deposit point.

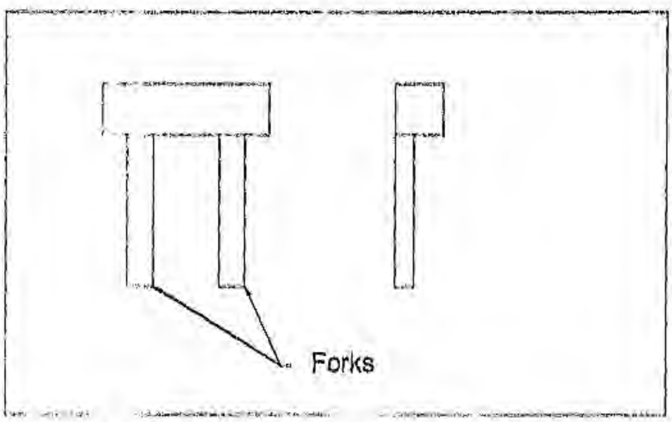


Figure 3.5 Preliminary design 1

This design has its drawbacks in that the pallet can be dislodged from the forks. In addition there is no positive stop to ensure that the pallet has been properly positioned.

3.6.3 The y-axis

The y-axis is constructed in exactly the same manner as the x-axis the only major difference is that three vertical shafts were used and that the support ends are manufactured from aluminium. The reason for using aluminium for the support ends of the y-axis is that the weight of the moving structure needs to be kept as low as possible to minimise the inertial forces of the device. The total travel distance of the y axis is 640 mm.

3.6.4 The z-axis

The z-axis is attached to the y-axis and the entire z-axis moves along the y-axis. A trolley, carrying the gripper, moves along the z-axis driven by a DC motor and ballscrew combination. The gripper assembly is mounted on the pneumatic cylinder that is able to provide an extra extension of 100 mm in conjunction with the 320 mm provided by the ballscrew travel distance.

The z-axis primary function is to position the gripper in the horizontal plane for the successful retrieval of the pallet.

The attachment of the steel shafts to the mild steel supports has been done using the clamping method shown in Figure 3.4. This is a much more effective method than using grub screws to hold the shaft in place. The clamping force is uniformly distributed around the shaft thereby providing excellent clamping of the shaft.

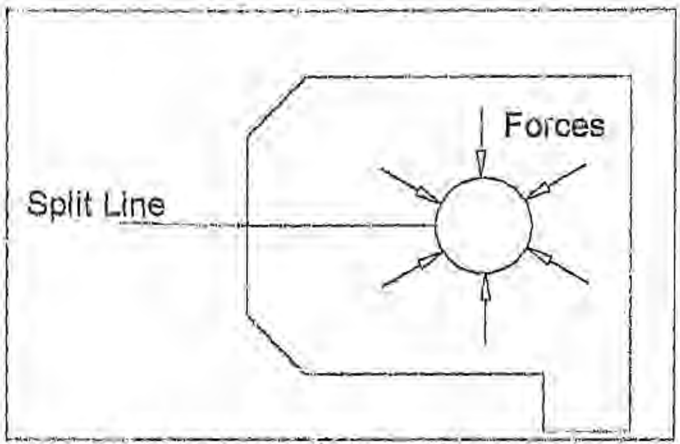


Figure 3.4 Clamping mechanism (side view).

The bearings have been fitted into the steel housing using an H7 tolerance fit. This is to ensure that the bearings are semi pressed but at the same time are able to be easily removed from their housing.

Both the bellhousings for DC motor and rotary encoders have been constructed with a window (Appendix B, drawing No. ASRS-15) for easy access to the couplings as well as a st. to centrally locate the bellhousing on the support end. Both bell housings have been constructed from mild steel and provide the interface between the DC motor and the rotary encoder with the x-axis

The ballscrew was chosen over a conventional ACME screw thread for two primary reasons :

- Ballscrews have a mechanical efficiency of 90 % as compared to 40-50 % of ACME screw thread.
- There is negligible backlash in ballscrews.

The purpose of using ball screws to drive the S/R mechanism along the x-axis, upon which the y-axis is mounted on, is to provide accurate positioning. The total travel distance of the x-axis is 800 mm.

3.6.1 Cost Breakdown

The approximate cost breakdown (excluding labour) of the device is given in Table 3-3.

Table 3-3 Cost breakdown for final design (Approximate figures).

Item	**Cost**
Ballscrews and nuts	R 2140
Pneumatics	R 400
Motors	R 425
Linear bearings	R 1200
Process control cards	R 3000
Power supplies	R 1200
Materials and electronics	R 2500
TOTAL COST	**R 10865**

3.6.2 The x-axis

The x-axis is mounted on two mild steel supports (see Appendix A drawing No. ASRS-14), each weighing approximately 20 kg to provide rigid support. Two steel shafts (ϕ 16 mm) are mounted between the steel supports and act as guide rails for the S/R mechanism. The DC motor is attached at the one end of the x-axis via a bellhousing. The DC motor is responsible for driving the ball screw via a Lovejoy coupling. The ball screw is mounted on deep groove roller bearings located within the steel supports; the ball screw in turn drives a ball screw nut that is attached to the S/R mechanism. On the other side of the x-axis the rotary encoder is attached to the steel support via a bellhousing and to the ball screw via a coupling.

3.6 The final design

The final design is based on a Cartesian configuration, having three degrees of freedom, namely x, y, z axis. The main drive mechanism consists of ball screws driven by DC motors, having rotary encoders attached at the end of each axis to monitor the axis position. The system is controlled by a personal computer that instructs the AS/RS to pick a pallet and oversees all the control aspects in terms of activating and monitoring the relevant axes of the AS/RS. Figure 3.3 shows a photograph of the final design and the assembly drawing is given in Appendix A drawing number 'ASRS-1'.

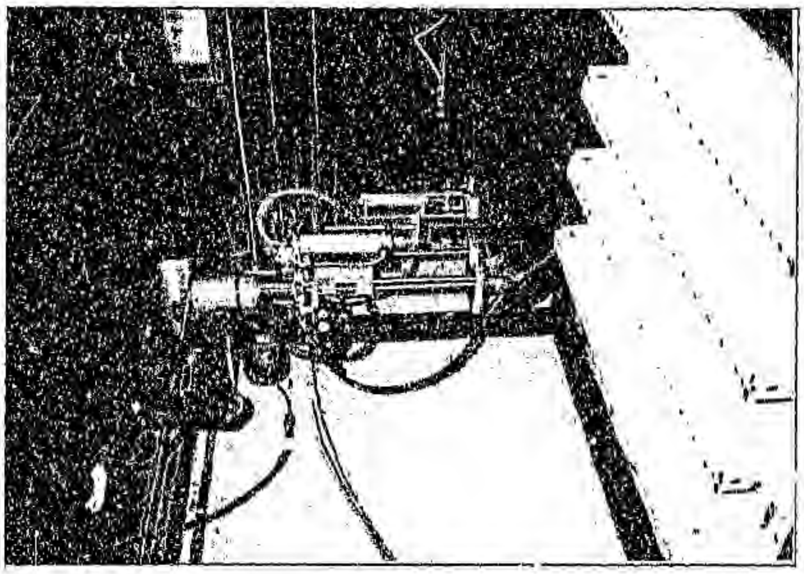


Figure 3.3 Final design of AS/RS.

be 2 m. This will obviously be a non viable option in terms of physical space required by the system.

The ball screws would be driven by either stepper motors or DC motors. Stepper motors have the advantage that no feedback is required and can be used as an open system while still being able to position itself accurately. It must noted, that although no feedback is required for stepper motors there exists the risk that the motors might lose steps if they don't develop sufficient torque.

DC motors however require feedback in order to provide accurate positioning. DC motors are also generally smaller in size than stepper motors for the same power ratings. Second hand DC motors were found to be readily available.

Table 3-2 Cost of hydraulic option

Description	**Amount**
Electronics	R 6600
Flow control valve and subplate	R 2200
Solenoid valve and subplate	R 1500
Hydraulic power pack	R 3000
Hoses and connectors	R 300
Linear pistons	R 1800
Total cost of system	R 16000

Shelf storage:

The storage facility resembles a multi-layer shelf system, with pallets being stored in specific compartments within each shelf.

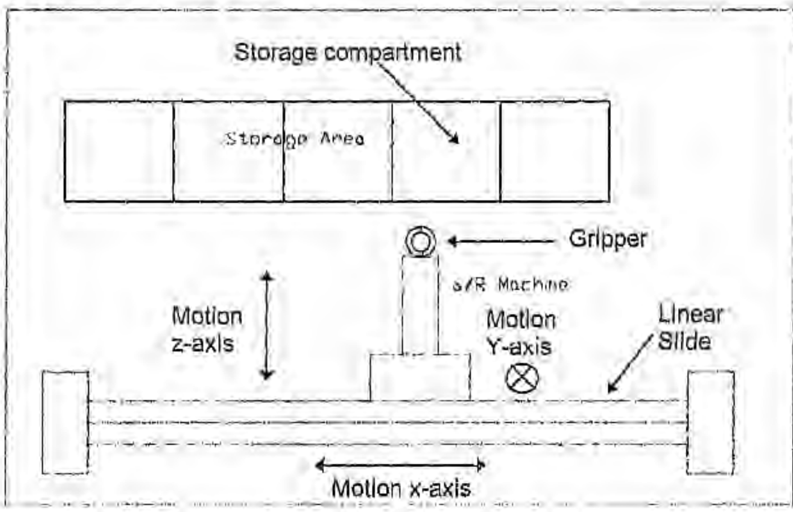


Figure 3-2 Shelf storage option (Top view).

As can be seen from Figure 3.2 it was decided that the operation of picking a pallet from a storage facility and depositing it into a storage buffer required three primary motions, namely, travel in the x direction, travel in the y direction and movement in the z direction. The configuration best suited to these requirements is the Cartesian configuration.

The length of travel of the three respective axis warrants the use of ball screws as the main drive mechanism. If pneumatics or hydraulics are used and a stroke of approximately 1 m is required, the full length of the cylinder when fully extended will

The design could be based on hydraulics, pneumatics, stepper motors, DC motors or a combination of these. The robot arm would have three degrees of freedom, namely rotation about the vertical axis, motion in the vertical plane and motion in the horizontal plane.

The base is driven by a stepper motor together with a gearbox, or alternatively using a DC motor and gearbox combination together with a rotary encoder to provide feedback on the relative position. The vertical axis on the other hand would be powered using hydraulics or pneumatics. However if pneumatics are used then there is no intermediate control of the axis movement i.e. the vertical axis cannot be held stationery at some intermediate point of its stroke. Hydraulics lend themselves to far superior control and are able to be stopped, with high accuracy, at any intermediate position. Pneumatics are cheaper to use and don't have the requirement of a power pack as in the case of hydraulics.

Owing to the nature of having a multi-layer storage facility, the robot has to have the ability to position itself accurately within the vertical plane. For this reason hydraulics would be the better option (Table 3-2). The same argument can be used for the use of hydraulics in the horizontal plane. The gripper would be pneumatically or hydraulically based as no trajectory control is necessary. To monitor the extension of both the vertical and horizontal movements rotary encoders would be used to provide high resolution and repeatable monitoring.

The storage facility would rotate about its vertical axis using either a stepper motor and gearbox combination or DC motor and gearbox combination. If a DC motor is used to drive the storage facility then a rotary encoder must be used in conjunction with the motor to provide accurate positioni. .

In total the system would have four degrees of freedom, namely the three degrees of freedom of the robot plus one for the storage facility. Thus at least two rotary encoders plus two stepper motors are required or alternatively four rotary encoders and two DC motors.

The stepper motor drives cost R1600 each and a stepper motor control card for a three axis system would cost in the region of R 2000. The cost of one rotary encoder would be R 200 and the control card to monitor three rotary encoders would cost R2500.

Thus if the configuration is taken as follows :

- Stepper motor to drive storage facility.
- DC motor to drive the base of the robot.
- Hydraulics to drive the vertical and horizontal axis.
- Rotary encoders to monitor the three degrees of the robot.

3.5 Secondary Design Ideas

Two main types of storage were seen to be viable:

Cylindrical storage:

If the storage area is to take form of a cylindrical storage facility, then the best configuration for the device is the cylindrical configuration. The layout would entail having a multi-layer circular storage facility that would be rotated about its vertical axis depending on the choice of pallet to be picked. The S/R would then extend its arm and pick the required pallet. Once the pallet has been retrieved the S/R machine would then rotate to a deposit point (see Figure 3.1).

Figure 3-1 Cylindrical storage option (Top view).

prevent the destruction of the transistors within the H-bridge configuration. The motor can draw as much as 50 A in the initial start-up and then drops down to its nominal value of 8.8 A.

$$R10 = \frac{V_{cc}}{I} \tag{3.2}$$

R10 = 50V/10A
R10 = 5 Ω

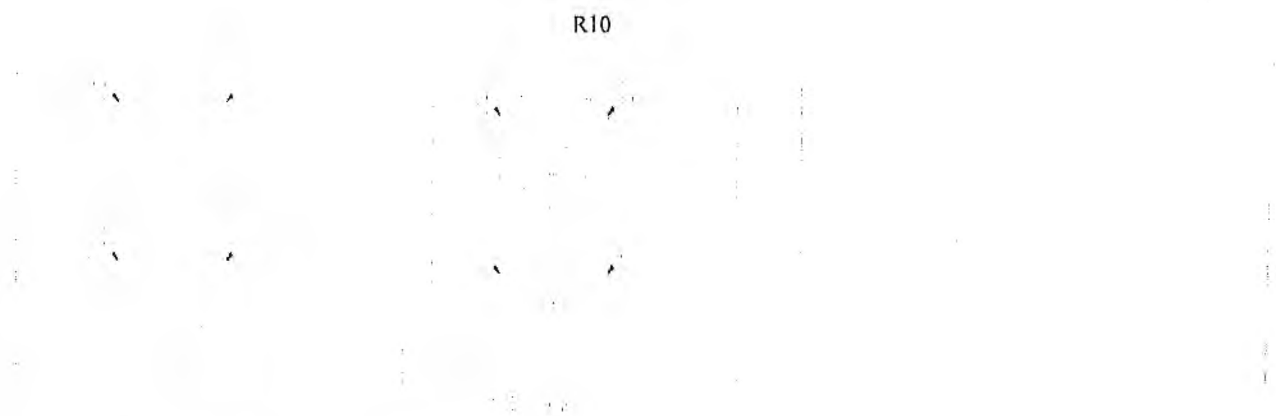


Figure 3-16 H-bridge configuration.

Table 3-4 Pin layout of DC drive.

Pin (On DC drive)	*Description*	*x-axis (390H) 37 pin con.*	*y-axis (310H) 37 pin con.*	*z-axis (310H) 37 pin con.*
a	+12V	Pin 1	Pin 1	Pin 1
b	+5V	Pin 2	Pin 2	Pin 2
c	Digital output of PC36(LSB)	Pin 4	Pin 12	Pin 4
d	Digital output of PC36	Pin 5	Pin 13	Pin 5
e	Digital output of PC36	Pin 6	Pin 14	Pin 6
f	Digital output of PC36	Pin 7	Pin 15	Pin 7
g	Digital output of PC36	Pin 8	Pin 16	Pin 8
h	Digital output of PC36 (MSB).	Pin 9	Pin 17	Pin 9
i	Ground	Pin 37	Pin 37	Pin 37
j	-12V	Pin 35	Pin 35	Pin 35

Resistors R0 act as pull up resistors to +5V to eliminate any floating outputs. The digital signals from the PC 36 (c-g) are fed to the digital to analogue converter (D/A) namely the L291. The L291 converts this 5 bit digital word to a voltage signal which is then fed to the operational amplifier (741). The offset voltage is set by the variable resistor VR, this ensures that when the digital word is zero the output voltage of the L291 is also zero and when the digital word value is 30 the output voltage is +10 V. The operational amplifier acts as a voltage follower or inverter depending on the state of pin (h). If pin (h) is at the high state it will then activate the relay (D32A3110) and thus the operational amplifier will act as an inverter. If however the pin (h) is set at the low state then the operational amplifier acts as a voltage follower.

The output of the operational amplifier ranges between +10 v and -10 V. The 10 V voltage level indicates maximum velocity of the motor. The output signal of operational amplifier is fed to pin 6 of the H-bridge motor driver (L292).

This signal is used to pulse width modulate the oscillator signal by means of the internal comparator. The pulse width modulated signal controls the duty cycle of the H-bridge to give an output current corresponding to the L292 input signal. The interval between one side of the bridge switching off and the other switching is programmed by C2 (see Figure 3.15). The value of C2 is taken as 1.5 nf. The resistor R8 determines the feedback loop of the L292 and ultimately the duty cycle of the motor. For effective functioning of the L292 a value of 4.7 KΩ is recommended.

The maximum current that the L292 can deliver is 2 A. However this is too low for the satisfactory operation of the DC motor. Thus a booster H-bridge was constructed to circumvent this problem as shown in Figure 3.16. The booster H-bridge is able to handle voltages up to 100 V and 10 A. A 5 Ω (R10) resistor is placed in line with the H-bridge to limit the maximum current drawn (Equation 3.2). This is done so as to

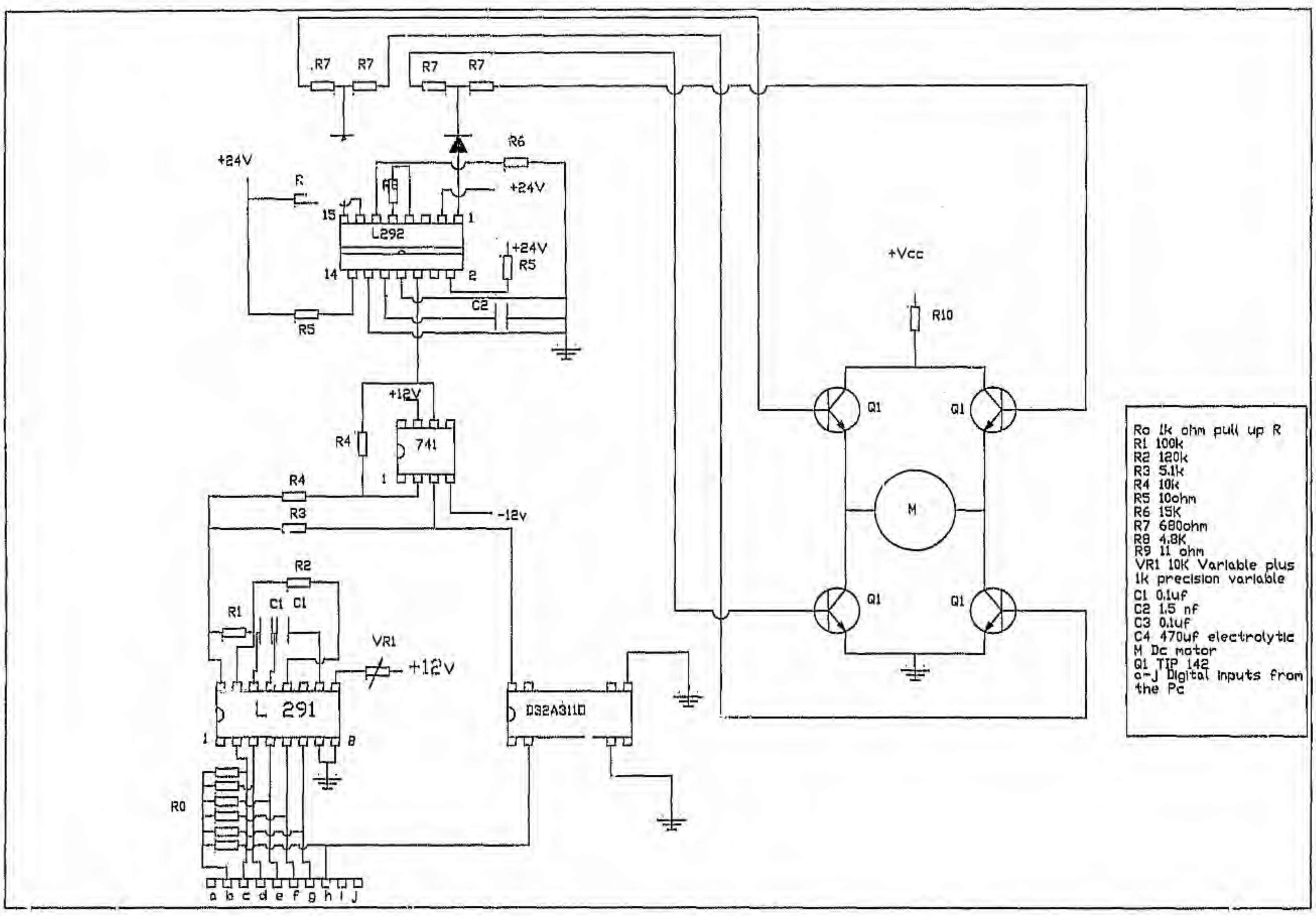


Figure 3.15 DC drive circuit

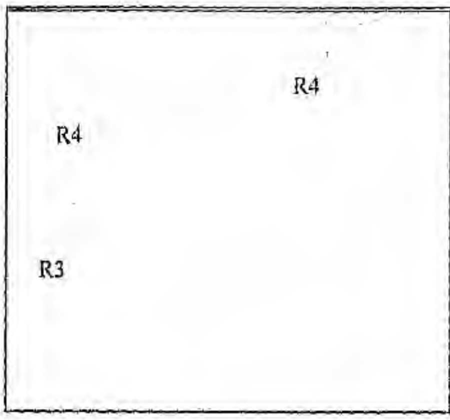


Figure 3-14 The 741 op-amp.

On the L292 chip the current sensing functions are done away with because the chip is designed for operating a 2A DC motor, while the motors run on 8.8A, thus the chip is used as a controller to drive external H-bridges (section 3.11.2) which in turn drive the motors.

3.11.2 Description of the motor control circuit

Six digital signals from the PC 36 are fed to pins c-h (see Figure 3.15 and Table 3.4). Pins c-g are responsible for the setting of motor velocity. Pin (c) being the least significant bit (LSB) while pin (g) the most significant bit. Pin (h) serves to set the motor direction. Thus a 6 bit digital word sets both speed and direction.

Thus the output of the L291 had to be tailored to meet these requirements. Thus a gain of 0.8333 is needed.

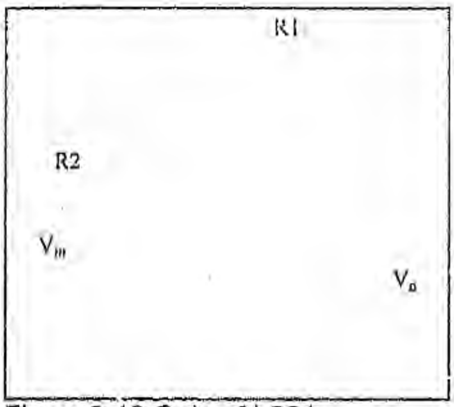


Figure 3-13 Gain of L291

Where the output voltage is given by equation 3-1.

$$V_o = -\frac{R1}{R2} V_{in} \qquad (3\text{-}1)$$

Where :

R1 = Resistance (Ohms)
R2= Resistance (Ohms)
V_o = Voltage out (Volts)
V_{in} = Voltage in (Volts).

Thus to have a gain of 0.8333.
R1= 100 KΩ.
R2= 120 KΩ.

The D/A converter has a resolution of 2^5 i.e. 32 divisions, thus the voltage resolution is 0.313 V. Thus the DC drive has a possibility of 32 different velocities.

However the output of the L291 only has voltage swing in the one direction thus a differential operational amplifier (741) had to be used (Figure 3.14). The requirements of the operational amplifier was to act as a voltage follower in the one case and as an inverter with no gain in the second case. This is to allow reversing of the DC motor. The output of the operational amplifier is then fed to pin 6 of the L292.

3.11.1 Design of the motor control circuit.

The design of the motor control circuit entails the use of an existing design (Appendix F) that was modified to suit the designs requirements (Figure 3.15).

The existing design as described in Appendix F section 'Linear Integrated Circuits' makes use of three monolithic large scale integrated circuit chips, namely, the L290, L291, L292.

The system in Appendix F was modified as follows :

Speed command for the system originate in the microprocessor (or computer). It is continuously updated on the motor position by means of pulses from the L290 tachometer chip, which in turn gets its information from the optical encoder. The function of this chip has been replaced by the PCL 833 encoder card together with the relevant code. The reason for using this card was that the L290 chip uses sinusoidal signals from the encoder while the encoder outputs digital pulses that are compatible with the PCL 833.
From this basic input, the microprocessor computes a 5 bit control word that sets the system speed dependant on the distance to travel.

As the target position is approached, the microprocessor lowers the value of the speed-demand word; this reduces the voltage at the main summing point (pin 6 on the L292), in effect braking the motor. The braking is applied progressively until the motor is running at minimum speed.

Thus from the original design only the L291 and L292 chips are used. The L291 chip has a D/A convertor together with two built in operational amplifiers (Appendix F), namely, the "ERR. AMP" and the "POS AMP" operational amplifiers. The "ERR. AMP" is normally used in conjunction with the L290 tachometer chip, and thus in this case was not used. The output of the D/A convertor (pin 12 on the L291) was fed to pin 15 on the L291 (i.e. the "-" of the "POS AMP"), the internal operational amplifier "POS AMP" was then used to amplify the D/A convertor signal as follows :

The L291 is a 5 bit D/A converter with built in operational amplifiers. It operates on a supply voltage of ±12 V, however the L292 accepts voltages of ±10 V as the command voltage. The variable resistor at pin 9 on the L191 is used to regulate the offset voltage of the L291.

The PCL 833 is used in these common applications :

- Motion control.
- Position sensing, monitoring and measuring.
- Co-ordinate measuring machines.
- X - Y table monitors.
- Robotics.
- Machine control.

3.11 Description of the control circuit.

The philosophy of the control of the DC motors is based on pulse width modulation (PWM) techniques. This basically entails pulsing the motor at a certain frequency, the higher the frequency the faster the motor rotates until a condition is reached where the frequency assimilates a continuous signal.

The motor is first pulsed in one direction and then in the opposite direction. Thus when the two pulses are at equal frequency the motor is stationary. As the frequency of pulsation in the one direction increases the motor rotates in that direction. In layman's terms what this action can be described as is 'three steps forward, one step back'.

This technique has an advantage over the conventional technique of varying the voltage across the motor in that at low speed PWM has good speed control.

The PC 36 was used to control the velocity of the DC motors and to monitor the limit switches of the S/R machine.

The PCL 833 is a 3-axis quadrature encoder and counter add on card for the IBM PC/AT and compatibles (ISA bus). This card allows the PC to perform position monitoring for motion control systems. It provides three 24 bit up/down counters as quadrature encoders and a 16 MHz oscillator timebase with a wide range multiplier. An on board interrupt controller handles nine different interrupt sources.

Each input includes a decoding circuit for incremental quadrature encoding. Inputs accept either single ended or differential signals. Quadrature input works with or without an index, allowing linear or rotary encoder feedback.

The PCL 833 has three independent 24 bit counters. The maximum quadrature input rate is 1 MHz, while the maximum input rate in counter mode is 2.4 MHz. Each counter can be configured for quadrature decoding, pulse/direction counting or up/down counting.

The PCL 833 provides five digital input channels. The channels accept digital input as an index input for a rotary encoder or as a home sensor input for a linear encoder.

The card can generate an interrupt to the system based on a signal from its digital inputs, overflow/underflow of its counters or on a programmed time interval. It can generate interrupts at any time interval specified, 0.1 msec to 255 sec. These interrupts allow the speed of the control system to be monitored precisely.

3.10 Control cards.

In the design two types of personal computer (PC) cards were used namely the PCL 833 and PC36 for the purpose of control (Appendix C).

The PC36 is a general purpose digital input/output card. It is built around the industry standard 8255 programmable peripheral interface (PPI) adapter. The 8255 controls 24 lines of digital I/O. It is both flexible and powerful when interfacing to peripheral equipment and can be programmed for almost any 8 bit or 16 bit I/O application. The 8255 can operate in either unidirectional or bi-directional mode, with or without hardware handshaking.

The PC36 can be used for versatile interfacing to:

- Other PC computers, for example another PC with another PC36 installed.
- Any other computer with an 8 bit or 16 bit parallel interface.
- Centronics compatible printers and plotters.
- Relays and opto-isolators.
- Switches of various types.
- Relay boards and industrial I/O mounting racks.
- Panel meters, instruments and test equipment which have digital readouts and controls.
- Sensors, transducers, instruments and test equipment with frequency (pulse) outputs and controls.

The board plugs into any fully bussed slot of an IBM PC/XT/AT or PS/2 model 25 or 30 or any compatible ISA or EISA machine, including 8088,286,386 or 486 based systems. It occupies four consecutive I/O addresses. The base I/O address can be set in the range 0h to 7F8h with a dual in line package (DIP) switch on the board. The power supplies +12V,+5V, -12V,-5V and ground are available on the external connector of the board.

The card at base address 390H is responsible for the following functions :

- Control of the X-axis DC drive (labelled 'board 1' in the electric panel on the AS/RS), using port A.
- Control of the pneumatics (labelled 'board P' in the electric panel on the AS/RS), using port C.
- Port B to be used as a communication interface with auxiliary equipment in future.

The PC generates a series of signals via the PC36 to set motor speed and direction. The PC also monitors the status of the micro-switches via the PC36. The encoder values are decoded by the PCL 833 and fed to the PC which uses these values to monitor the respective positions of the axes.

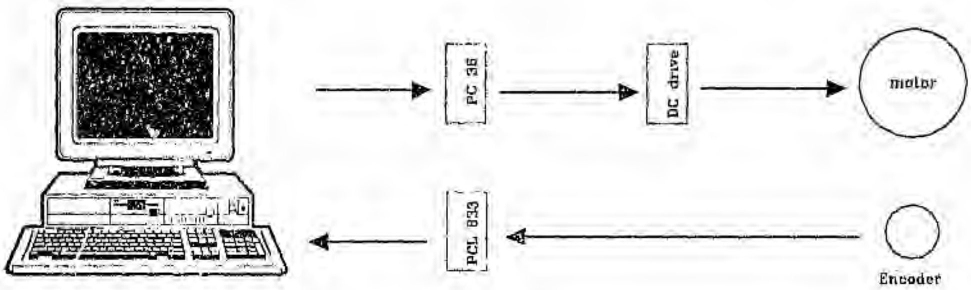


Figure 3-12 System overview.

3.9 Electronic system Overview

The control system consists of a closed loop system as shown in Figure 3.12 where two PC36 cards were used for the control of the DC motors and the monitoring of the micro-switches. Each card resides at a specific base address within the computer's I/O address space, thus allowing the installation of more than one card at a time. The two base addresses used by the PC36 cards are 310H and 390H respectively.
The card has a 37-pin D type male connector to communicate with external devices. The 24 bits of the card are divided into three groups of 8 bits each namely Port A, Port B, and Port C. Each group can be configured for various type of communication. In this case all the ports or groups have been configured for simple I/O.

The card at base address 310H is responsible for the following functions :

- Control of the y-axis DC drive (labelled 'board 3' inside the electric panel on the AS/RS), using port B.
- Control of the z-axis DC drive (labelled 'board 2' inside the electric panel on the AS/RS), using port A.
- Monitoring of the digital inputs from the micro-switches (labelled board '1' in the electric panel on the AS/RS), using port C.

3.8 The storage area

The storage area shown in Figure 3.11 is constructed from "handy angles" that allow the storage facility to be modular and thus changed as more shelves are added to the facility. Each shelf shown in Figure 3.10 has been machined from 20x640x120 mm plastic plate stock and may hold a maximum of four pallets. There are four such shelves in the storage area thus giving a total storage capacity of sixteen pallets.

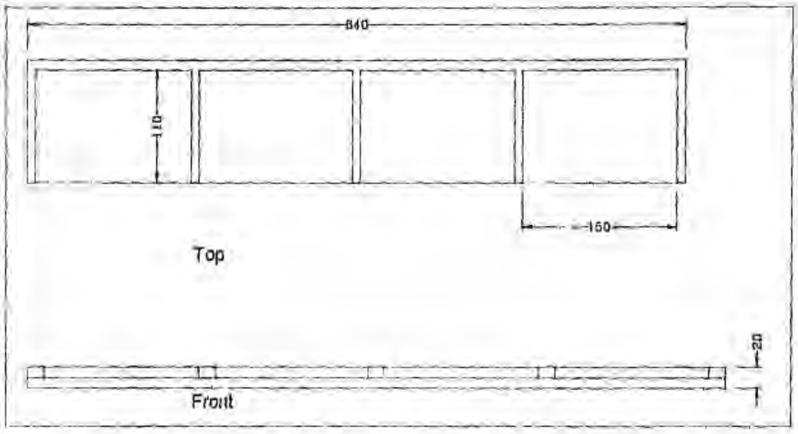


Figure 3.10 Shelf.

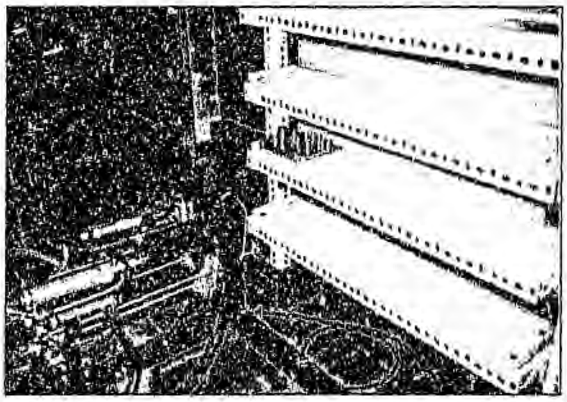


Figure 3.11 Storage shelves of final design.

5. TESTS AND ANALYSIS

5.1 ANALYSIS

When fluid energy is transformed into mechanical energy there are two operating mechanisms to be considered: static and dynamic.

For this design only the static case will be considered due to the relatively low speeds with which the robot moves.

In the static mode potential energy stored in the fluid when under pressure is used directly in motors, pistons to produce low speed fluid flow. The force generated by a linear actuator is given by:

$$F = S(P1 - P2) \tag{5-1}$$

where:

F = Force (N).
S = Surface area (m^2).
P1 = Pressure in chamber A1 (Pa).
P2 = Pressure in chamber A2 (Pa).

vii. The change in reading of the encoder is noted and the value is assigned to the variable change_x. Change_x is converted from number of pulses to linear measurement. (Tenths of a mm). The variable change_x indicates the difference in position of its present position as compared to its previous position, before the repeat loop was invoked.

viii. The previous value of the encoder is compared with the new value of the encoder. If there is no change then the motor's minimum speed is increased.

ix. The device's present position is compared to the final destination (dx) and the difference is assigned to the variable change_dx. Variable change_dx is converted into linear displacement.

x. The three "if " statements i.e. 'if (change_dx<10) ', 'if (change_dx>-10)' , 'if (change_dx<10) and change_dx>-10) ' are used to determine whether the motor should rotate clockwise (cw), or counterclockwise (ccw) to reach the final destination. If the device is within the tolerance specified by the "if" statement, namely ' if (change_dx<10) and change_dx>-10) ', then the speed is set to zero and a true flag for the variable 'pos' is set.

xi. If the device finds itself returning to the home position then the device monitors the micro-switches to determine when the home position is reached.

xii. Once the motors direction has been determined, the procedure will set the motors velocity depending on its position with respect to its starting point and final destination.

xiii. The procedure will end once the true flag for 'pos' has been set.

4.7.15 *Procedure y_axis.*

The procedure operates in the exact same manner as Procedure x_axis.

4.7.16 *Procedure x_axis.*

This procedure operates in the same manner as the x_axis and y_axis

4.7.17 *Main body of program.*

The main body of the program executes each procedure in turn. It starts by resetting all the variables, and thereafter checks whether the device is at the home position, if the device is not at the home position it invokes the procedure return_home.

The main program is responsible for activating each axis in turn, to extend or retract the z-axis piston and open and close the gripper.

4.7.14 Procedure Xaxis.

The control of the x-axis is performed by this procedure, whereby the motor speed is determined by the position of the S/R machine along the x-axis. The logic of the procedure is outlined in the block diagram in Figure 4.2.

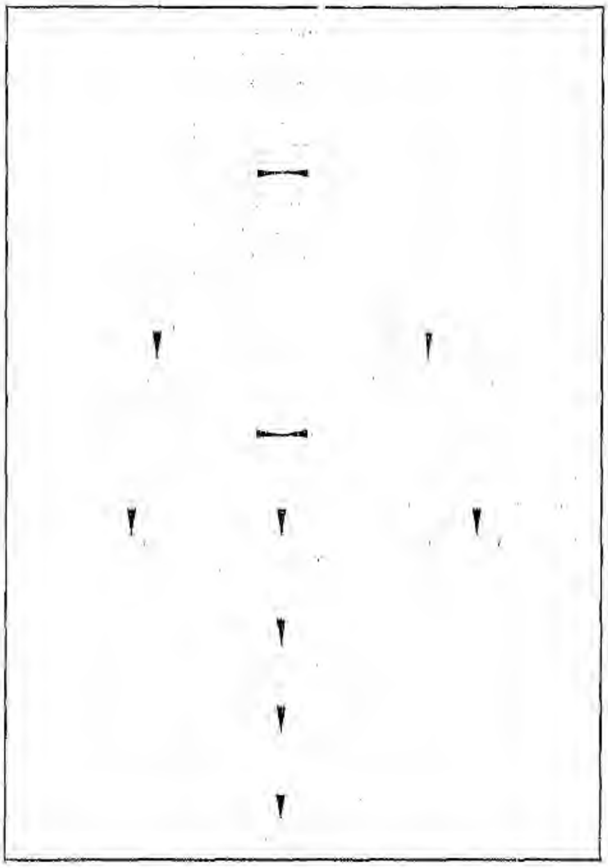


Figure 4-2 Block diagram of Procedure Xaxis

The primary function of the procedure can be outlined as follows :

i. The procedure firstly obtains the value of the rotary encoder.
ii. It assigns the read value to the variable x0.
iii. It then reads the x co-ordinate from the procedure pallet_address. It must be noted that the value of the x co-ordinate is given in tenths of a millimetre.
iv. The value of the x co-ordinate is converted to pulses of the encoder and assigned to the variable dx. (Note 5 mm = 512 pulses).
v. A repeat loop is initiated.
vi. The encoder is read again.

4.7.10 *Procedure Get_value*

This procedure assigns the value of channel one of the encoder card to the variable x1· the channel two value to the variable x2; and the channel three value to x3. Variables x1, x2, x3 correspond to the x, y, and z axis respectively.

4.7.11 *Procedure Show_value.*

The display of velocit, , position and status of its micro-switches is performed by this procedure.

4.7.12 *Procedure Start.*

This procedure resets all the variables to zero.

4.7.13 *Procedure Return_home.*

The function of procedure Return_home is to ensure that prior to the commencement of any movement, the axes are at their respective home positions. If for any reason, any axis is not at the home position the program will then activate a set of instructions such that the axis in question is returned to its home position.

4.7.5 *Procedure Pallet_address*

The information contained within the text files is assigned to variables so that the program may be able to interpret the information using this procedure.

4.7.6 *Procedure x_motor*

This sets the velocity of the x axis motor. Vx is an integer value ranging from 0 to 60. The range of values 0-30 rotate the motor in the one direction with the value 0 corresponding to no movement while value 30 is the maximum velocity of the motor. Values 31-60 have the identical characteristics except for the direction of rotation. Procedure y_motor and z_motor are for the control of the y-axis and z-axis respectively.

4.7.7 *Procedure change_value*

This procedure allows the encoder values to change on the screen without causing the screen to scroll as the values are displayed.

4.7.8 *Procedure Read_rotary*

The procedure reads the value of the PCL 833 encoder card and stores the values within an array called 'Inreg'. The array records the lower byte, middle byte, and high byte for each of the three channels of the card.

For example to store the high byte of channel one in the variable 'inreg[3]', the following command is invoked:

```
Inreg [3]=Port [200+2]
```

The command port indicates that its accessing the value stored at the base address 202H (see appendix C for description of base addresses) and assigns it to the array Inreg at position 3.

For every 256 increments of the low byte, the middle byte value increments by one and for every 256 increments of the middle byte the high byte increments by one.

4.7.9 *Procedure Set_encoder*

This procedure sets the encoder card's three channels to accept quadrature encoding and resets the channel values to zero. It also configures the card to latch the values after every count into the register. The card is also configured not to lockup if the count is too large but to wrap over the old values.

e.g. file "P6"

2700 { x co-ordinate in tenths of a millimetre}
1500 { y co-ordinate in tenths of a millimetre}
1620 { z co-ordinate in tenths of a millimetre}
r {r = retract cylinder, e = extend cylinder}
y {y = close gripper, n = open gripper}

4.7.4 *Procedure Pallet_choice.*

The function of this procedure is to prompt the user whether the pre-defined movements of the retrieval of a pallet are required or the step by step method of retrieving the pallet is required.

If the user wishes to use the automatic retrieval option, he is then required to enter the text filename that contains the sequence of movements. The valid filenames are as follows : I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,I14,I15,I16,I17.

The number of the filename indicate the pallet of interest. Filename I17 indicates the deposit point of the system. Pallets are assigned as per Figure 4.1

Figure 4-1 Pallet locations (As viewed from gripper).

If the user on the other hand wishes to perform each action in turn then the valid filenames are preceded by the letter 'P' e.g. 'P6'.

4.6 'Rotary.pas' Program.

This program is used to monitor only the rotary encoders, and can be used as a diagnostic tool to position the AS/RS.

4.7 'ASRS14.pas' Program

The program 'ASRS14.pas' is the controlling program for the AS/RS written in Turbo Pascal ver. 6 code. The program is discussed in terms of modular procedures.

4.7.1 Procedure front_page

This procedure presents the introduction of the program on the user screen, giving the title of program and author's name.

4.7.2 *Procedure setup*

This sets up the computer interface between the computer and the user, allowing the user to enter the required inputs into the system.

4.7.3 *Procedure Automatic_choice.*

The procedure Automatic_choice is responsible for reading the text files that contain the sequence of instructions e.g. text file "I6"

P6
P6R
P17
P17R
P0

This issues the instruction of first reading text file 'P6' then 'P6R' up to 'P0'.
Each text file in turn contains the relevant instructions in terms of the co-ordinates of the move, whether the z-axis cylinder is to be extended or retracted and whether the gripper has to close.

4. CONTROL SYSTEM SOFTWARE

The controlling program (Appendix B) is written in TURBO PASCAL ver. 6.0 and is called 'ASRS14.pas'. A number of sub programs were developed as steps towards the final program. These were written to ensure that each facet of the controlling algorithm was functioning before the full program was formulated.

4.1 'LPC36x.pas' program.

To test the function of only the x-axis independent of the encoder readings the program called 'LPC36X' (Appendix B), is invoked and can be used as a diagnostic tool to ensure that the axis is functioning correctly.

The program prompts the user for values of 'S'. Values 0-30 increase the motor velocity from zero to maximum rotation in the one direction. While values 31-60 increase the motor velocity from zero to maximum velocity in the opposite direction.

4.2 'LPC36y.pas' Program.

A diagnostic program similar in function to the one for the x-axis.

4.3 'LPC36z.pas' Program.

A diagnostic program for the z-axis which is identical in function to the programs listed for the x and y axis.

4.4 'Linput.pas' Program.

This program can be used to display, the binary value of the input port as the micro-switches are activated.

4.5 'Air.pas' Program.

This program is used to demonstrate the function of the solenoids as described below :

The user is prompted for an integer value of s.
The corresponding actions are as follows :

- S=0 then the z-axis will retract and the gripper will open.
- S=1 then the z-axis will extend and the gripper will close.
- S=2 then the z-axis pneumatic cylinder will retract and the gripper will close.
- S=3 the z-axis pneumatic cylinder will extend and the gripper will open.

The reason that rotary encoders were used instead of other displacement sensors, was that the rotary encoders lend themselves to more accurate positioning. This is due to the fact that a specific number of turns corresponds to a certain displacement. By making use of a rack and pinion arrangement, rotary encoders can be made to measure linear displacement, assuming negligible backlash in the gears.

The three rotary encoders are connected to a computer-based quadrature encoder and counting card (PCL 833). The card has three independent channels, supporting simultaneous reading of three rotary encoders. The card also has the ability to double or multiply by a factor of four, the amount of pulses of the rotary encoder. The card achieves this by counting the two channels of the rotary encoder, i.e. the counter will increment (or decrement) whenever a rising or falling edge occurs on input channel A, or B.

3.14 Pneumatic solenoids

The pneumatic solenoids are activated via the output port C of the PC36 at the base address 390H. Two digital outputs are used to activate the relays (D32A2110) which in turn activate the solenoid valves for the pneumatics. Figure 3.18 illustrates the driver used to activate each of the solenoid valves.

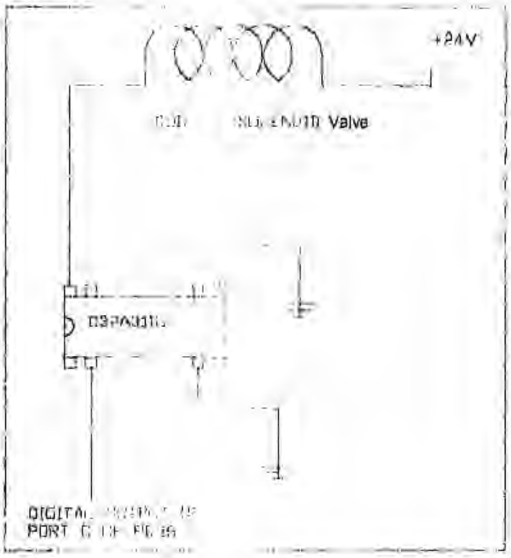


Figure 3-18 Diagram of solenoid driver.

3.15 Rotary Encoders.

Three HEDS-5500 rotary encoders were used (Appendix F). These rotary encoders serve as position sensors, i.e. they indicate the relative position of the robot arm. The encoders used have the following specifications:

- Five hundred and twelve pulses per revolution.
- Bi-directional.

The encoder contains a lensed light emitting diode (LED) light source, an integrated circuit (IC) with detectors and output circuitry, and a code wheel which rotates between the emitter and detector IC. The outputs of the encoder are two square waves in quadrature. The collimated light and special photodetector configuration allow for high resolution and excellent encoding performance as well as increased long life reliability. The encoder may be quickly and easily mounted onto a motor. No mechanical or electrical adjustments are required.
The two channel digital outputs and the single 5V input supply are accessed through the pinout at the back of the encoder.

3.13 Micro-switches

The micro switches shown in Figure 3.17 were connected as follows :

Figure 3-17 Micro-switch

Each of the common pins is connected to a pin of the PC 36's port C located at the base address 310H. The limit switches are used as the home sensing position of the device as well as end sensors if the maximum travel of any of the axis has been breached. Each micro-switch when activated increases the binary value of port C (Table 3-5).

Table 3-5 Binary values when switch is activated.

DESCRIPTION	**VALUE**	**Pin 37 pin con.**
The micro-switch located at the x-axis home position	16	Pin 24
The micro-switch located at the extreme end of the x-axis	32	Pin 25
The micro-switch located at the y-axis home position	64	Pin 26
The micro-switch located at the extreme end of the y-axis	4	Pin 21
The micro-switch located at the z-axis home position	8	Pin 20
The micro-switch located at the extreme end of the z-axis	2	Pin 22

3.12 Power Supplies

Four main power supply units were used :

- The computer's power supply.
- A 1 kW 50V DC power supply.
- A 100 watt 24V DC power supply.
- A variable DC power supply.

The +12V,-12V and +5V power railings on the PC were used to supply the DC voltage requirements for the motor drives and the rotary encoders power requirements.

The 50V power supply was used to power the x axis and y axis motors, while the 100 Watt, 24V DC power supply was used to power the z axis motor.

The variable voltage power supply was set at 24V and used to power the L292 chip on all the DC drives, the solenoid valves for the pneumatics and the cooling fan.

Condition of test.
Travel distance of x-axis : 450 mm
Loading condition : unloaded.

Table 5-3 X-axis reading 450 mm

Reading	Clock reading (mm)	Encoder Value (mm)
1	2.83	449.47
2	2.25	449.15
3	4.45	450.07
4	2.33	449.13
5	2.21	448.86
6	4.5	450.22
7	4.76	450.48
8	2.7	449.59
9	3.96	449.73
10	2.11	449.06
11	3.77	449.05
12	2.23	449.19
13	2.35	449.13
14	2.25	449.13
15	3.65	449.05
16	2.59	449.48
17	3.42	449.45
18	2.3	448.99
19	3.63	449.06
20	3.53	449.31
avg.	**3.09**	**449.38**
variance	**0.77**	**0.19**
std deviation	**0.88**	**0.44**
accuracy	**2.66**	**1.33**

Condition of test.
Travel distance of x-axis : 300 mm
Loading condition : unloaded.

Table 5-2 X-axis readings 300 mm

Reading	Clock reading (mm)	Encoder value (mm)
1	1.31	299.09
2	1.45	299.22
3	1.62	299.25
4	1.52	299.07
5	1.78	299.49
6	3.05	299.04
7	3.22	300.05
8	1.52	298.99
9	1.37	299.20
10	3.72	299.66
11	0.98	298.89
12	1.1	299.39
13	1.21	299.14
14	0.95	299.27
15	1.72	299.13
16	1.18	299.45
17	4.55	300.67
18	1.8	299.20
19	2.84	299.25
20	0.65	299.34
avg.	**1.88**	**299.34**
variance	**1.08**	**0.16**
std deviation	**1.04**	**0.40**
accuracy	**3.12**	**1.22**

Testing of the X axis.

Testing of the x axis was carried out as follows:

Four distances were chosen i.e. 150 mm, 300 mm, 450 mm, 600 mm for testing. The axis was then moved from the home position to these respective distances and discrepancies were noted by the dial gauge. The encoder value was also noted. No load was used as the impact on the readings would be negligible in the absence of gravity.

Condition of test.
Travel distance of x-axis : 150 mm
Loading condition : unloaded.

Table 5-1 X-axis readings. 150 mm

Reading	Clock reading (mm)	Encoder Value (mm)
1	1.55	149.35
2	3.55	149.42
3	1.61	149.26
4	1.89	149.52
5	2.18	149.45
6	1.65	149.28
7	1.54	148.99
8	2.67	150.29
9	2.05	149.63
10	1.75	149.11
11	1.75	149.18
12	3.95	150.16
13	3.6	150.15
14	1.75	149.02
15	3.05	149.03
16	1.59	149.17
17	1.76	149.16
18	2.73	149.24
19	1.73	149.34
20	1.82	149.25
avg.	**2.21**	**149.40**
variance	**0.59**	**0.14**
std deviation	**0.77**	**0.38**
accuracy	**2.31**	**1.15**

Each axis was tested in turn using different travel distances.

To determine the accuracy of the different axis the following equation is used :

$$accuracy = \frac{CR}{2} + 3\sigma \qquad (5\text{-}10)$$

Where :

CR = control resolution (in this case 0.00977 mm)
σ = std. dev. of mechanical error. (mm)

To determine the repeatability of the different axis the following equation is used :

$$\text{Repeatability} = 6\sigma \qquad (5\text{-}11)$$

5.2 TESTS

The method to test the accuracy and repeatability of the AS/RS was carried out as follows :

i. An axis was chosen; either X, Y, or Z axis
ii. A dial gauge was placed at either point 'A' (x axis), 'B' (Y axis), or 'C' (Z axis) depending on the axis being tested at a certain distance from the home position (Figure 5-6).
iii. The device was then moved to the point (with the gripper retracted), and the co-ordinates were noted.
iv. The value of the dial gauge was recorded.
v. The device was returned to the home position.

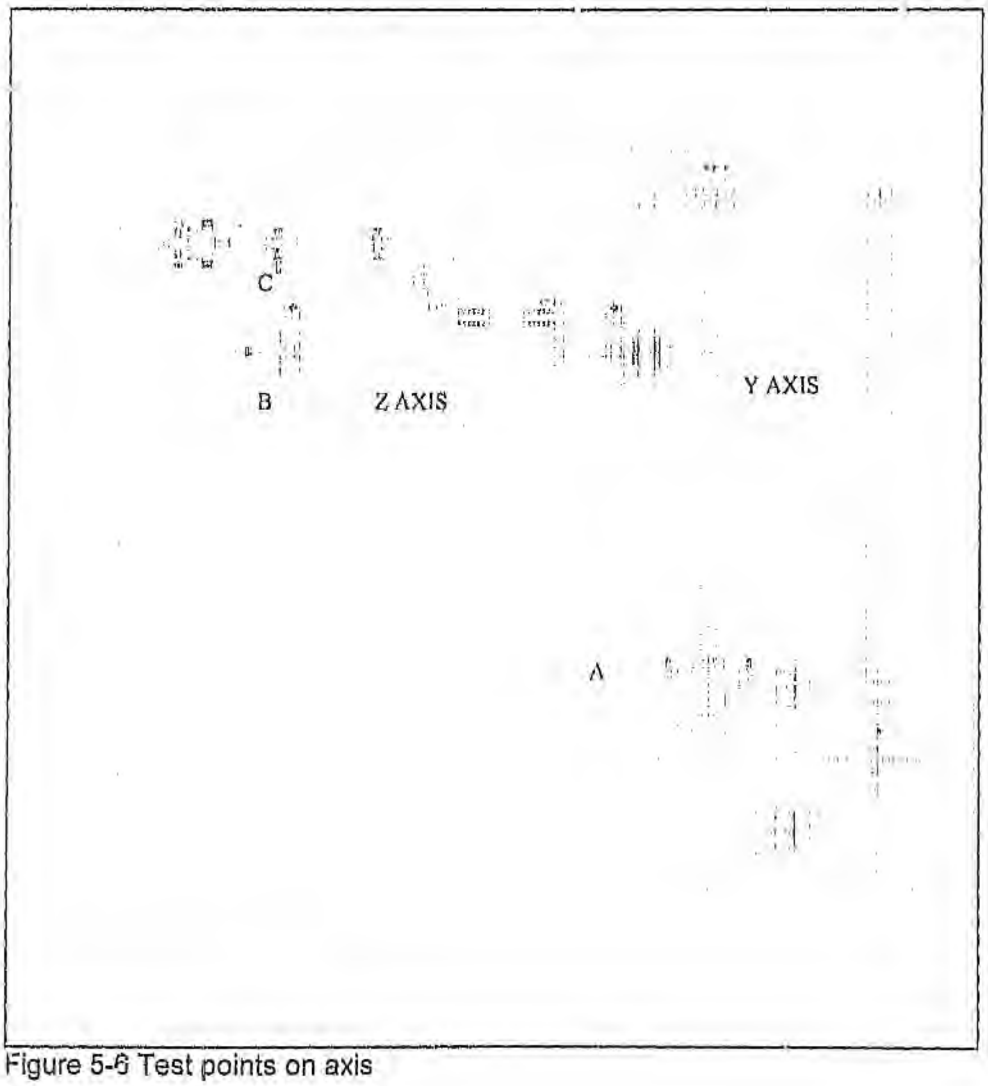


Figure 5-6 Test points on axis

Thus $I = \pi(12x10^{-3} + 12x10^{-3} + 16x10^{-3})^4/64$
$= 1.256637x10^{-7}$

and the following data is given.

F = 3600 N
ℓ = 0.68 m
E = $200x10^9$ Pa
I = $1.256637x10^{-7}$ m^4

Thus

y_{max} = $(3600x0.68^3)/(3x200x10^9x1.256637x10^{-7})$
= 15 mm

This deflection is far too great for use in practice, where a deflection of no greater than 2 mm is required.

However in practice the maximum load lifted is : 20 N
Using equation 5.8 the amount of deflection would be :

y_{max} = $(20 \times 0.68^3)/(3x200x10^9x1.256637x10^{-7})$
= 0.08 mm

For the z-axis an 84 Watt motor rotating at 1400 rpm was used.

Thus T = 0.57 N.m
and F = 0.65 KN

These motors are obviously over-designed to drive the x, y and z axis where the maximum load that consists of lifting the z-axis together with the gripper assembly, having a maximum weight of 100 N.

The reason for the over-design was that the motors were available and thus were used in terms of their low cost rather than meeting the exact design needs.

Thus the maximum driving force is given as

F = (3.18)(2000)(π)(0.9)/5
= 3.6 KN

However this is an unrealistic value as the amount of deflection is not considered:

Equation 5-8 provides the expression for the deflection of a cantilever load.

$$y_{max} = -\frac{Fl^3}{3EI} \qquad (5\text{-}8)$$

Where :

y_{max} = Max. deflection (m)
F = Force (N)
ℓ = Distance (m)
E = Elastic modulus (Pa)
I = Second moment of area (m^4)

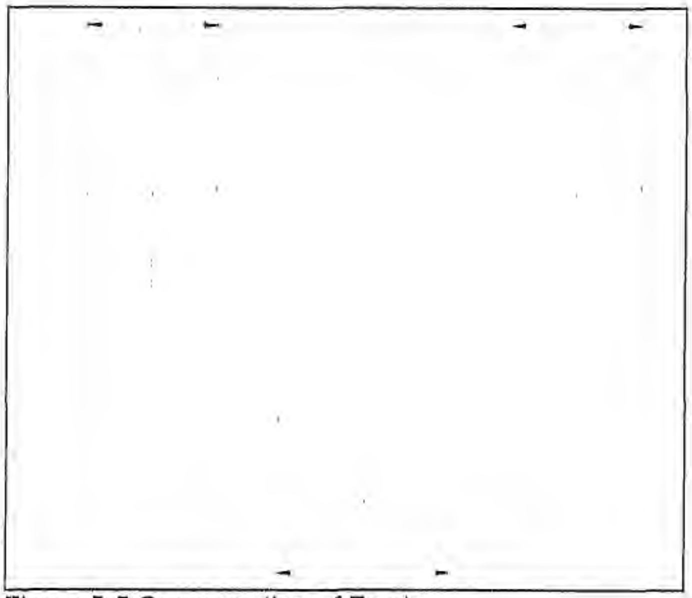


Figure 5-5 Cross section of Z-axis

To determine the amount of deflection of the Z-axis equation 5-8 is used.
The Z-axis consists of three rods (cross section shown in Figure 5.5) whose second moment of area is given as follows ;

$$I = \frac{\pi d^4}{64} \qquad (5\text{-}9)$$

Where d= equivalent cross section diameter (m)

Calculation of the encoder resolution is given below.

The rotary encoders produce 512 pulses per revolution.
The ball screw has a pitch of 5 mm.

Thus each pulse corresponds to 0.00977 mm of linear travel.

Calculation of systems lifting ability.

The motors used were 50 V 8.8 A DC permanent magnet motors.

The motors power rating is given as : 440 Watts

The formula that relates rotational speed, torque and power is given as :

$$T = \frac{60H}{2\pi n} \qquad (5\text{-}6)$$

where H = power (Watts).
T = torque (N.m).
n = speed (rpm)

At 50 V the rated speed of the motor is 1320 rpm

Thus the output torque is given as :

$T = (60)440/(2\pi 1320)$
$= 3.18$ N.m

The motor is used to drive a ballscrew with a lead of 5 mm.

Thus to determine the maximum driving force of the x-axis, and y-axis equation 5.7 (refer to Appendix D) is used.

$$F = \frac{T \times 2000 \times \pi \times \eta}{P} \qquad (5\text{-}7)$$

Where F = Operating load (N).
η = Mechanical efficiency (approx. 0.9).
P = Lead (mm)
T = torque (N.m)

Then taking moments about point A (refer to Figures 5.2 and 5.4) the grasping force of the gripper can be determined. Only the static case is considered.

$$\Sigma M_A = F_{b1} x R_{b1} - F_{Grasp\ force} \times R_{grasp\ force} = 0 \qquad (5\text{-}3)$$

where

M_A = Moment about point A (N.m)
F_{b1} = Force due to member b1 (N).
R_{b1} = Perpendicular distance of b1 to point A (m)
$F_{grasp\ force}$ = Reaction force (N).
$R_{grasp\ force}$ = Perpendicular distance of reaction force to point A (m).

To obtain $F_{grasp\ force}$, equation 5.5 is rearranged as :

$$F_{Grasp\ force} = \frac{(F_{b1} \times R_{b1})}{R_{grasp\ force}}$$

From Figure 5.3 the following data is taken :

R_{b1} = 0.0075xCos(23) = 0.007 m
$R_{grasp\ force}$ = 0.030 m
F_{b1} = 21.6 N

thus $F_{grasp\ force}$ = 5 N

However 5 N only represents half the grip force, and due to symmetry the full grip force is 10 N

To determine the gripping force of the gripper, only the case where the pneumatic cylinder is extending needs to be considered i.e. F= 47N.

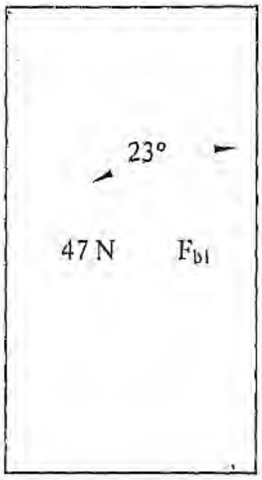


Figure 5-3 Triangle of forces

Taking the equilibrium case of the two members b1 and b2 together with the piston force it can be seen from symmetry (refer to Figure 5.2) that the forces in the members b1 and b2 are (refer to 5.3):

F_{b1} = 47/2 Cos. 23°.
Thus F_{b1} = 21.6 N

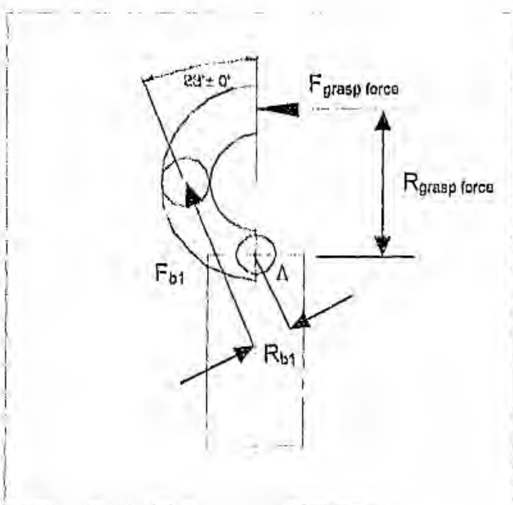


Figure 5-4 Free body diagram

And the differential pressure P is given as :

P= P1-P2

thus P= 600 KPa

And using equation 5-2 the resultant force on the piston is :

$$F = 7.85\times10^{-5}(600\times10^{3})$$
$$= 47\ N$$

Now when chamber A2 is pressurised to 700 KPa absolute pressure and chamber A1 is at atmospheric pressure the retracting force of the piston is as follows :

P=100-700

P=-600 KPa.

and

$$S = \pi\left(\frac{d1^2 - d2^2}{4}\right) \quad (5\text{-}4)$$

S = 3.1415(0.000016)

$S = 5.0365\times10^{-5}\ m^2$

Using equation 5-2 the force is given as :

$F=-600\times10^{3}\times5.0365\times10^{-5}$

F= -30 N (i.e. in the opposite direction)

Figure 5-2 Forces acting on gripper.

5.1.1 Calculations

To determine the gripping force the following analysis was carried out :
Using equation 5-1 and letting the differential pressure of chamber 'A1' and 'A2' be given as 'P' , thus equation 5-1 becomes :

$$F = PS \qquad (5\text{-}2)$$

where:

F = Force (N)
P = Differential pressure (P_1-P_2) (Pa)
S = Area (m^2)

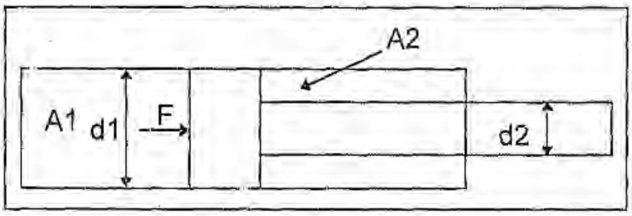


Figure 5-1Linear cylinder.

Using the general equation 5-2 the force available when chamber A1 is pressurised is given as follows :

Given data :

d1 = Diameter of pneumatic cylinder (ϕ of chamber A1). Given as 10 mm.
d2 = Diameter of rod. Given as 6 mm.
P1 = Pressure in chamber A1. Given as 700 KPa absolute pressure.
P2 = Pressure in chamber A2. Given as 100 KPa absolute pressure

The surface area of the piston in chamber A1 is given as :

$$S = \pi\left(\frac{d1}{2}\right)^2 \qquad (5\text{-}3)$$

S= $3.1415 \times (0.005)^2$
S= 7.85×10^{-5} m^2

Thus for the design the following data is given :

Horizontal travel speed : 55 mm/sec (operating at 660 rpm)
Vertical travel speed : 55 mm/sec (operating at 660 rpm)
Z-axis (shuttle) : 117 mm/sec (operating at 1400 rpm)

Distance between one pallet and the next one : 150 mm
Distance between one shelf and the next one : 150 mm
Number of pallets per shelf : 4 pallets.

Thus using equations 5.9 and 5.10.

H_s = 160(4) = 640 mm
L_s = 160(4) = 640 mm

and using equations 5.11 and 5.12

t_h = 640/55 = 11.6 sec.
t_v = 640/55 = 11.6 sec.

And using equation 5.16

T = 23.2 sec.

Thus using equation 5.17

T_{avg} = 23.2(1.3333)+2(2).

= 34.9 sec

Using these travel times and assuming simultaneous movement in two axes, the following parameters are defined :

$$T = \max(t_h, t_v) \tag{5-5}$$

$$Q = \min\left(\frac{t_h}{T}, \frac{t_v}{T}\right) \tag{5-6}$$

Where :

T = longest travel time.(s)
Q = Ratio of axis travel time with respect to T.

The average time to perform a pick operation is given by equation 5.15 (Bozer 1984).

$$T_{avg} = T\left(\frac{Q^2}{3} + 1\right) + 2T_{pd} \tag{5-7}$$

Where :

T_{pd} = Time of shuttle to perform a pickup and deposit.

However in this case the x, and y axis are activated one at a time and thus the total time taken will be the combination of the horizontal and vertical travel times.

$$T = (t_h + t_v) \tag{5-8}$$

and the ratio Q =1;

Thus equation 5.15 reduces to

$$T_{avg} = T\left(\frac{1}{3} + 1\right) + 2T_{pd} \tag{5-9}$$

Device performance

The actual performance of the AS/RS was compared to theoretical performance and conclusions were drawn from these observations.

The capacity of the storage shelf is defined by equation 5-8.

$$Capacity = N_v x N_h \qquad (5\text{-}8)$$

where :

N_v = Number of load compartments arranged vertically.
N_h = Number of compartments arranged horizontally.

The horizontal and vertical travel lengths are defined by equations 5.9 and 5.10.

$$H_s = N_v(y+10 \text{ mm clearance}) \qquad (5\text{-}9)$$
$$L_s = N_h(x+10 \text{ mm clearance}) \qquad (5\text{-}10)$$

Where :

H_s = Height travel length (mm).
y = Distance between vertical compartments (mm).
L_s = Length travel of the AS/RS (mm).
x = Distance between compartments along the length (mm).

The time to travel the full length of the horizontal travel is given by equation 5.11.

$$t_h = \frac{L_s}{V_h} \qquad (5\text{-}11)$$

Where :

V_h = Velocity of the x axis (mm/s).

The time to travel the full length of the vertical axis is given as :

$$t_v = \frac{H_s}{V_v} \qquad (5\text{-}4)$$

Where :

V_v = Velocity of the y axis (mm/s).

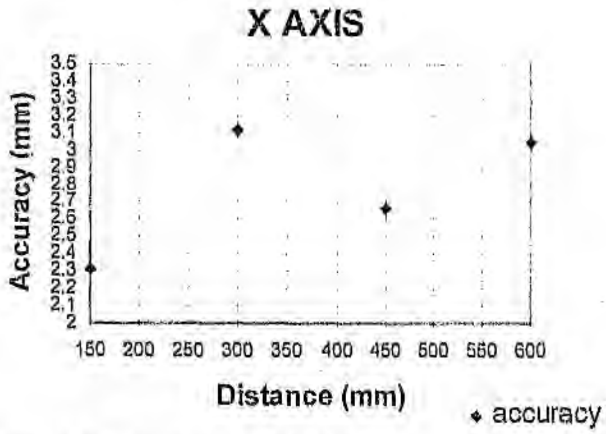


Figure 5-7 Accuracy of X Axis

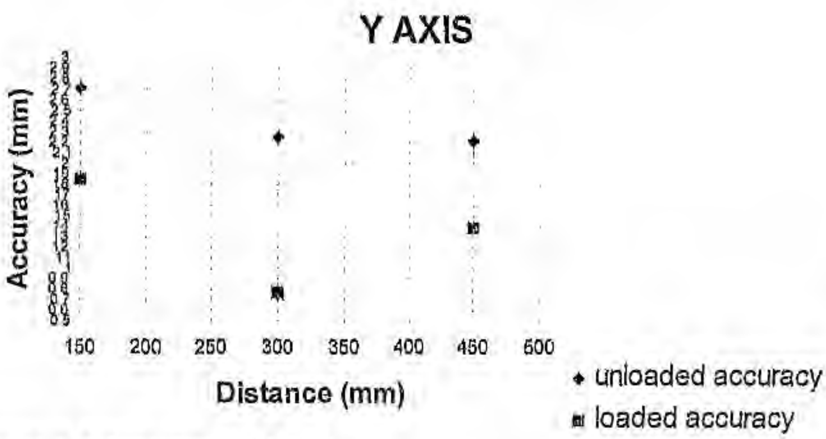


Figure 5-8 Accuracy of Y Axis

These results compare favourably with the accuracies cited in Table 5-11 by Kulwiec (1985).

Table 5-12 Accuracies of various interfaces.

Interface	Accuracy (mm)
Manual load/unload	± 76
Conveyor/AGVs interface (automatic)	± 25
AS/RS load/unload (automatic)	± 6
Machine Tool interface (automatic)	± 0.25

Summary of testing

Table 5-10 Encoder values vs. position

	X-axis	Y-axis	Z-axis
Distance (mm)	**Encoder (mm)**	**Encoder (mm)**	**Encoder (mm)**
150	149.55	149.44	-
160	-	-	159.51
300	299.64	299.45	-
450	449.83	449.65	-
600	600	-	-

Table 5-11 Accuracy and repeatability results.

	X-AXIS			Y-AXIS	unload	loaded	unload	Z-AXIS		
Distance (mm)	Std. dev. (mm)	Accur. (mm)	Repeat. (mm)	Std. dev. (mm)	Accur. (mm)	Accur. (mm)	Repeat (mm)	Std dev. (mm)	Accur. (mm)	Repeat (mm)
150	'7	2.31	4.62	0.89	2.71	1.85	5.34	-	-	-
160		-	-	-	-		-	2.27	6.82	13.62
300	1.04	3.12	6.24	0.75	2.25	0.76	4.5	-	-	-
450	0.88	2.66	5.28	0.61	2.22	1.38	3.66	-	-	-
600	1.06	3.05	6.36	-	-	-	-	-	-	-
Average	0.94	2.79	5.63	0.75	2.39	1.33	4.5	2.27	6.82	13.62

The accuracy of the device is taken in the X-Y plane where the most critical positioning is required i.e. :

$$\sqrt{2.79^2 + 2.39^2} = 3.67mm$$

Figures 5.7 and 5.8 show accuracy deviations of the position of the x axis and y axis respectively. The error fluctuates between 2.3 mm and 3.1 mm for the x axis with no apparent linearity with respect to distance moved. The main reason is due to the variance of the home position as discussed in 5.3.1 and 5.3.2. The y axis fluctuates between 0.7 mm and 2.7 mm.

5.3 RESULTS

The results of each axis is discussed in turn.

5.3.1 X Axis

The x-axis encoder readings were consistent through the different positions, with little deviation between encoder reading and actual distance moved. Discrepancy within the positioning of the x-axis is a result of the error band of the homing micro-switch.

5.3.2 Y Axis

The Y-axis encoder readings were consistent through the different positions, with little deviation between encoder reading and actual distance moved. Discrepancy within the positioning of the Y-axis is a result of the error band of the homing micro-switch. The improvement in position accuracy with the load is a result that the load acted as a damping force in the vertical movement.

5.3.3 Z Axis

The large discrepancy between distance moved and actual position can be attributed to two main factors mainly , the high travel speed of the z axis thus difficulty is experienced in stopping the z axis at the required position and the error band of the micro switch. The speed can be better controlled by using a lower supply voltage to the z axis motor, using step down gears or replacing the DC motor with a stepper motor.

Testing of deflection of the Z axis

The device was then tested for amount of deflection of the Z axis under different loading conditions and compared to the theoretical values derived from equation 5.8. The test was conducted with the following parameters :

Distance of x-axis : 0 mm (To minimise the influence of the X axis members)
Distance of Y-axis : 450 mm
Distance of Z-axis :160 mm
Distance of weight from y-axis centre line : 680 mm
Dial gauge placed at gripper end.

Table 5-9 Deflectio s

Weight (N)	Deflection (mm)	Theoretical (mm)
0	0	0
2.45	0.3	0.01
4.90	0.57	0.02
7.36	0.87	0.03
9.81	1.17	0.04
12.26	1.73	0.05
14.72	2.19	0.06
17.17	2.33	0.07
19.62	2.75	0.08

The discrepancy of the readings between actual and theoretical can be attributed to the following reasons :

- Assumption made that the AS/RS is a rigid cantilever structure.
- Play in the linear bearings.
- Flexibility between bolted components.
- Deflection of the Y-axis.

Thus a realistic lifting capacity of 20 N is achieved

Testing of the Z axis.

Testing of the Z axis was carried out as follows:

One distance was chosen i.e. 160 mm for testing. Only one distance was chosen due to the short travel length of the Z axis. The axis was then moved from the home position to the respective distance and discrepancies were noted by the dial gauge. The encoder value was also noted. No load was used as the impact on the readings would be negligible in the absence of gravity.

Condition of test.
Travel distance of z-axis : 160 mm

Table 5-8 Z-axis reading

Reading	Clock (mm)	Encoder (mm)	Reading	Clock (mm)	Encoder (mm)
1	5,00	160,55	18	7,04	160.09
2	2,20	156,23	19	6,54	162,26
3	2,60	155,52	20	9,61	163,93
4	4,80	159.62	21	3.00	158,80
5	4,38	157,41	22	5,75	157,58
6	5,23	160,77	23	3.[illegible]7	159.13
7	4,08	159,76	24	4,85	159,69
8	3,41	159.11	25	5,25	157.10
9	2,50	157,43	26	2,40	155,65
10	2,20	158.13	27	6 78	162,57
11	3,42	159.15	28	8.10	163.86
12	6,88	162,73	29	5,78	159,36
13	10,22	16[illegible],01	30	3.10	159,04
14	3.95	159,70	31	3,05	157.72
15	2,54	155,68	32	6.15	157,82
16	8,20	162,54	33	1,05	160,60
17	2,30	156,83	34	6,29	162,53
			avg.	4.68	159.34
			variance	5.15	5.81
			std deviation	2.28	2.41
			accuracy	6.82	7.23

Condition of test.
Travel distance of y-axis : 450 mm

Table 5-7 Y-axis reading 450 mm

	Unloaded		**Loaded 1 kg**	
Reading	**Clock reading (mm)**	**Encoder value (mm)**	**Clock reading (mm)**	**Encoder value (mm)**
1	2.18	449.24	2	449.13
2	1.92	448.85	2.75	449.54
3	2.7	449.39	2.65	449.39
4	2.85	44[illegible].83	2.15	448.8[illegible]
5	2.01	448.86	2.28	448.93
6	1.52	448.74	3.18	449.75
7	0.8	449.26	3.32	449.03
8	0.36	448.99	2.65	449.21
9	0.75	449.22	2.15	448.89
10	1.21	449.48	2.98	449.23
11	0.52	448.90		
12	0.77	449.16		
13	0.56	448.98		
14	0.41	449.00		
15	0.95	449.30		
16	0.89	449.20		
17	0.95	449.18		
18	1.08	449.29		
19	1.08	448.87		
20	1.7	449.09		
avg.	**1.26**	**449.09**	**2.61**	**449.19**
variance	**0.61**	**0.04**	**0.37**	**0.08**
std deviation	**0.74**	**0.21**	**0.46**	**0.29**
accuracy	**2.22**	**0.63**	**1.38**	**0.88**

Condition of test.
Travel distance of y-axis : 300 mm

Table 5-6 Y-axis reading 300 mm

	Unloaded		Loaded 1 kg	
Reading	**Clock reading (mm)**	**Encoder value (mm)**	**Clock reading (mm)**	**Encoder value (mm)**
1	3.92	298.87	5.05	299.07
2	3.71	299.21	5.48	299.09
3	4.18	299.51	5.2	299.07
4	4.1	299.43	5.3	299.07
5	4.22	299.66	5.57	299.08
6	4.13	298.78	5.05	299.11
7	5.08	299.44	5.22	298.97
8	4.73	300.21	4.91	299.00
9	4.6	299.09	5.65	299.38
10	5.33	299.21	5.51	299.65
11	5.42	299.43		
12	5.6	299.33		
13	5.91	299.43		
14	5.4	299.20		
15	5.31	299.36		
16	6.18	299.84		
17	5.43	299.19		
18	5.31	299.15		
19	5.9	299.45		
20	5.69	299.51		
avg.	**5.02**	**299.36**	**5.29**	**299.15**
variance	**0.56**	**0.10**	**0.21**	**0.04**
std deviation	**0.75**	**0.32**	**0.25**	**0.21**
accuracy	**2.25**	**0.95**	**0.76**	**0.63**

Testing of the Y axis.

Testing of the Y axis was carried out as follows:

Three distances were chosen i.e. 150 mm, 300 mm, 450 mm for testing. The axis was then moved from the home position to these respective distances and discrepancies were noted by the dial gauge. The encoder value was also noted. A 1 Kg load was used as the impact on the readings would be significant in the presence of gravity. Only ten tests were carried out as there was an improvement in performance in the loaded condition.

Condition of test.
Travel distance of y-axis : 150 mm.

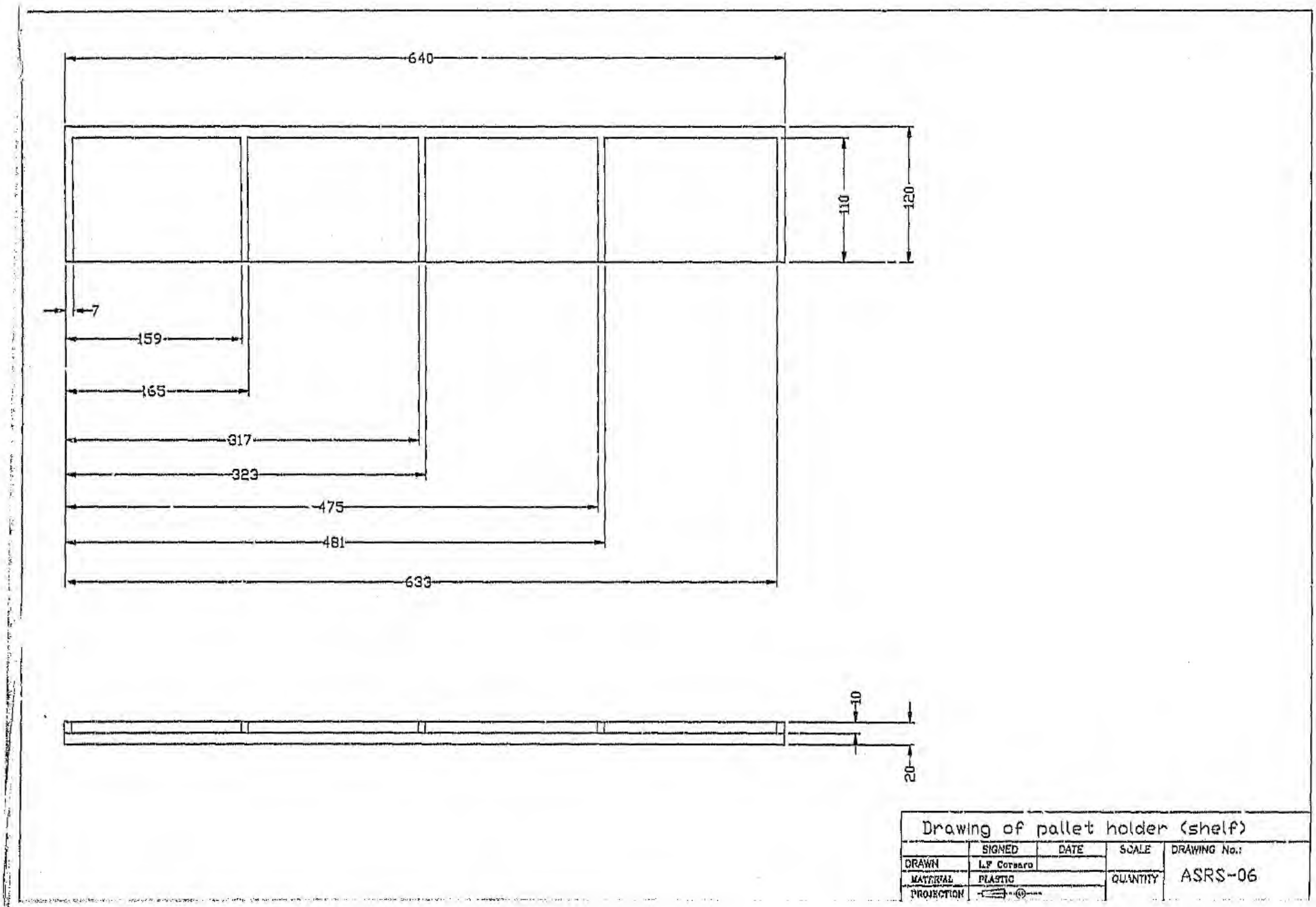
Table 5-5 Y-axis reading 150 mm

	Unloaded		**Loaded**	**1 kg**
Reading	**Clock reading (mm)**	**Encoder value (mm)**	**Clock reading (mm)**	**Encoder value (mm)**
1	2.85	149.32	0.78	148.96
2	1.87	149.04	0.79	149.45
3	2.1	149.04	0.43	149.01
4	2.5	149.48	0.96	149.45
5	2.87	149.72	1.21	149.38
6	2.61	149.18	0.8	149.26
7	2.84	149.58	1.05	148.95
8	2.25	149.28	1.3	149.35
9	2.23	149.13	2.25	149.52
10	2.36	148.98	2.25	149.56
11	2.62	149.03		
12	2.87	149.36		
13	3.3	149.57		
14	3.78	149.52		
15	4.28	149.80		
16	4.62	150.07		
17	4.08	149.27		
18	4.50	149.88		
19	4.7	148.98		
20	2.87	150.19		
avg.	**3.31**	**143.42**	**1.18**	**149.29**
variance	**0.79**	**0.14**	**0.37**	**0.06**
std deviation.	**0.89**	**0.37**	**0.61**	**0.24**
accuracy	**2.71**	**1.10**	**1.85**	**0.71**

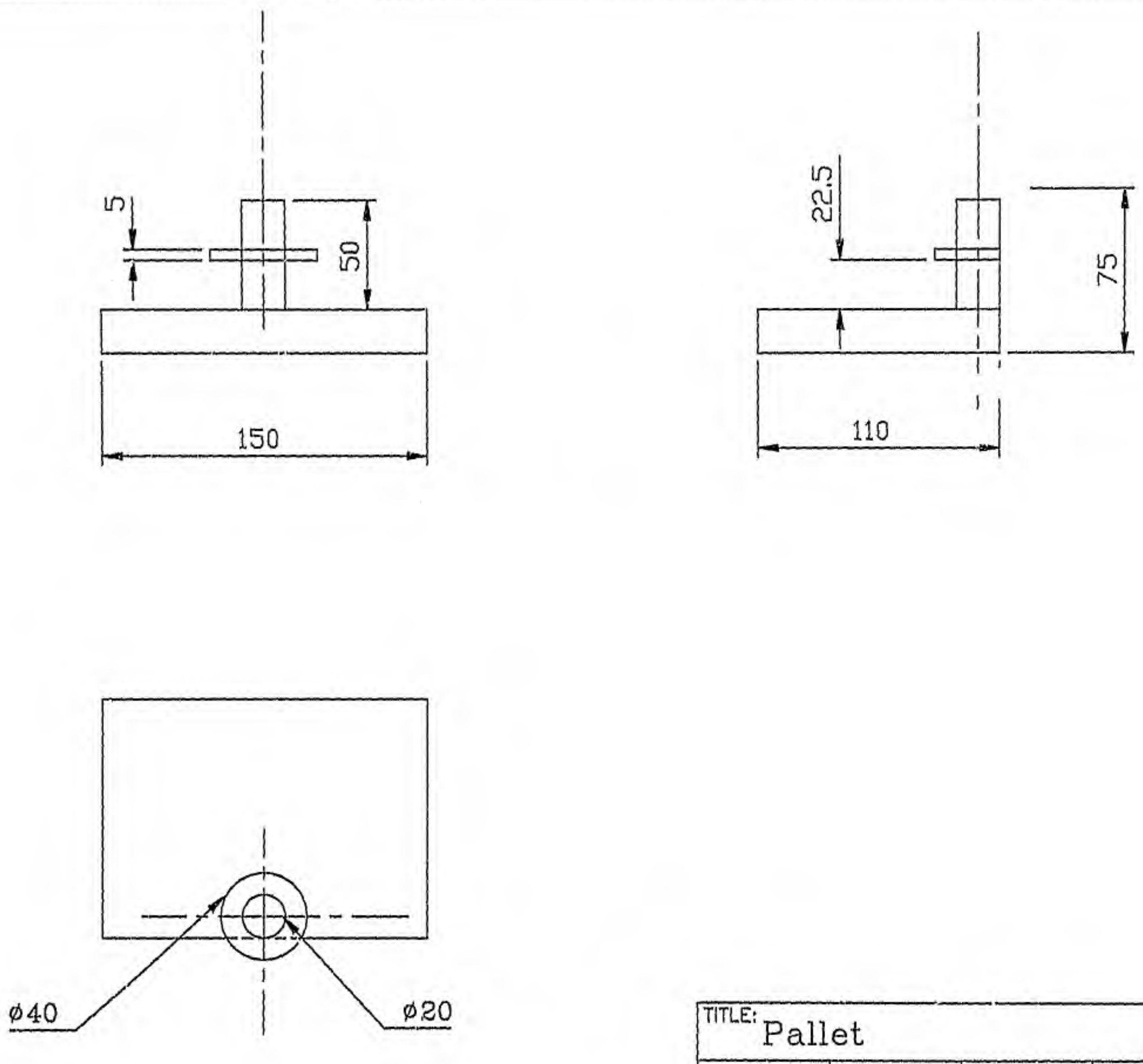
Condition of test.
Travel distance of x-axis : 600 mm
Loading condition : unloaded.

Table 5-4 X-axis reading 600 mm

Reading	**Clock reading (mm)**	**Encoder Value (mm)**
1	4.22	600.08
2	4.24	600.05
3	3.21	598.73
4	1.97	599.04
5	2.14	599.22
6	2.22	599.30
7	2.03	598.99
8	1.87	598.81
9	3.78	599.85
10	3.66	599.43
11	2	598.85
12	4.2	600.21
13	2	598.99
14	3.31	599.25
15	4.97	601.02
16	2.04	598.98
17	3.82	599.88
18	2.02	598.90
19	2.26	599.19
20	2.31	599.09
avg.	**2.91**	**599.39**
variance	**1.12**	**0.36**
std deviation	**1.06**	**0.60**
accuracy	**3.05**	**1.80**

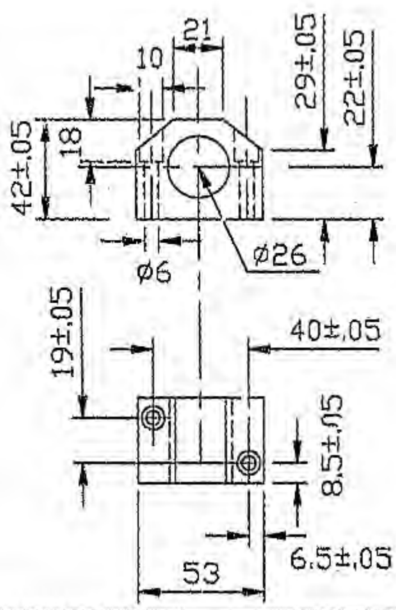


640
110
120
7
159
165
317
323
475
481
633
10
20
Drawing of pallet holder (shelf)
SIGNED
DATE
SCALE
DRAWING No.:
DRAWN
LF Corsaro
MATERIAL
PLASTIC
QUANTITY
ASRS-06
PROJECTION

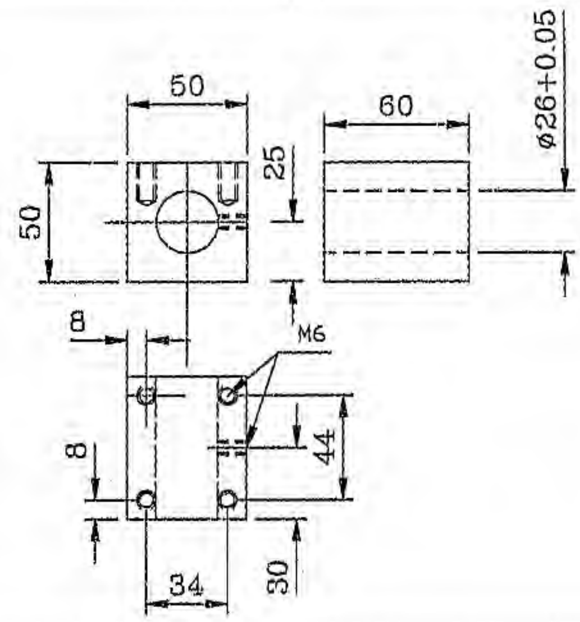


TITLE: Pallet

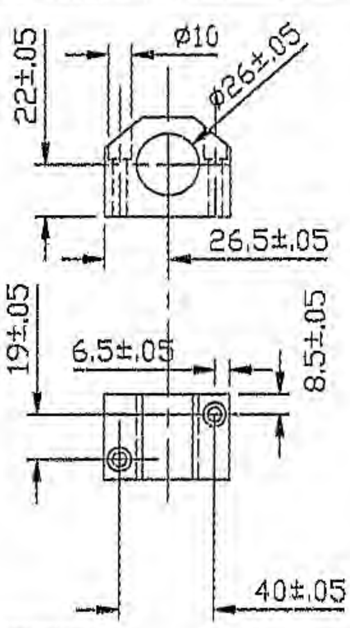
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro	JAN 95		ASRS-05
MATERIAL			QUANTITY	
PROJECTION				



LB1

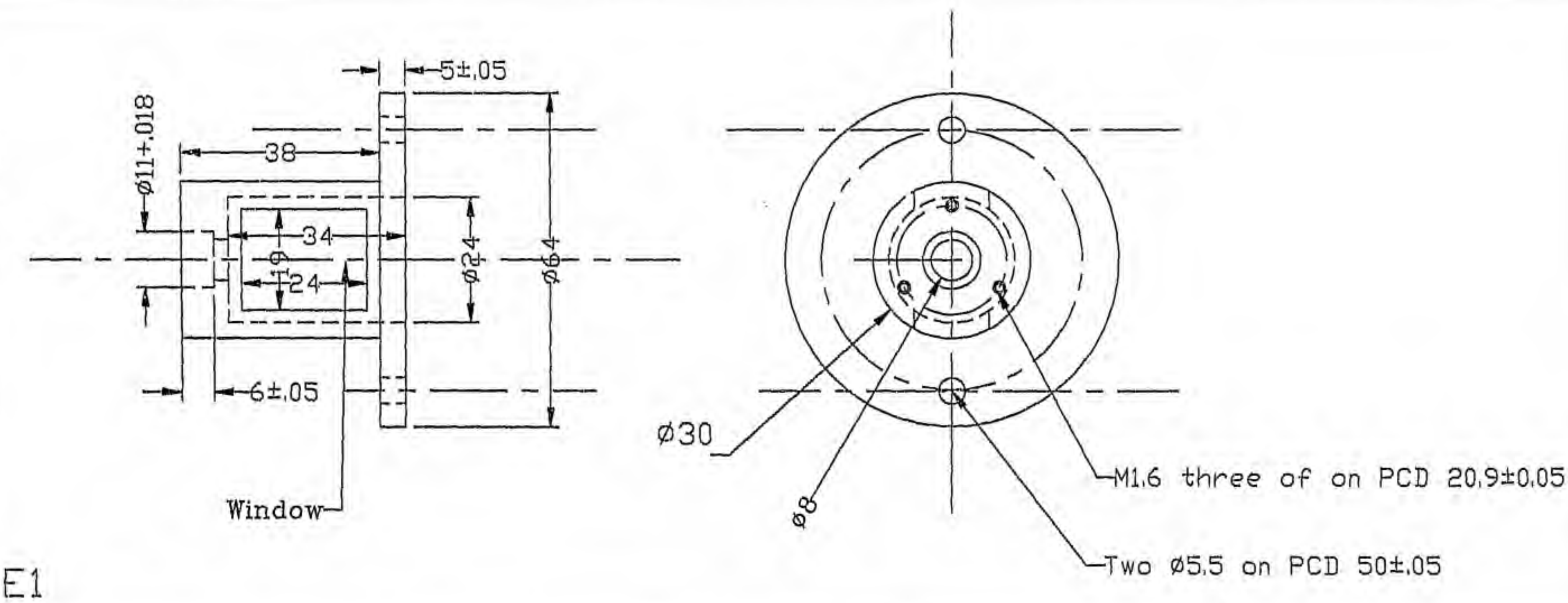


LB3

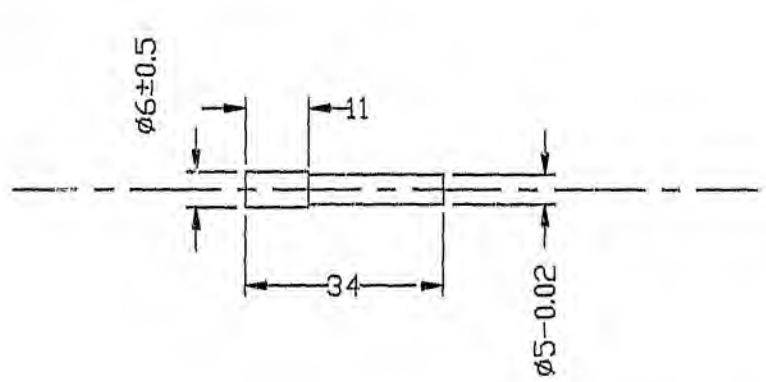


LB2

TITLE: Drawing of bearing housings LB1, LB2, LB3.				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro	JAN 05		ASRS-04
MATERIAL	MILDSTEEL		QUANTITY	
PROJECTION				

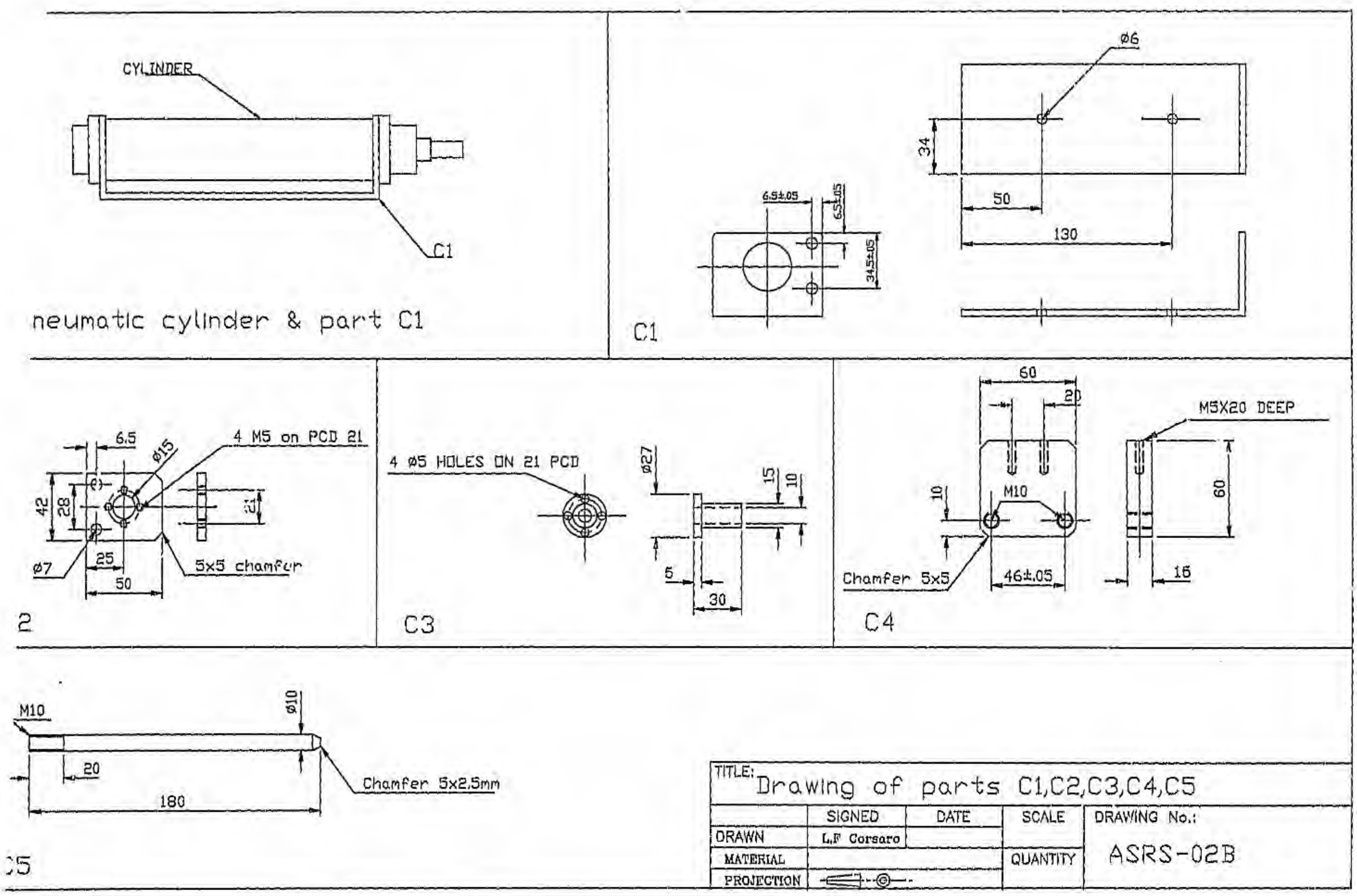


E1

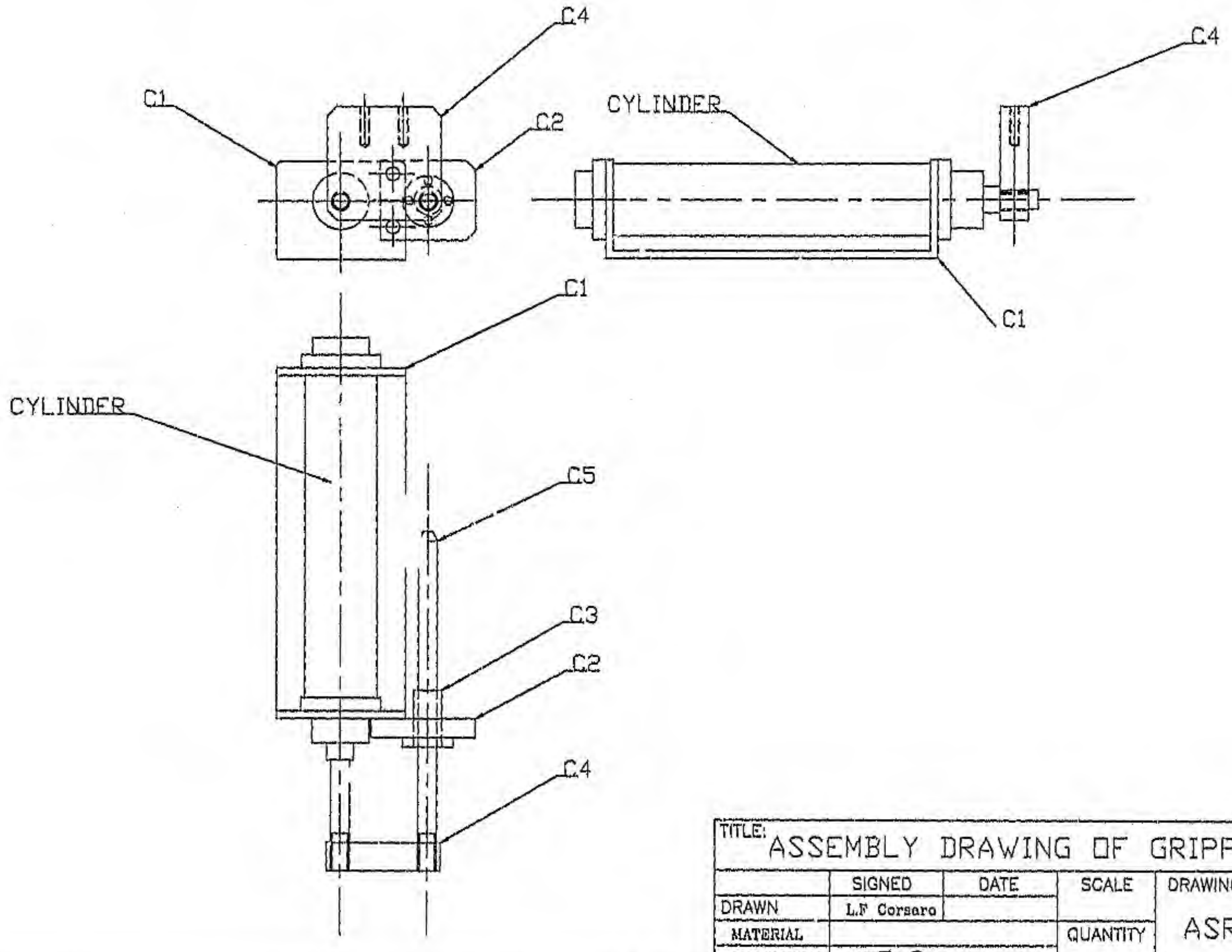


Pin1

TITLE: Drawing of part E1 & Pin1				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-03
MATERIAL			QUANTITY	
PROJECTION				



CYLINDER
C1
neumatic cylinder & part C1
ø6
34
50
130
6.5±.05
6.5±.05
34.5±.05
C1
60
20
M5X20 DEEP
6.5
ø15
4 M5 on PCD 21
42
28
21
25
50
ø7
5x5 chamfer
2
4 ø5 HOLES ON 21 PCD
ø27
15
10
5
30
C3
10
M10
60
Chamfer 5x5
46±.05
16
C4
M10
ø10
20
180
Chamfer 5x2.5mm
:5
TITLE: Drawing of parts C1,C2,C3,C4,C5
SIGNED
DATE
SCALE
DRAWING No.:
DRAWN
L.F Corsaro
MATERIAL
QUANTITY
ASRS-02B
PROJECTION



TITLE: ASSEMBLY DRAWING OF GRIPPER CARRIER				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-02A
MATERIAL			QUANTITY	
PROJECTION				

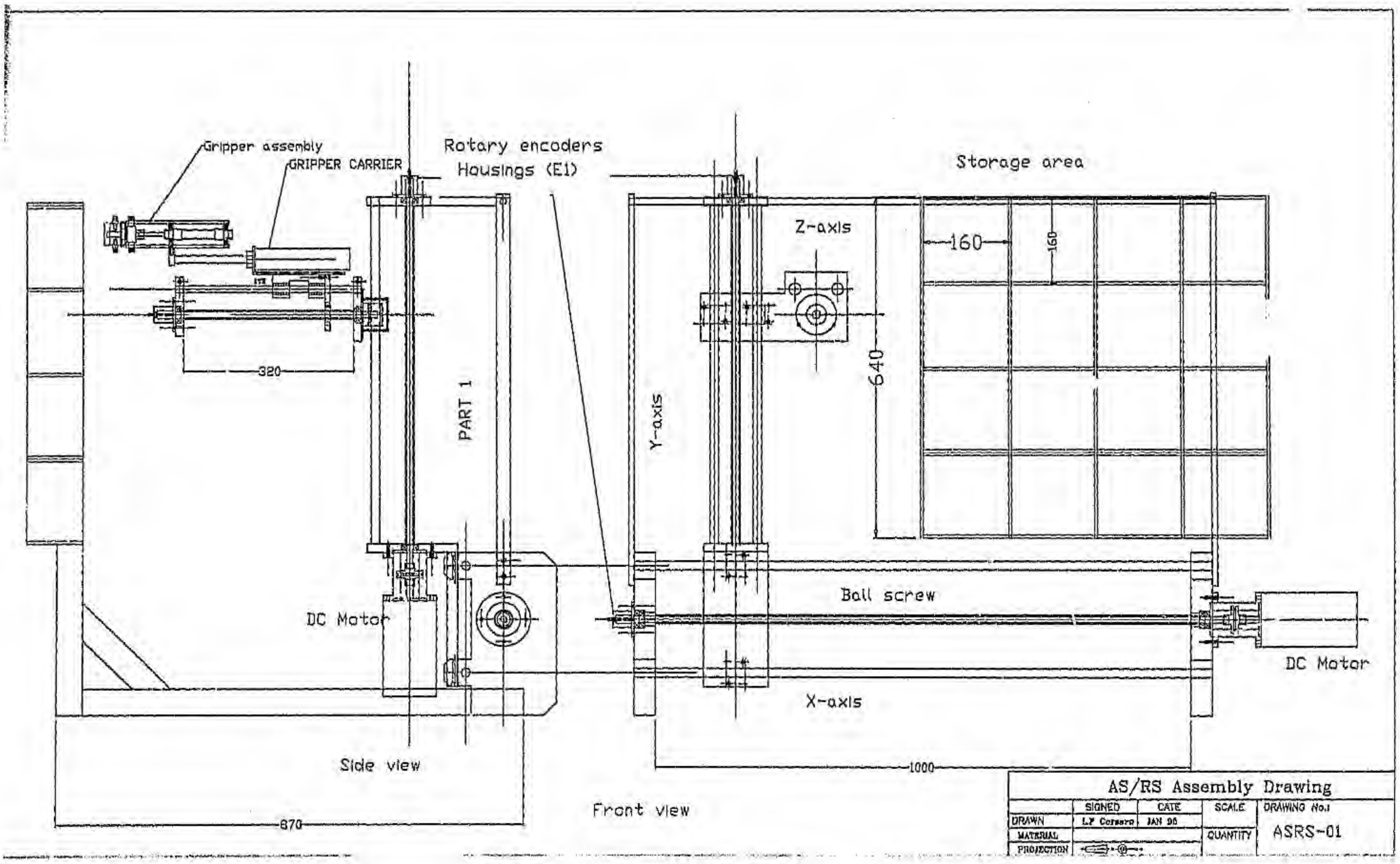

Gripper assembly
GRIPPER CARRIER
Rotary encoders
Housings (E1)
Storage area
Z-axis
160
160
320
640
PART 1
Y-axis
DC Motor
Ball screw
DC Motor
X-axis
Side view
1000
870
Front view
AS/RS Assembly Drawing
SIGNED
DATE
SCALE
DRAWING No.
DRAWN
LF Corsero
JAN 95
MATERIAL
QUANTITY
ASRS-01
PROJECTION

Table A1 Index of drawings

Family of parts	Name of drawing	Drawing No.
GENERAL	Assembly drawing of AS/RS	ASRS-01
	Assembly drawing of gripper carrier.	ASRS-02A
	Drawing of parts C1,C2,C3,C4, C5.	ASRS-02B
	Drawing of part E1 & Pin 1	ASRS-03
	Drawing of bearing housings LB1, LB2, LB3	ASRS-04
	Pallet	ASRS-05
	Drawing of pallet holder (shelf)	ASRS-06
	Drawing of general parts of AS/RS	ASRS-07
	Drawing of supporting structure.	ASRS-08
GRIPPER	Assembly drawing of gripper	ASRS-12
	Drawing of parts G1, G2, G8.	ASRS-09
	Drawing of parts G3,G4,G5,G7	ASRS-10
	Drawing of parts G6B, G6A.	ASRS-11
X-AXIS	Assembly drawing of the x-axis	ASRS-14
	Drawing of Bx ballscrew	ASRS-13
	Drawing of part XH1	ASRS-15
	Drawing of part XN1	ASRS-16
	Drawing of part XS1	ASRS-17
	Drawing of part XS2	ASRS-18
	Drawing of part XT1	ASRS-19
Y-AXIS	Assembly drawing of the Y-axis.	ASRS-22
	Drawing of ballscrew By	ASRS-20
	Drawing of part Y1	ASRS-21
	Drawing of part YN1	ASRS-23
	Drawing of part YS1	ASRS-24
	Drawing of part YS2	ASRS-25
	Assembly drawing of part Y1 & part YS2	ASRS-26
Z-AXIS	Assembly drawing of Z-axis.	ASRS-28
	Drawing of ballscrew Bz	ASRS-27
	Drawing of part ZH1	ASRS-29
	Drawing of part ZN1	ASRS-30
	Drawing of part ZS1	ASRS-31
	Drawing of part ZS2	ASRS-32
	Drawing of part ZT1	ASRS-33

Appendix A Drawings

7. REFERENCES

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6. CONCLUSION AND RECOMMENDATIONS

6.1 Summary and Conclusion

In conclusion the design was accomplished using low cost automation that was within the budget constraints. The AS/RS is fully autonomous and controlled using a personal computer with a facility to communicate with the other material handling devices of the FMC. The AS/RS was constructed at a cost of R10865 using a combination of DC motors, ballscrews and pneumatics. The AS/RS has a storage matrix of sixteen pallets with a retrieval time comparable to other material handling devices of the FMC. The AS/RS is sufficiently flexible to allow future improvements, such as increasing the storage matrix, generating managerial reports, using scheduling rules such as first in first out, shortest operating time, and due date. The software has been developed to allow automatic functioning of the AS/RS as well as allowing a user friendly interface.

The AS/RS has the following specifications :

Table 6-1 Summary.

	Value	**Units**
Accuracy	3.67	mm
Repeatability	7.2	mm
Resolution	0.00977	mm
Average pick & place time	41.6	s
Lifting capacity	20	N
Gripping force	10	N

6.2 Recommendations for Future Work

The design can be extended as follows :

- Replace the DC motors with stepper motors, having similar torque and speed characteristics to provide finer control. This is feasible only if the motors obtained have the same cost and performance characteristics as the DC motors.
- Use seeder blocks in the ballscrew support housings to absorb any vibrations generated by the axis, especially the y-axis.
- Incorporate scheduling rules for despatching the pallets.
- Incorporate a bar coding system for the pallet identification.

The data obtained in real time of the sequence of operation of picking the pallet and placing it into a buffer storage area is tabulated in Table 5-13.

Table 5-13 Pick and place times.

Pallet number	Time (s)
1	38
2	39
3	38
4	37
5	40
6	42
7	40
8	43
9	44
10	41
11	42
12	43
13	45
14	44
15	46
16	43
Total Time	665

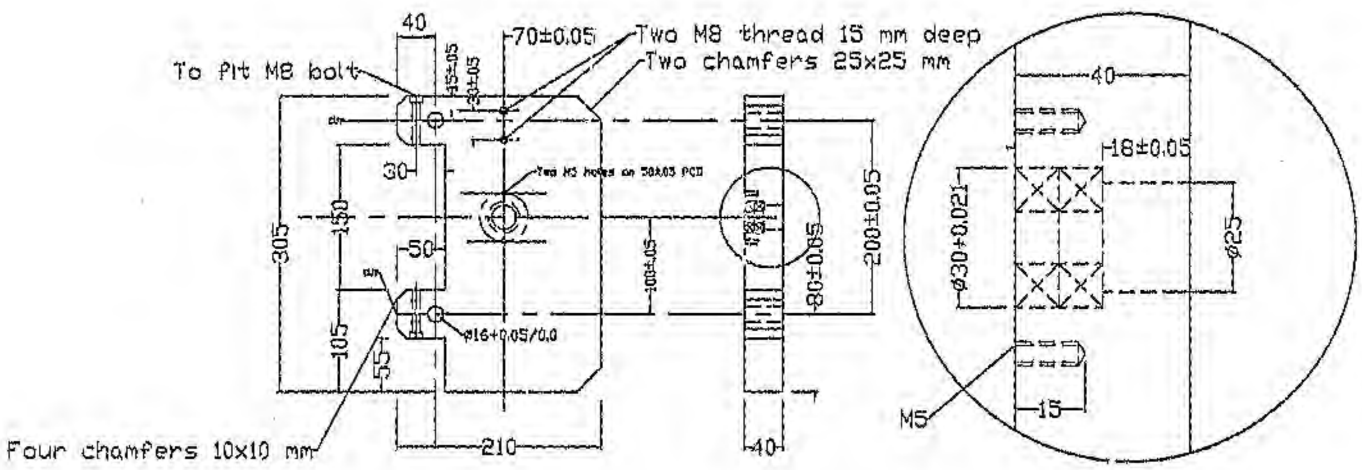
Mean time : 41.6 sec
Standard deviation (σ) : 2.7 sec

Thus the longest time of the pallet pick and deposit is : 46 seconds.

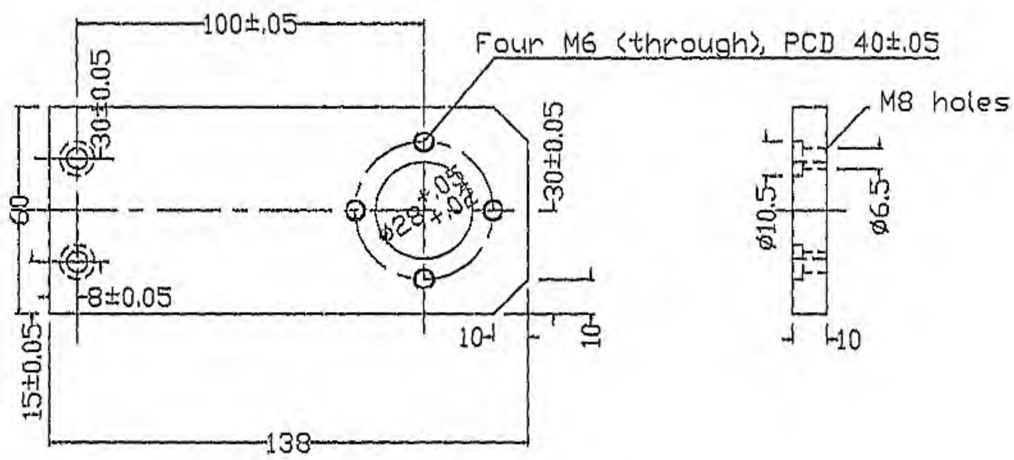
The deviation between the times observed and the time predicted can be attributed to the acceleration and de-acceleration of the respective axis. Due to the nature in terms of the size of the structure, the accelerations play an important role in determining the time of operation.

Table 5-14 Summary of results.

	Value	Units
Accuracy	3.67	mm
Repeatability	7.2	mm
Resolution	0.00977	mm
Average pick & place time	41.6	s
Lifting capacity	20	N
Gripping force	10	N



Drawing of part XS1				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	LF Corcoro			
MATERIAL			QUANTITY	ASRS-17
PROJECTION				



Drawing of part XN1				
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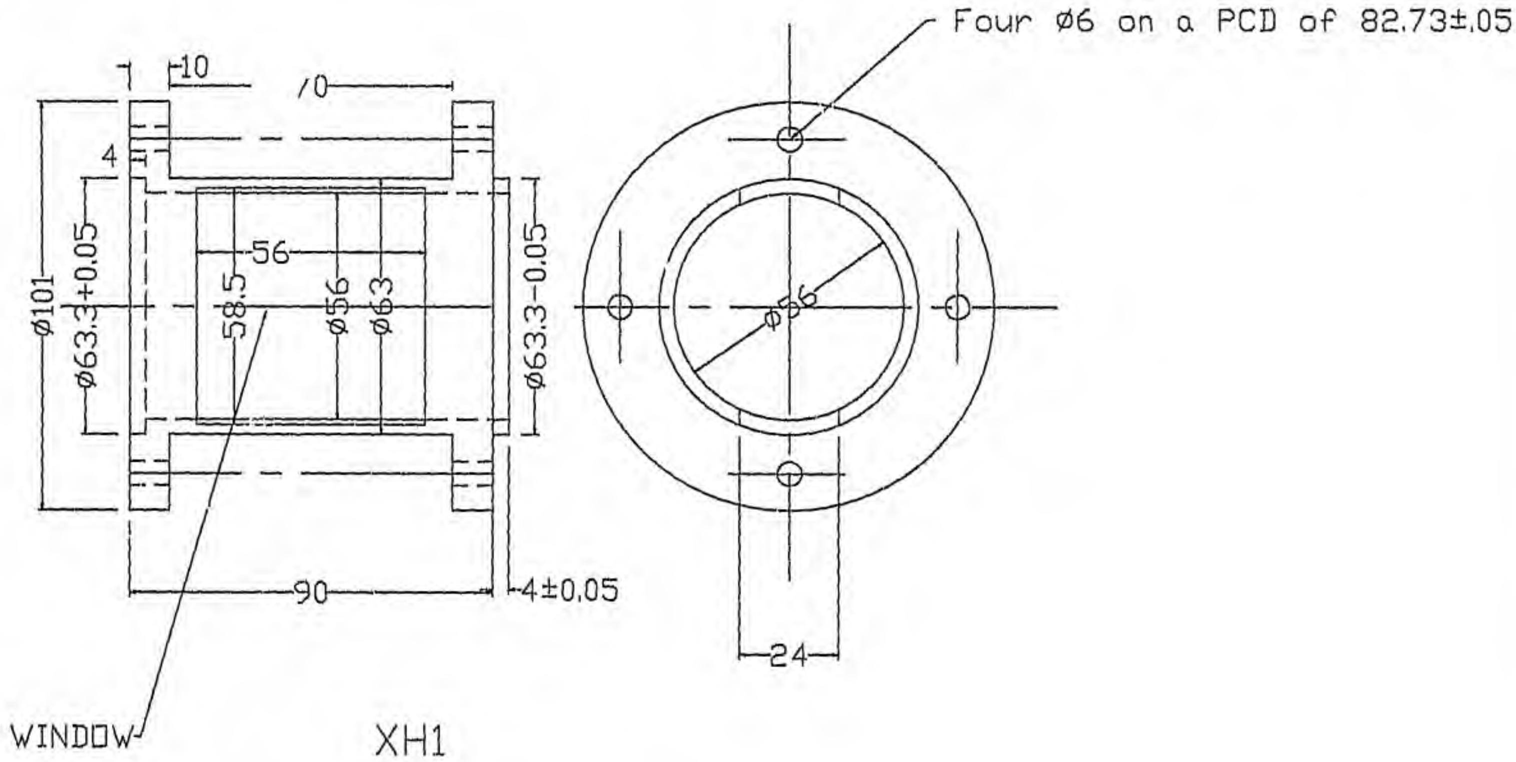
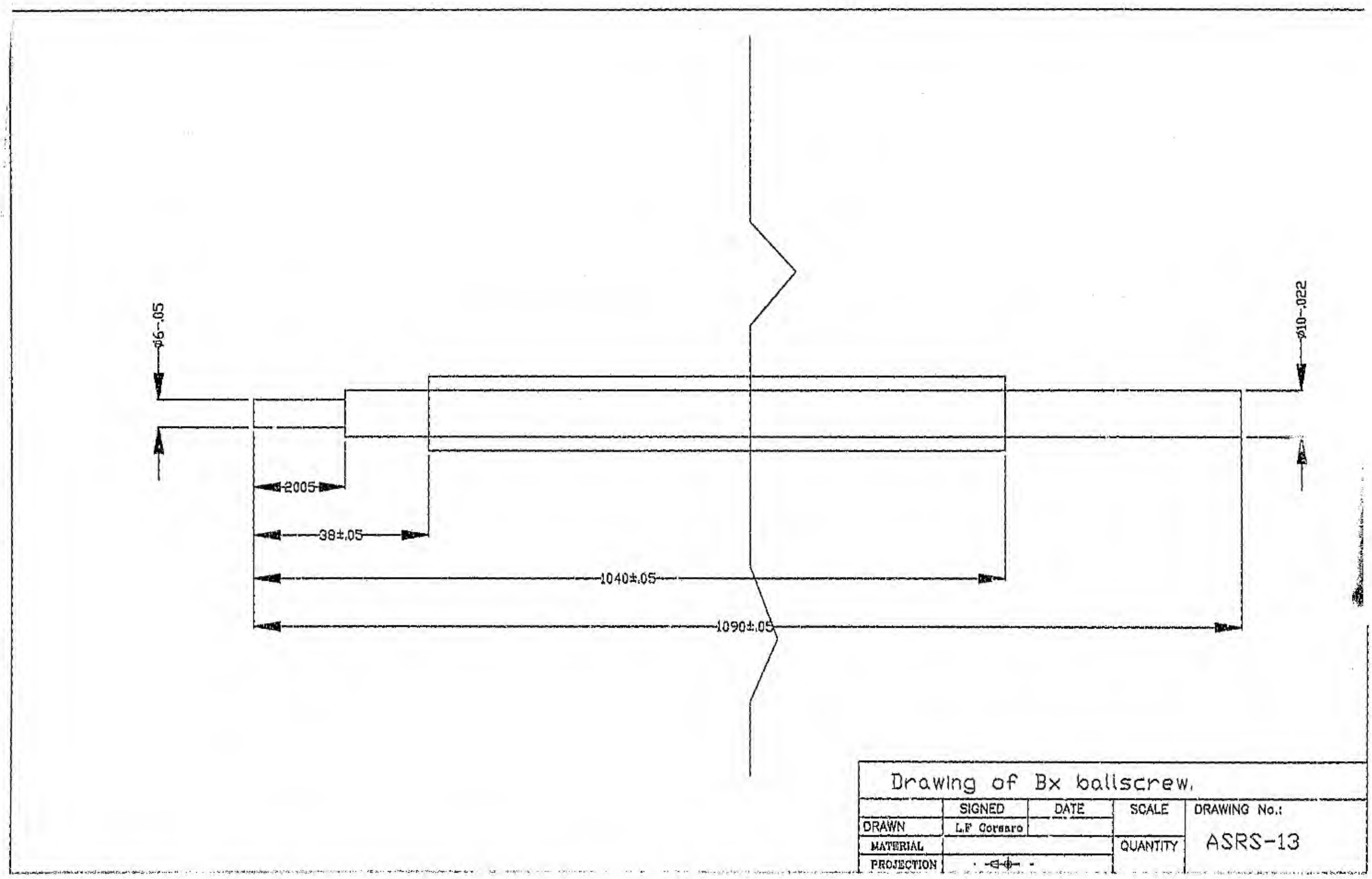
DRAWN	L.F Corsaro			ASRS-16
MATERIAL			QUANTITY	
PROJECTION				

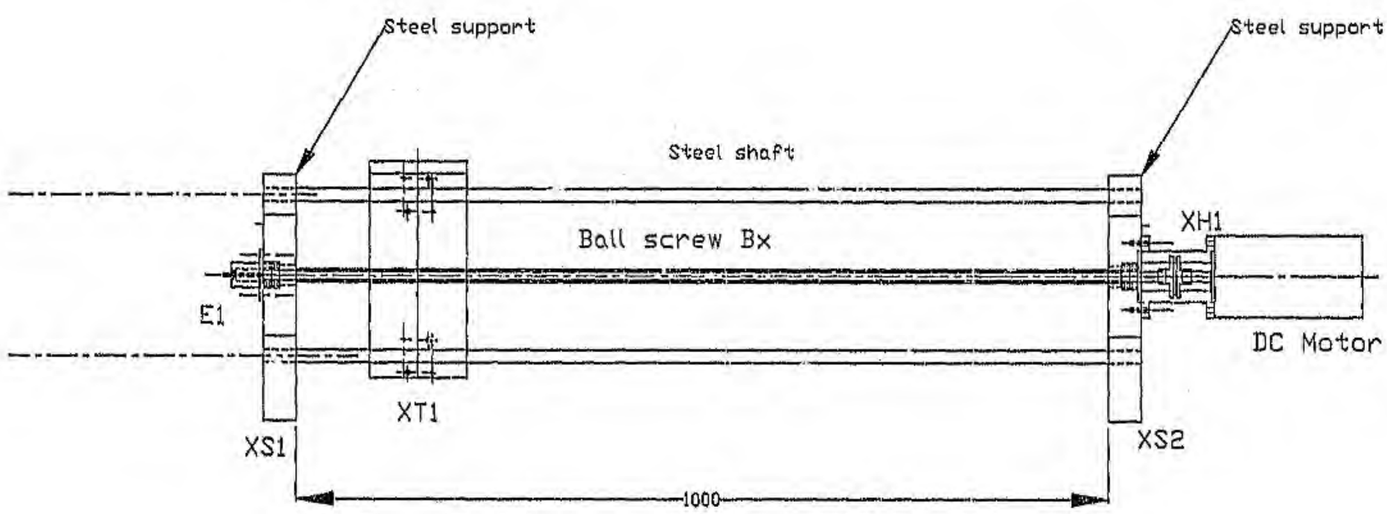


XH1

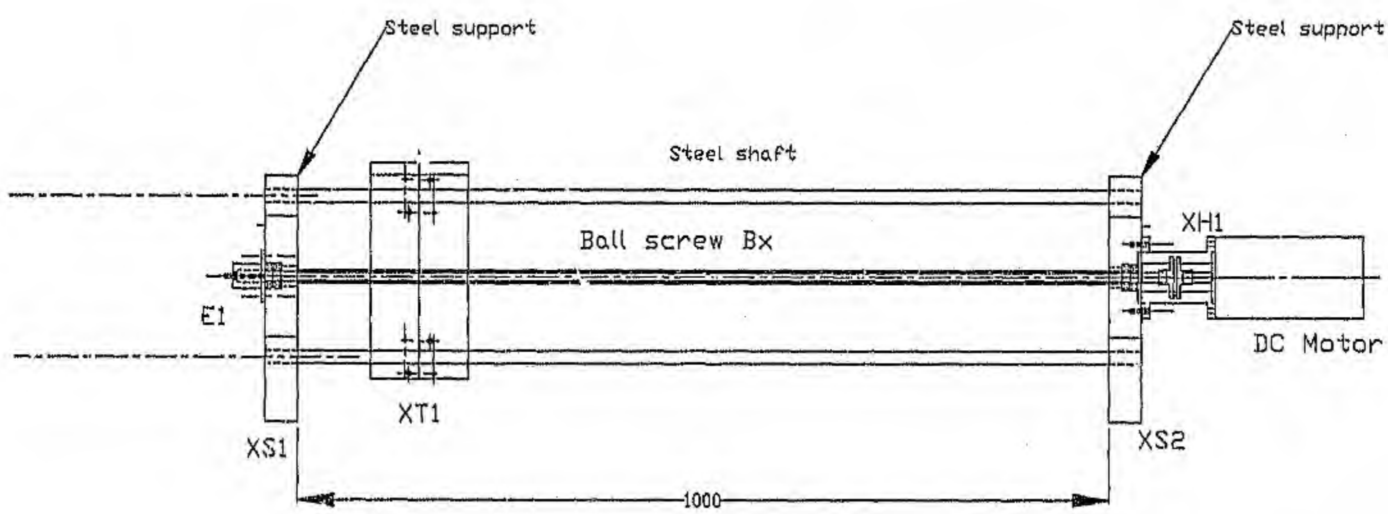
Drawing of part XH1				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-15
MATERIAL			QUANTITY	
PROJECTION				



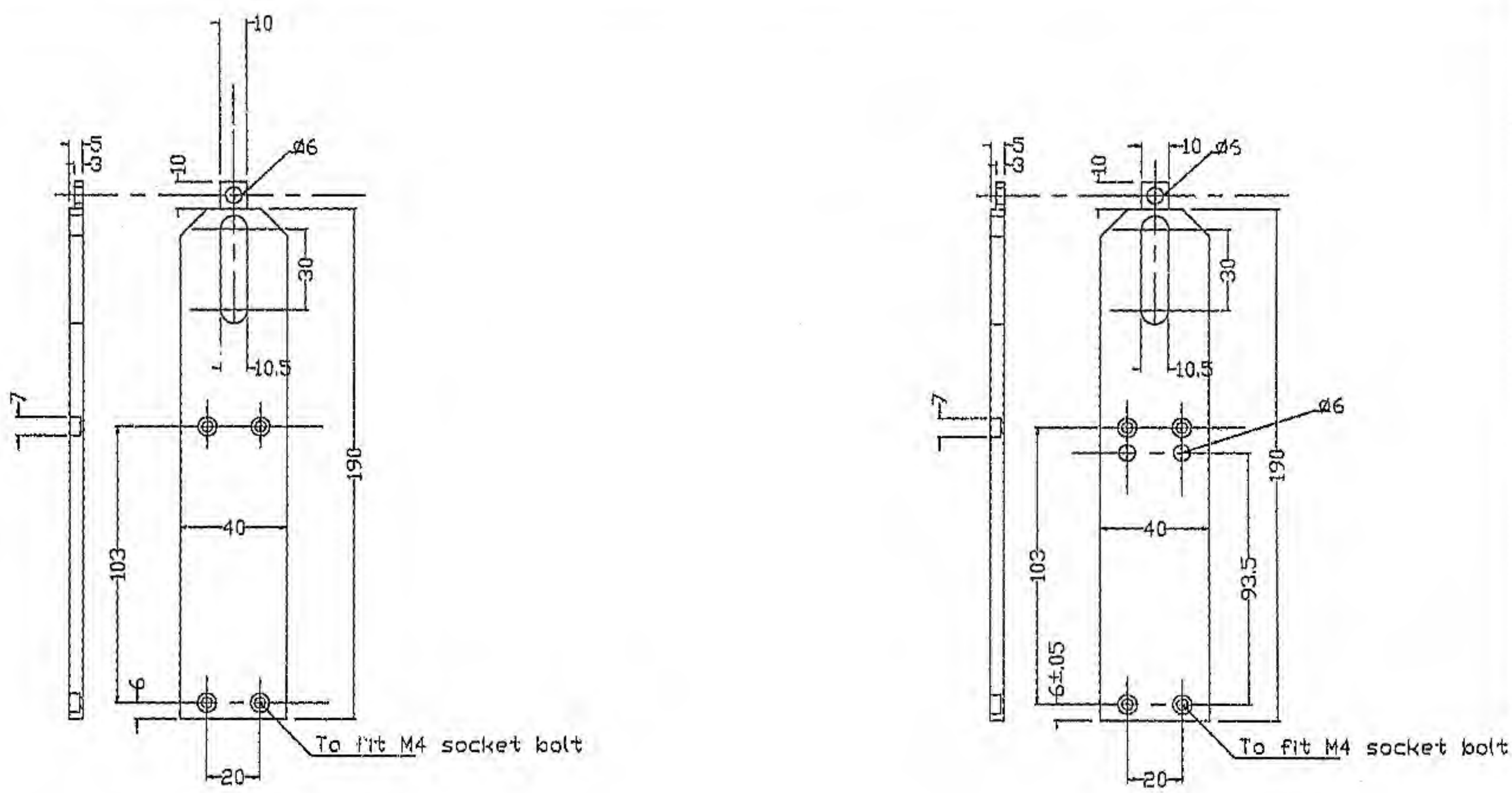
φ6-.05
φ10-.022
2005
38±.05
1040±.05
1090±.05
Drawing of Bx ballscrew.
SIGNED
DATE
SCALE
DRAWING No.:
DRAWN
LF Corsaro
MATERIAL
QUANTITY
ASRS-13
PROJECTION



Assembly drawing of the X axis				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS−14
MATERIAL			QUANTITY	
PROJECTION				

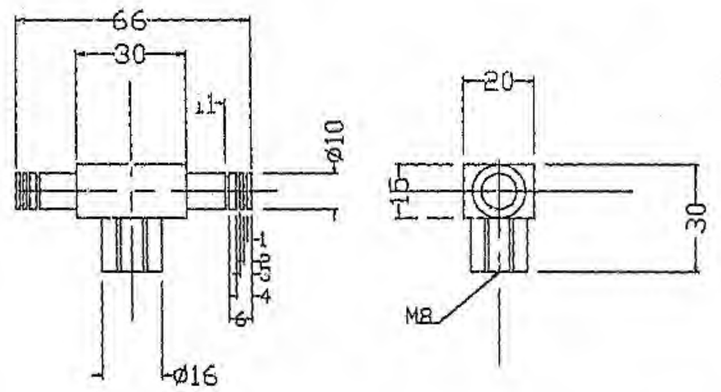


Assembly drawing of the X axis				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-14
MATERIAL			QUANTITY	
PROJECTION				



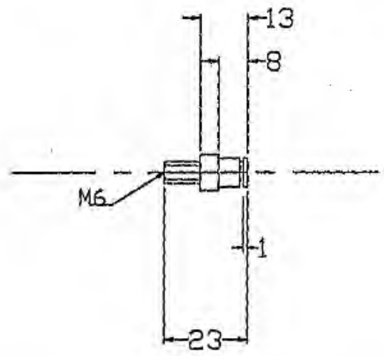
G6B G6A

Drawing of part's G6B and G6A				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	LF Corsaro			ASRS-11
MATERIAL			QUANTITY	
PROJECTION				

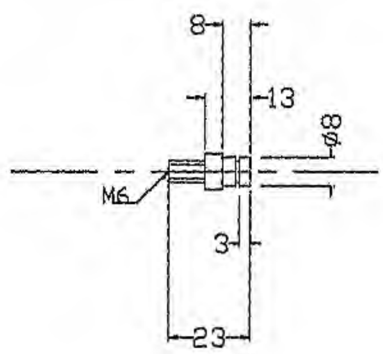


G3

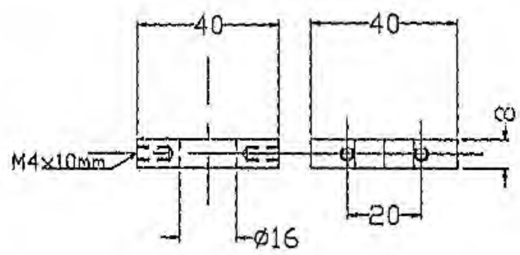
G5



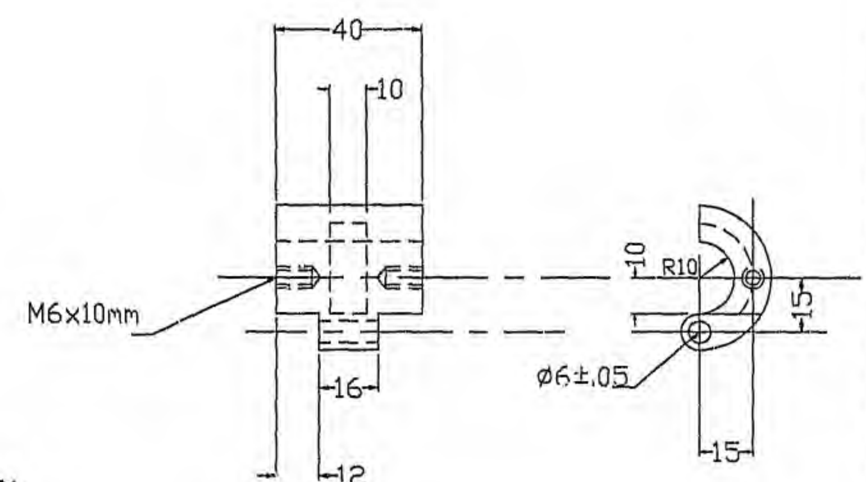
G4



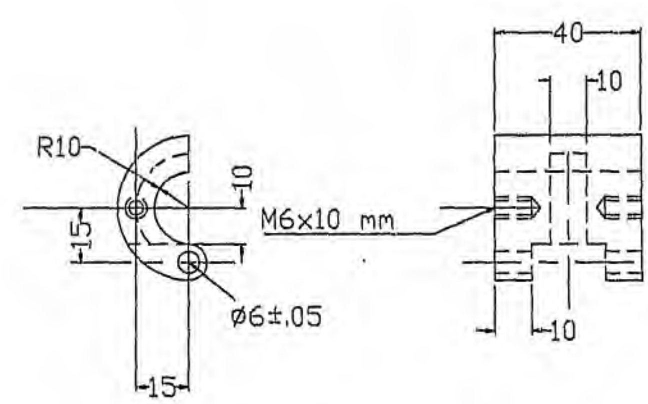
G7



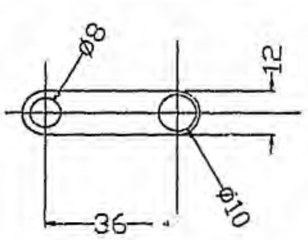
Drawing of part's G3, G4, G5 & G7				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-10
MATERIAL			QUANTITY	
PROJECTION				



G1



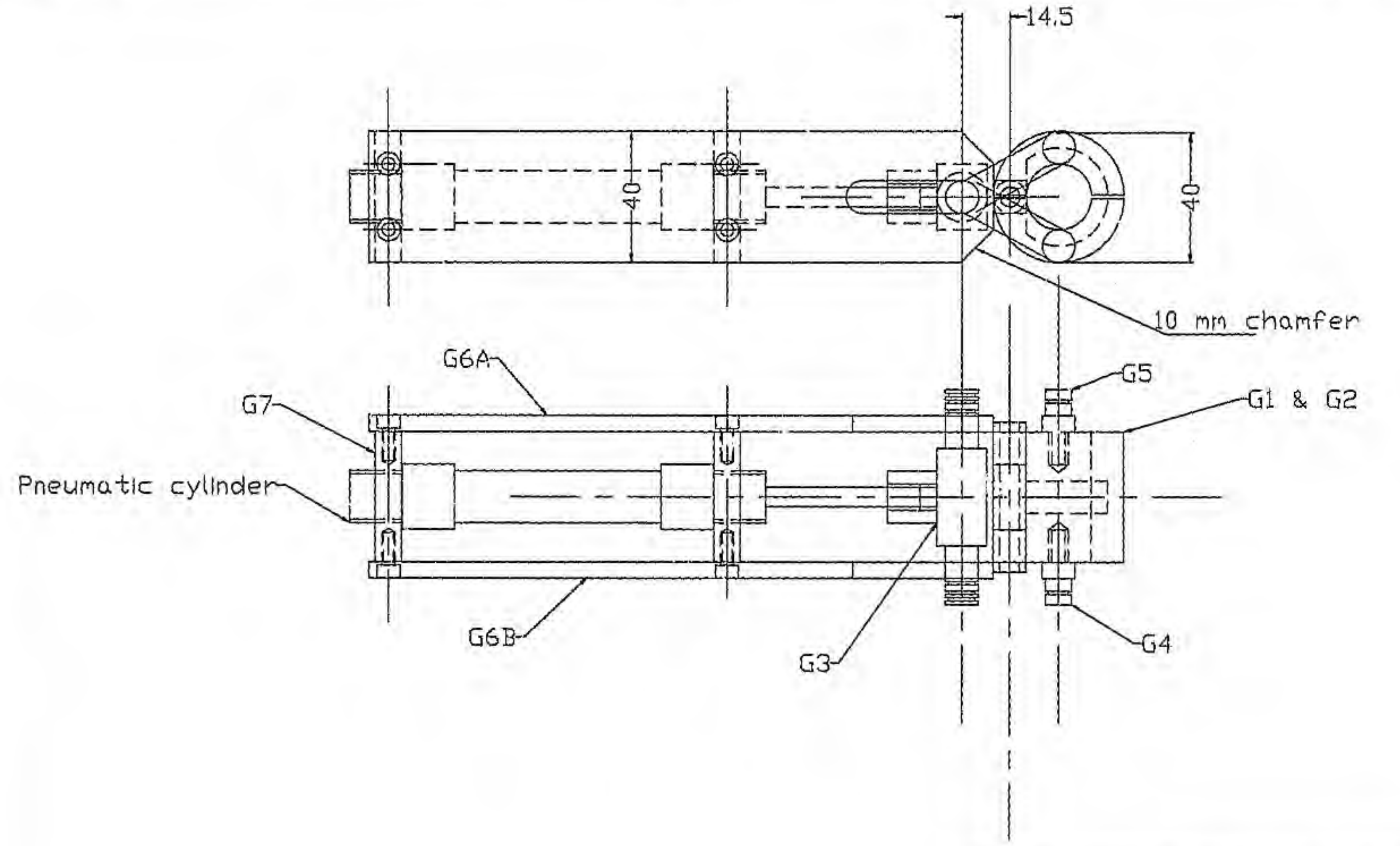
G2



1mm thick

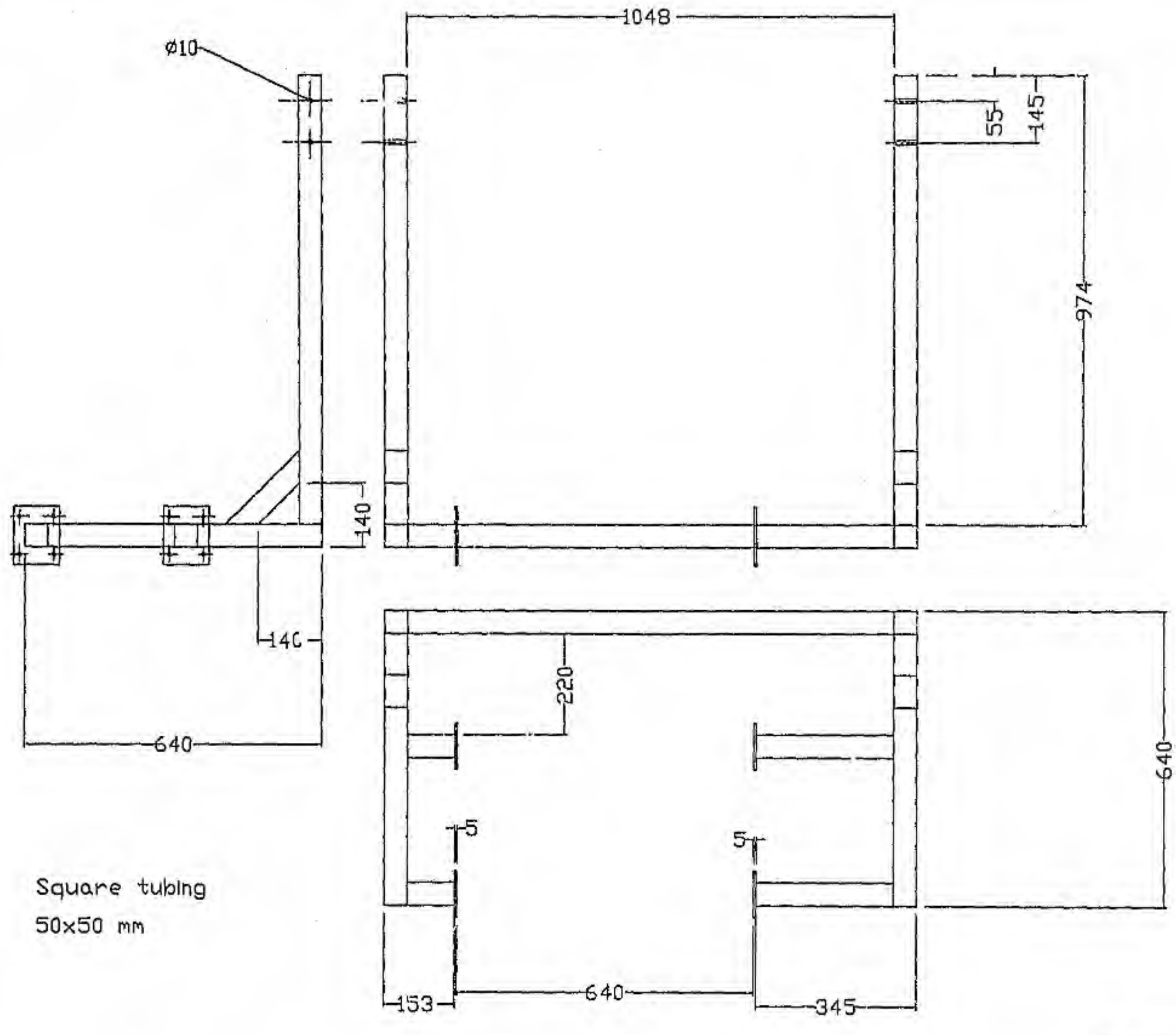
G8

Drawing of part's G1, G2 & G8				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Cursaro			ASRS-09
MATERIAL			QUANTITY	
PROJECTION				



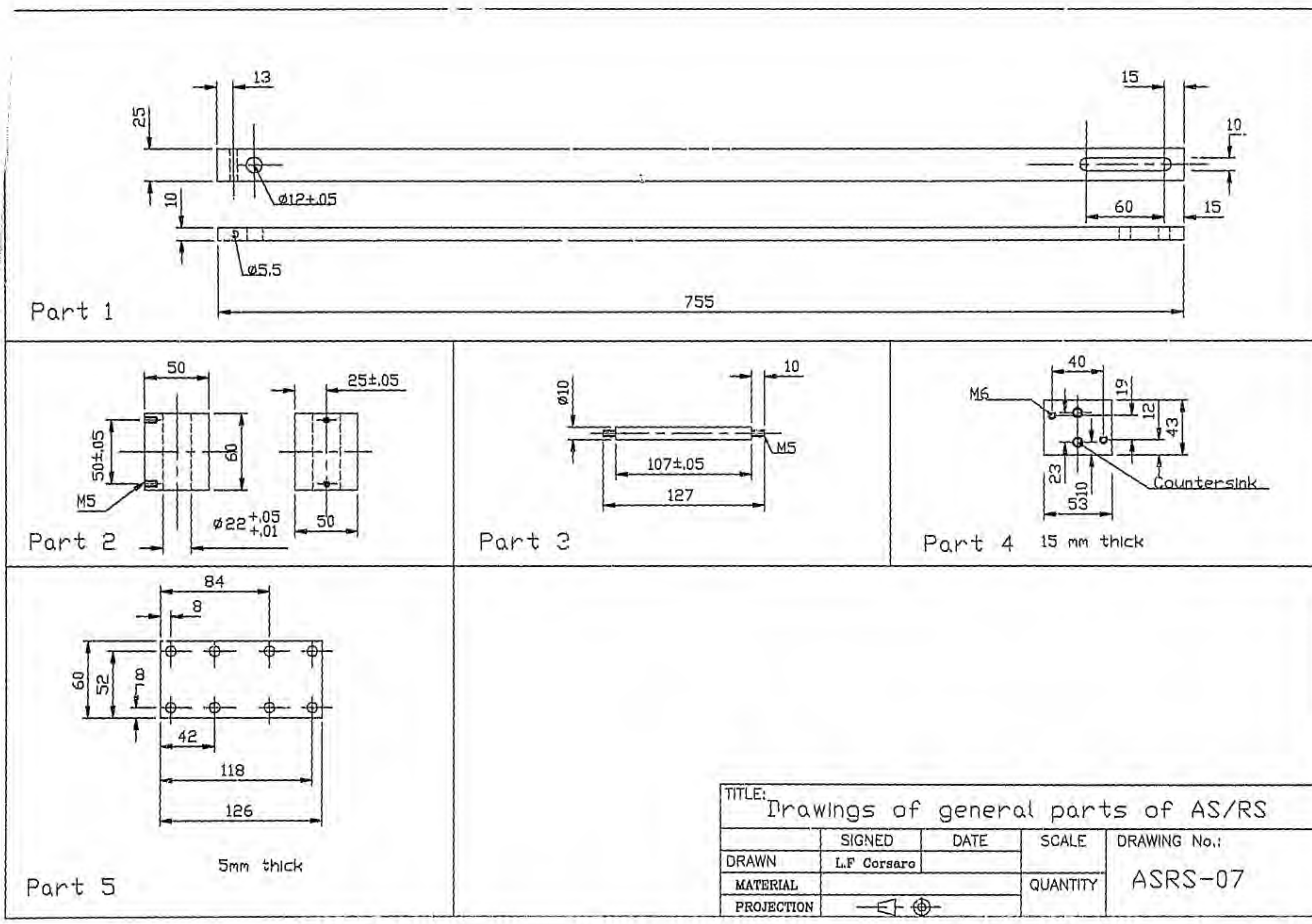
Assembly drawing of gripper.

	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			
MATERIAL			QUANTITY	ASRS-12
PROJECTION				

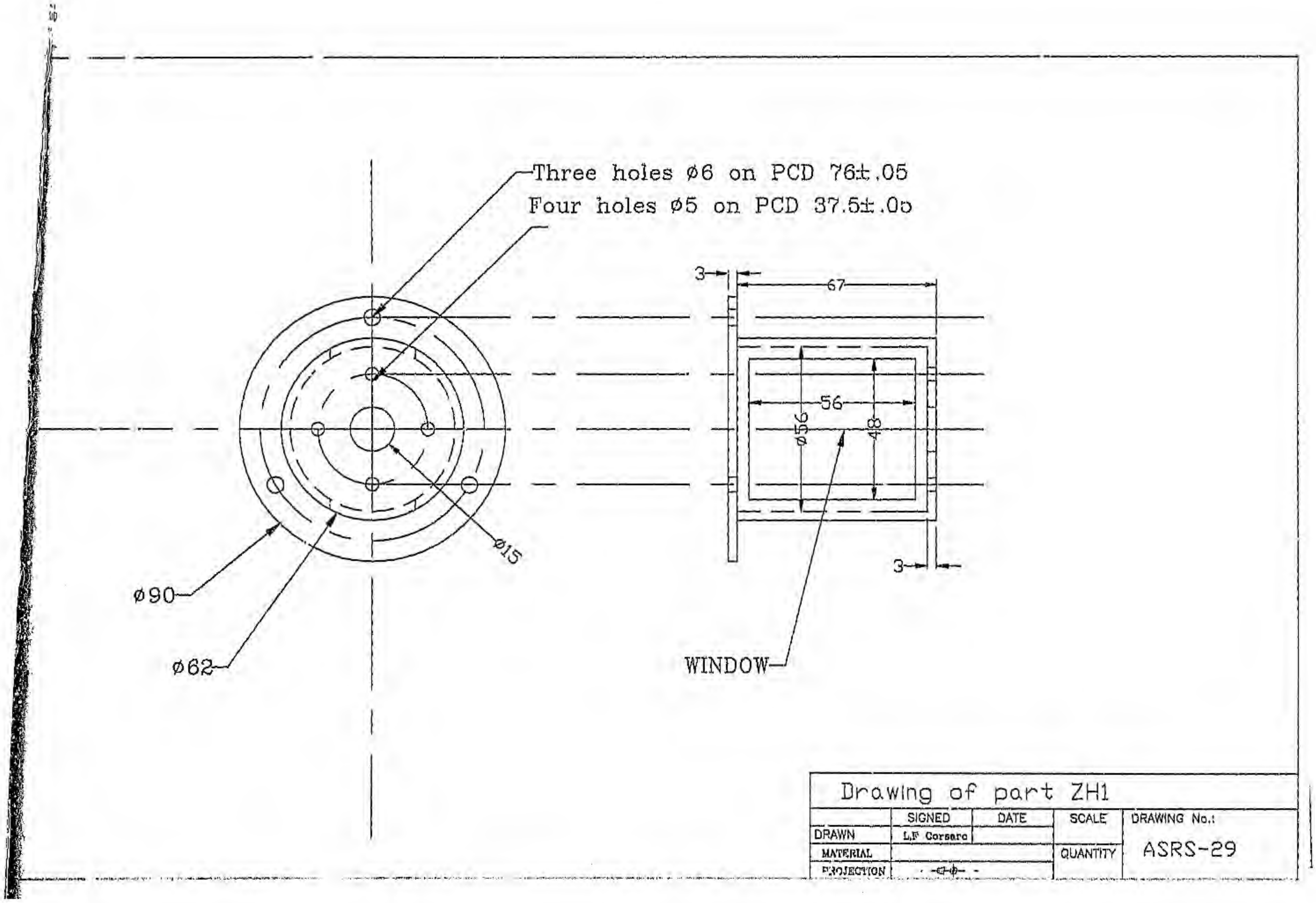


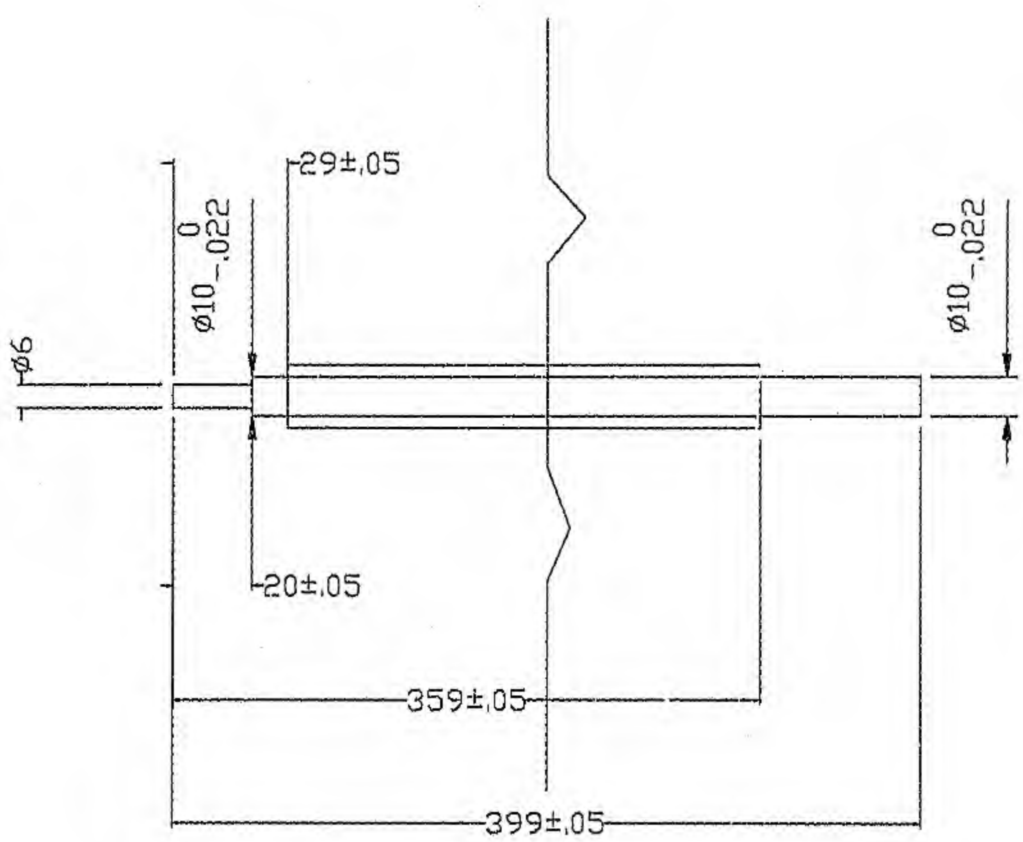
Drawing of supporting structure

	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	LF Corsaro	JAN 96		ASRS-08
MATERIAL	MILD STEEL		QUANTITY	
PROJECTION				



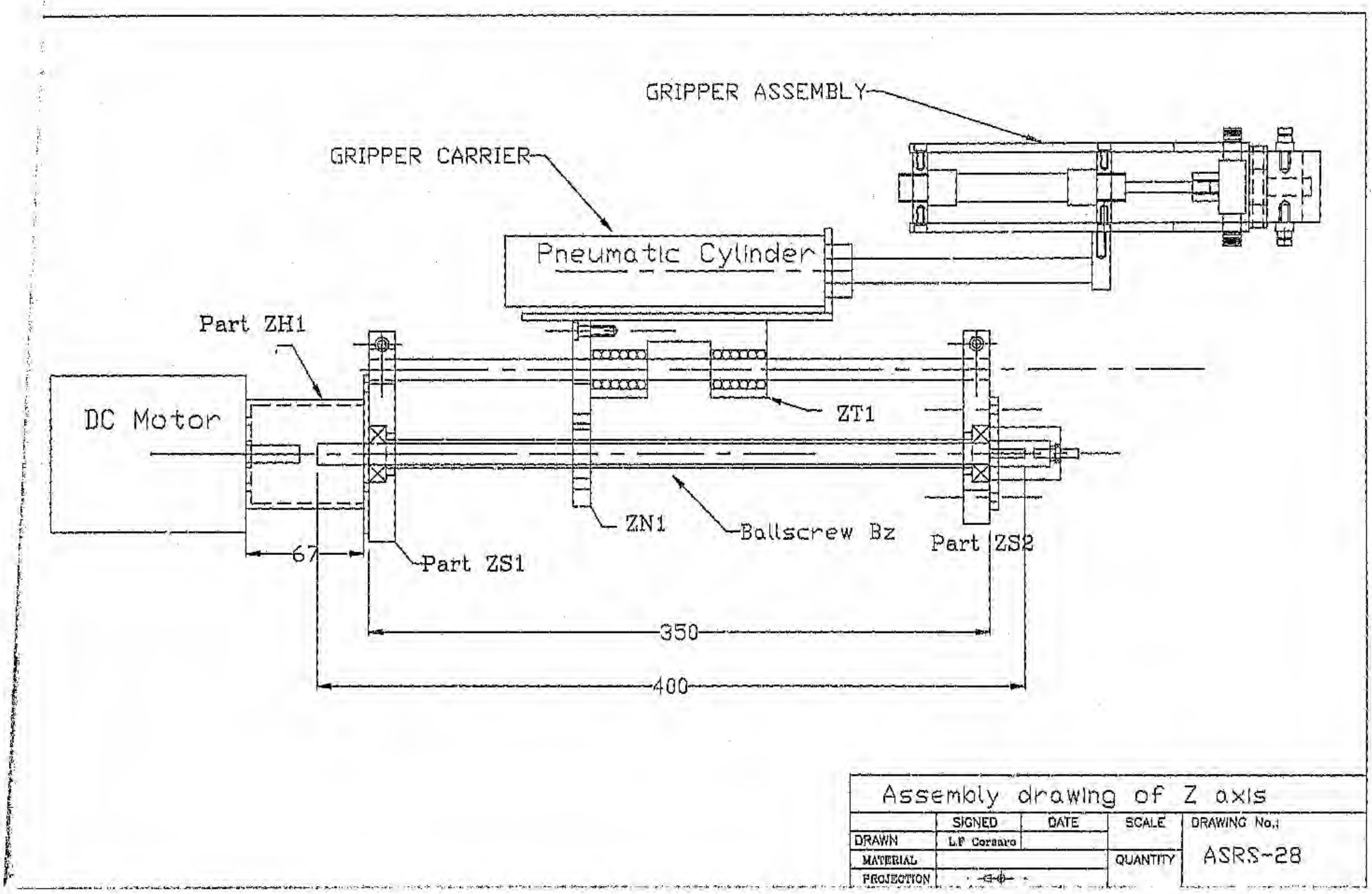
Part 1
13
15
25
10
10
ø12±.05
60
15
ø5.5
755
Part 2
50
25±.05
50±.05
60
M5
ø22 +.05 +.01
50
Part 3
ø10
10
M5
107±.05
127
Part 4
40
M6
19
12
43
23
10
53
Countersink
15 mm thick
Part 5
84
8
60
52
8
42
118
126
5mm thick
TITLE: Drawings of general parts of AS/RS
SIGNED
DATE
SCALE
DRAWING No.:
DRAWN
L.F Corsaro
MATERIAL
QUANTITY
ASRS-07
PROJECTION

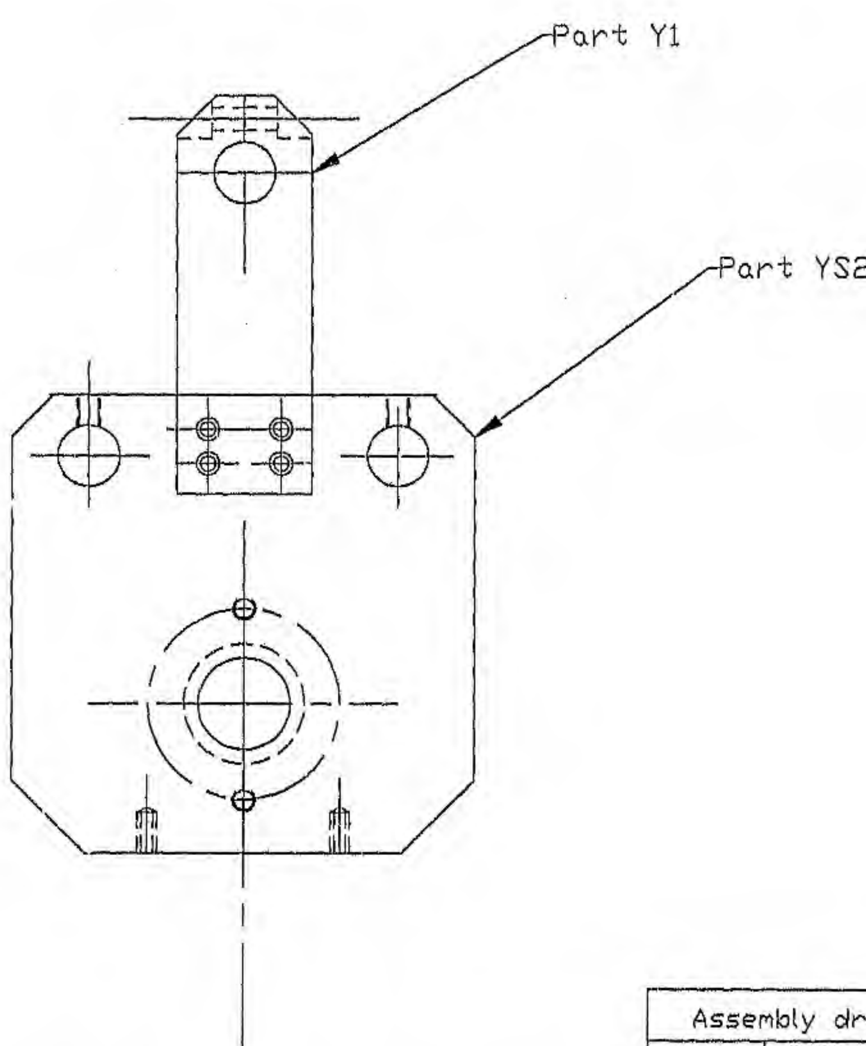

Three holes ø6 on PCD 76±.05
Four holes ø5 on PCD 37.5±.05
3
67
56
ø56
48
ø15
3
ø90
ø62
WINDOW
Drawing of part ZH1
SIGNED
DATE
SCALE
DRAWING No.:
DRAWN
L.F Corsaro
MATERIAL
QUANTITY
ASRS-29
PROJECTION



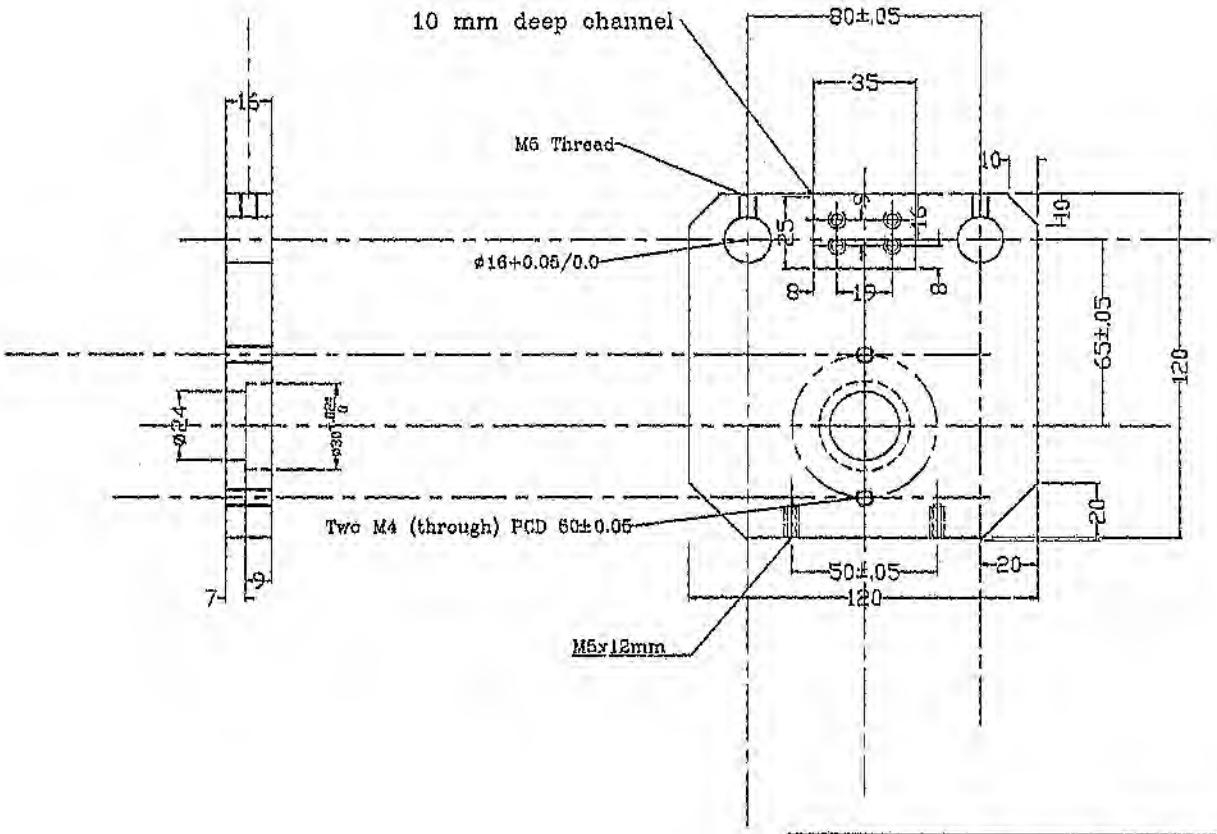
Drawing of ballscrew Bz.

	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-27
MATERIAL			QUANTITY	
PROJECTION				


GRIPPER ASSEMBLY
GRIPPER CARRIER
Pneumatic Cylinder
Part ZH1
DC Motor
ZT1
ZN1
Ballscrew Bz
Part ZS2
67
Part ZS1
350
400
Assembly drawing of Z axis
SIGNED
DATE
SCALE
DRAWING No.:
DRAWN
LF Corsaro
MATERIAL
QUANTITY
ASRS-28
PROJECTION

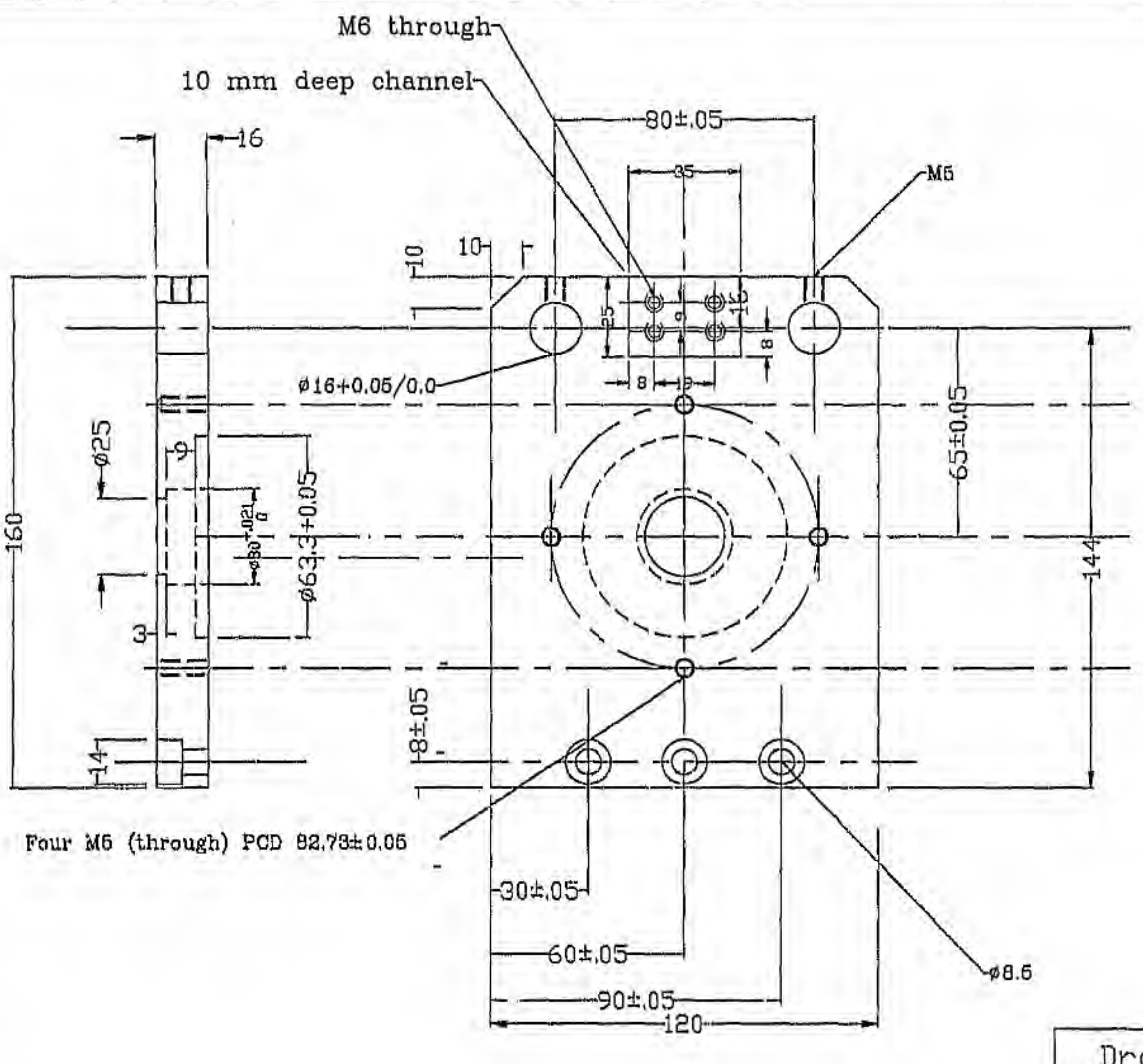


Assembly drawing of part Y1 with part YS2				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-26
MATERIAL			QUANTITY	
PROJECTION				

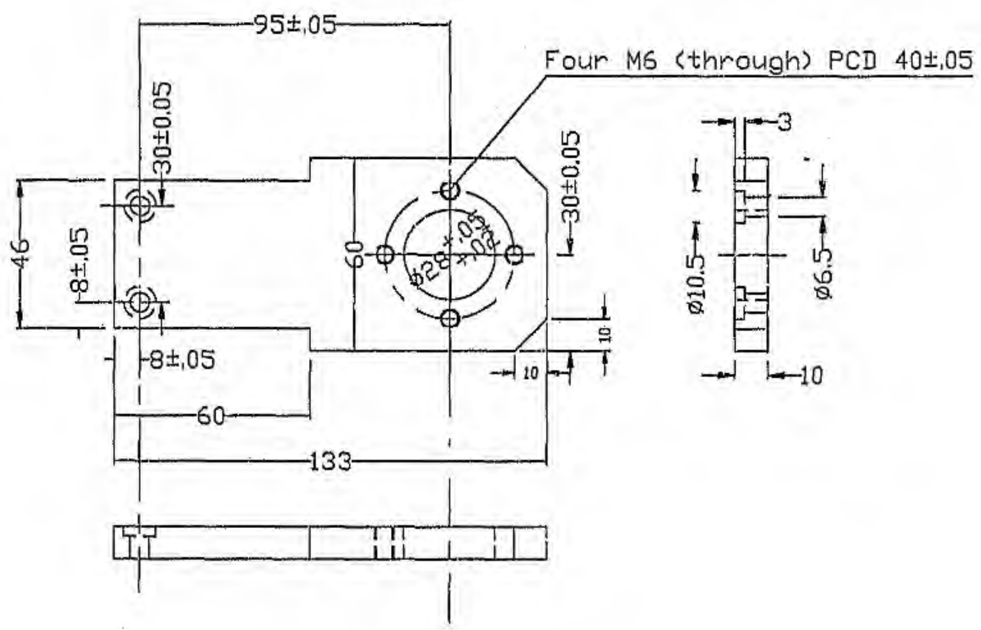


Drawing of part YS2

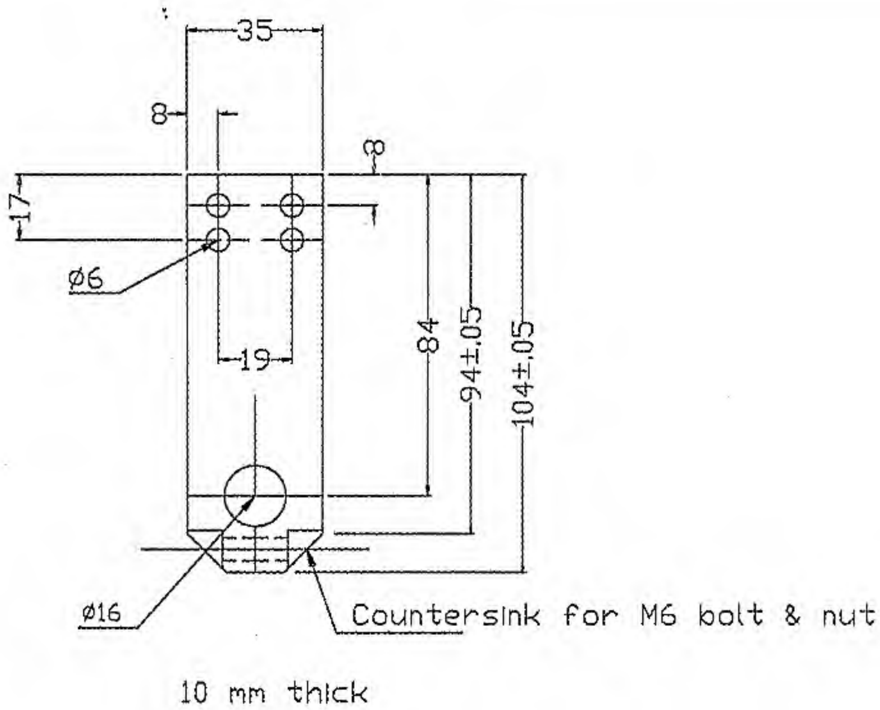
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-25
MATERIAL			QUANTITY	
PROJECTION				



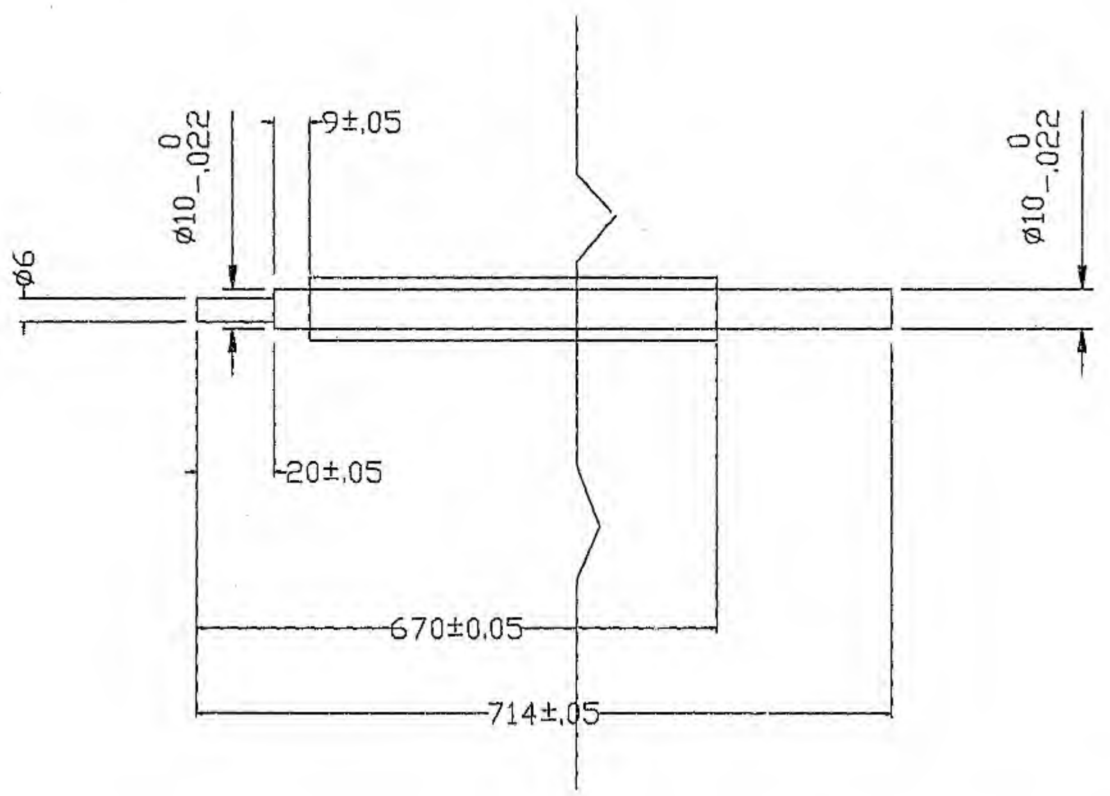
Drawing of part YS1				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-24
MATERIAL			QUANTITY	
PROJECTION				



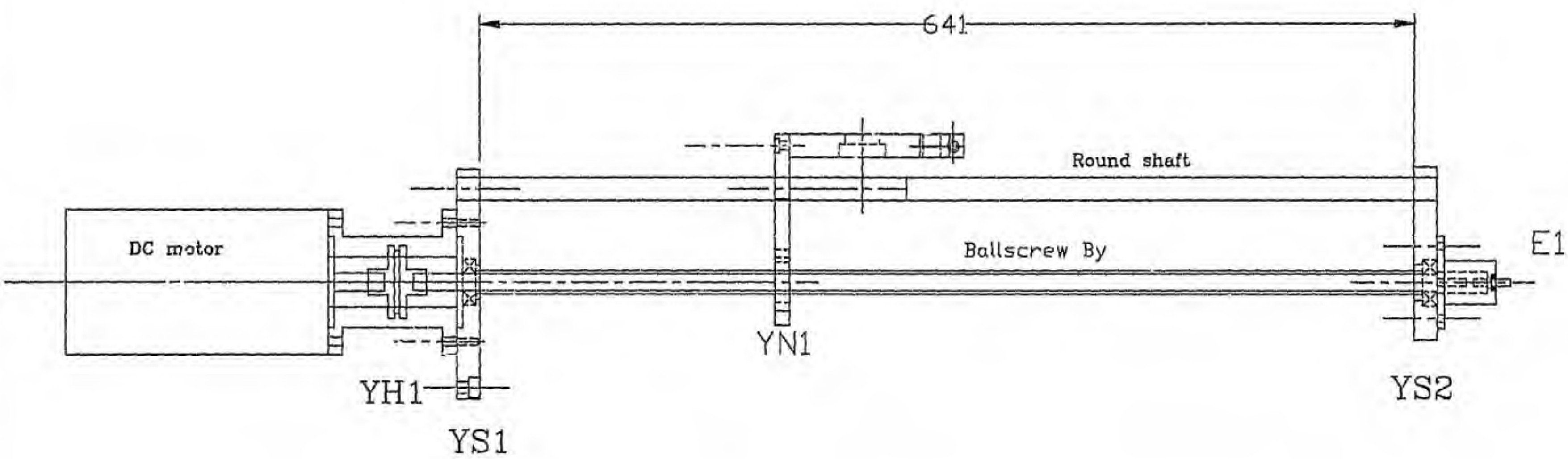
Drawing of part YN1				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-23
MATERIAL			QUANTITY	
PROJECTION				



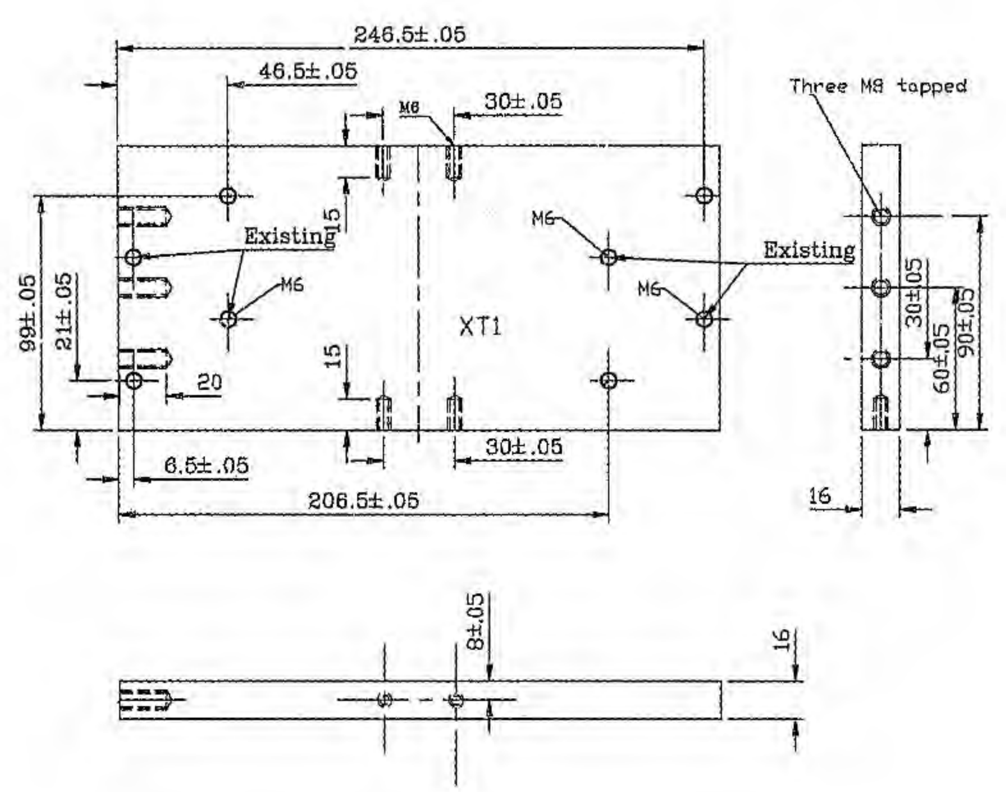
Drawing of part Y1				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-21
MATERIAL			QUANTITY	
PROJECTION				



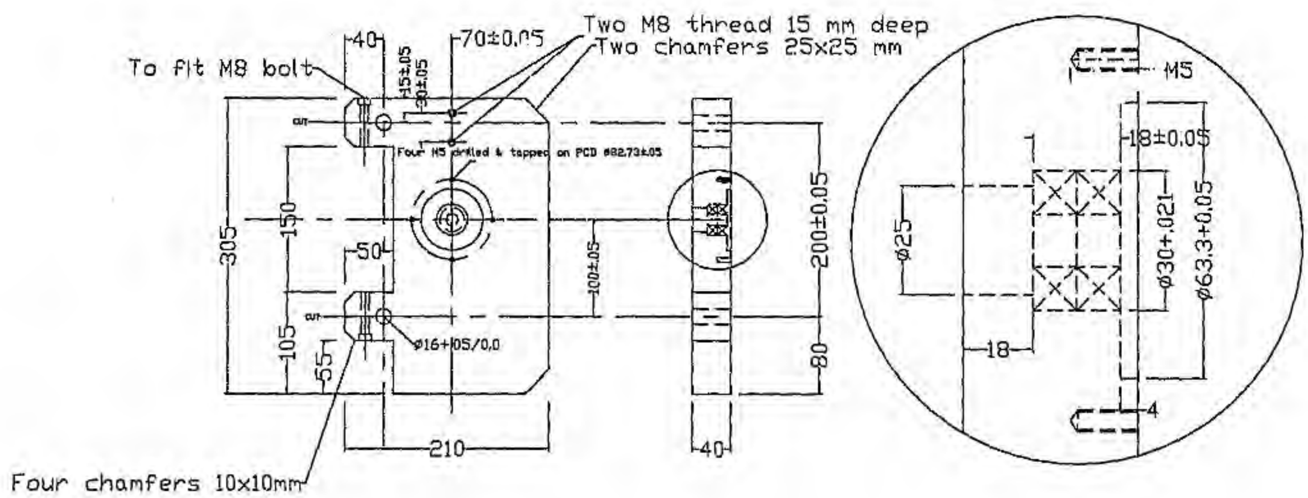
Drawing of ballscrew By				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-20
MATERIAL			QUANTITY	
PROJECTION				



Assembly drawing of Y axis				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-22
MATERIAL			QUANTITY	
PROJECTION				



TITLE: Drawing of part XT1				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	LF Corsaro	JAN 95		ASRS-19
MATERIAL			QUANTITY	
PROJECTION				



Drawing of part XS2

	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-18
MATERIAL			QUANTITY	
PROJECTION				

```
Procedure Set_Encoder;

Begin
    x1:=0;
    x2:=0;
    x3:=0;
    Port[base+0]:=$1;
    Port[base+1]:=$1;
    Port[base+2]:=$1;
    Port[base+3]:=$0;
    Port[base+4]:=$0;
    Port[base+5]:=$0;
    Port[base+6]:=$7;
    Port[base+7]:=$7;
    Port[base+8]:=$2;
End;

procedure GET_value;

begin
 x1 := Inreg[3]*65536+Inreg[2]*256+Inreg[1];
 x2 := Inreg[6]*65536+Inreg[5]*256+Inreg[4];
 x3 := Inreg[9]*65536+Inreg[8]*256+Inreg[7];
END;

PROCEDURE SHOW_VALUE;

BEGIN
 change_value(10,11,15,x1);
 change_value(10,12,15,x2);
 change_value(10,13,15,x3);
end;

begin
   clrscr;
   Inreg[1]:=0;
   Inreg[2]:=0;
   Inreg[3]:=0;
   Inreg[4]:=0;
   Inreg[5]:=0;
   Inreg[6]:=0;
   Inreg[7]:=0;
   Inreg[8]:=0;
   Inreg[9]:=0;
   x1:=0;
   x2:=0;
   x3:=0;
   SET_ENCODER;
   DELAY(1000);
   set_encoder;
   repeat
       begin
       read_rotary;
       get_value;
       show_value;
       end;
   until keypressed;

end.
```

```
PROGRAM Rotary (input,output);

USES dos,crt;


var
  Inreg          :array[1..16] of longint;
  x1,x2,x3              : longint;


const

base  = $200;

PROCEDURE Change_Value (xx,
                yy,
                box_width : INTEGER;
                value: REAL);
VAR
 digits: INTEGER;
BEGIN
 Gotoxy (xx+1,yy+2);
 WRITE (' ':box_width-2);
 IF (ABS(value) < 5E-3)
   THEN
    digits .= 0
   ELSE
    digits := TRUNC (LN(ABS(value))/LN(10)) + 1;
 Gotoxy (xx+((box_width-(digits+3)) DIV 2), yy+2);
 WRITE (value:(digits+3):2);
END;

Procedure Read_Rotary;

Begin

Inreg[3] := Port[base+2];
Inreg[2] := Port[base+1];
Inreg[1] := Port[base];

Inreg[6] := Port[base+6];
Inreg[5] := Port[base+5];
Inreg[4] := Port[base+4];

Inreg[9] := Port[base+10];
Inreg[8] := Port[base+9];
Inreg[7] := Port[base+8];
End;
```

Program air;

```
uses
crt;

var
s,a :Integer;

const

base=$390;

begin
port[base+3]:=128;

repeat
        writeln('Inpust s= ');
        readln(s);
        port[base+2]:=s;
        writeln('a ');
        readln(a);
        until a=1;
end.
```

Program Linput (input,output);

```
uses crt;
var

s, a: integer;

Const

base=$310;

begin
a:=0;
repeat
port[base+3]:=137;
a:=port[base+2];
write('a= ',a);
delay(100);
until keypressed;
readln
end.
```

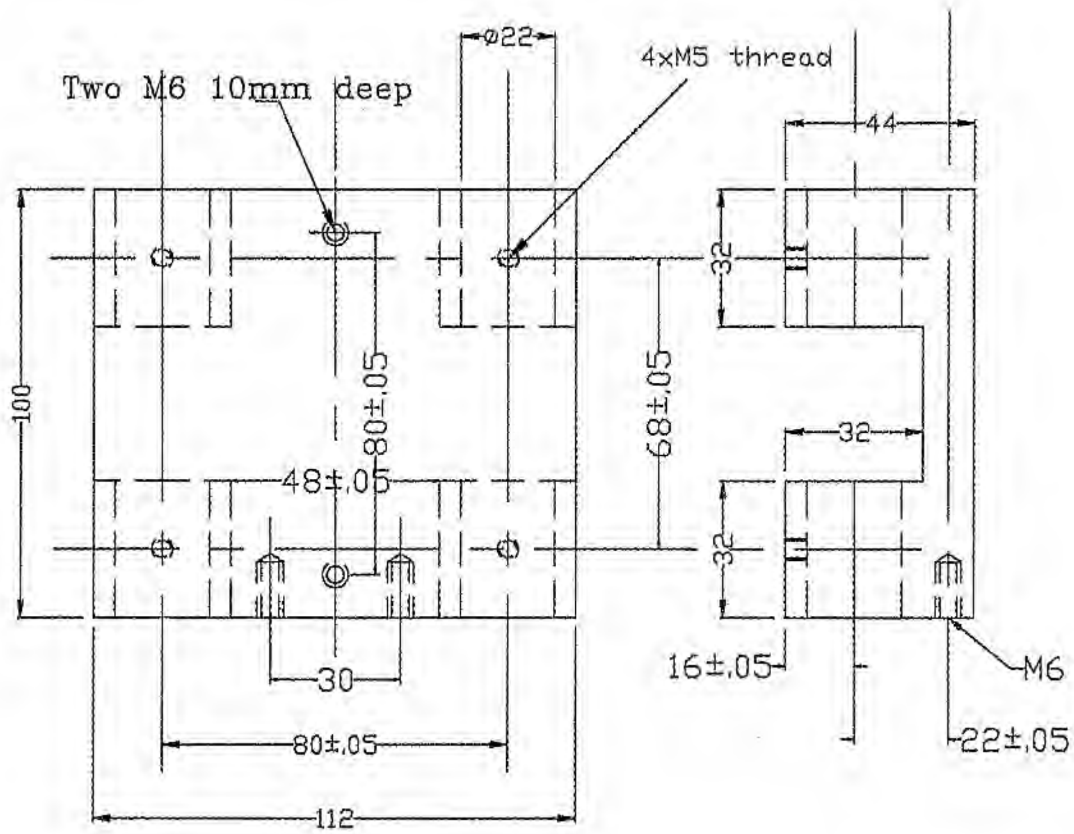
Program PC362 (Input,output);

```
var

s, a: Integer;

Const

base=$310;

begin
repeat
a:=0;
port[base+3]:=128;
write('S value = ');
readln(s);
port[base]:=s;
write('a= ');
readln(a);
until a=1;
end.
```

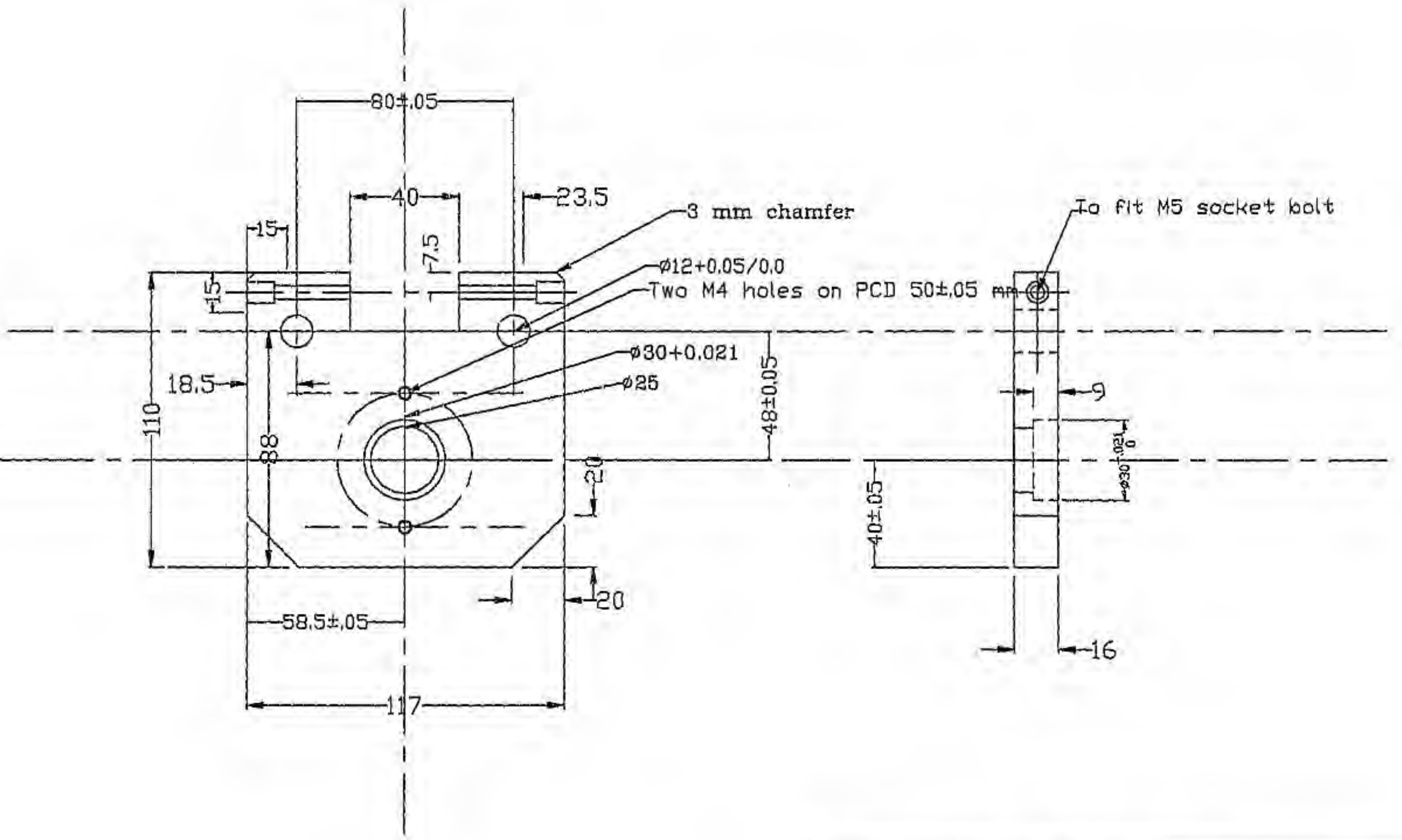
```
Program PC36y (input,output);

var

s, a: integer;

Const

base=$310;

begin
repeat
a:=0;
port[base+3]:=128;
write('S value = ');
readln(s);
port[base+1]:=s;
write('a= ');
readln(a);
until a=1;
end.
```

```
Program PC36x (input,output);

var

s, a: integer;

Const

base=$390;

begin
repeat
        a:=0;
        port[base+3]:=128;
        write('S value = ');
        readln(s);
        port[base]:=s;
        write('a= ');
        readln(a);
until a=1;
end.
```

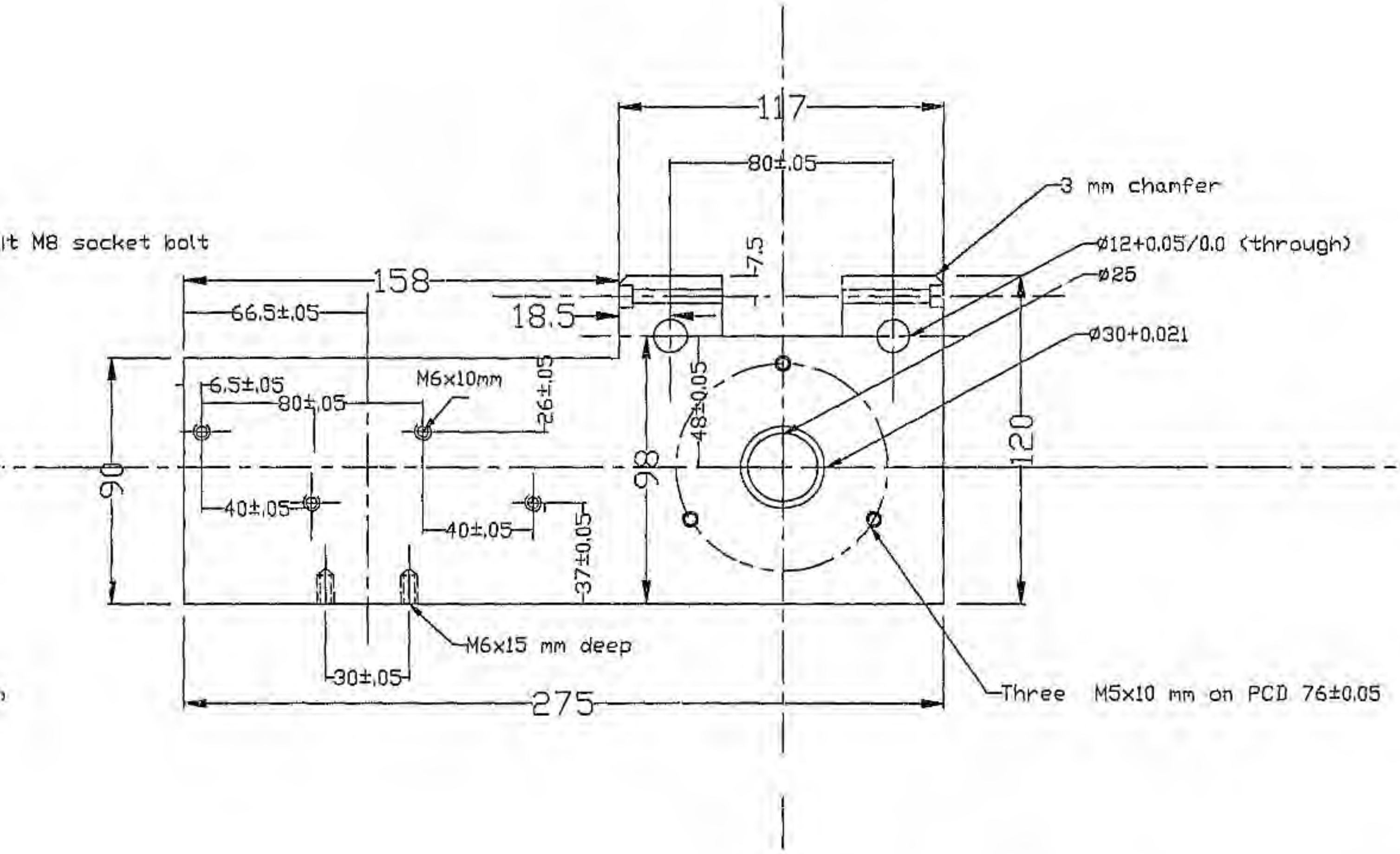
Appendix B Program Listing.



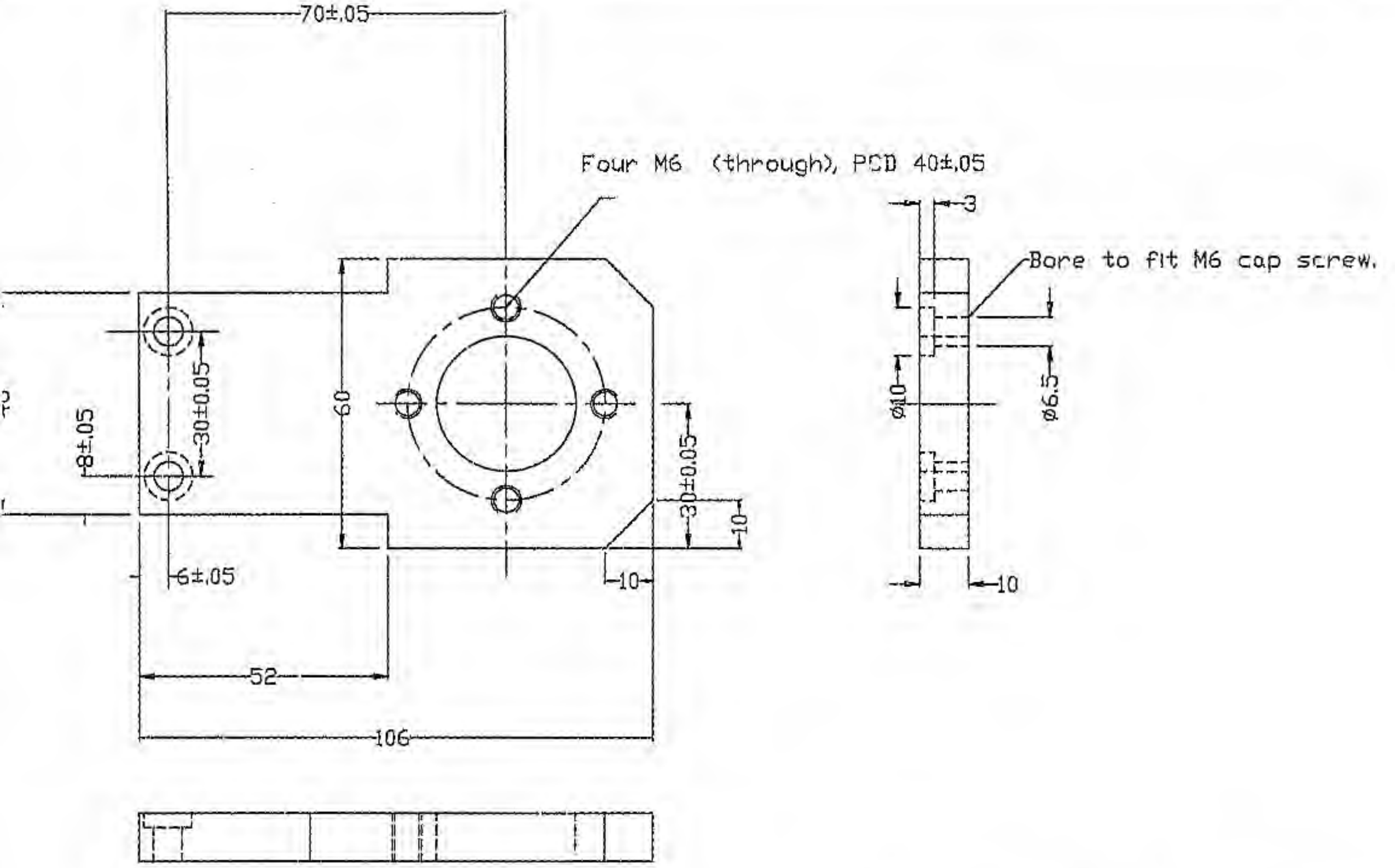
Drawing of part ZT1				
	SIGNED	DATE	SCALE	DRAWING Nc
DRAWN	L.F Corsaro			ASRS-
MATERIAL			QUANTITY	
PROJECTION				



Drawing of part ZS2				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-32
MATERIAL			QUANTITY	
PROJECTION				



Drawing of part ZS1				
	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			
MATERIAL			QUANTITY	ASRS-31
PROJECTION				



Drawing of part ZN1

	SIGNED	DATE	SCALE	DRAWING No.:
DRAWN	L.F Corsaro			ASRS-30
MATERIAL			QUANTITY	
PROJECTION				

```
If dirz='ccw' then
   begin
   vz:=22;
    end;
If vz>=0 then
zmotor;

until (posz=true);
vz:=0;
zmotor;
end;



begin
    start;
    clrscr;
    front_page;
    setup;
    vy:=0;
    Vx:=31;
    vz:=0;
    x0:=0;
    y0:=0;
    z0:=0;
    dx:=0;
    dy:=0;
    dz:=0;
    start;
    xmotor;
    ymotor;
    zmotor;
    start;

    repeat
    return_home;
    until homepos=true;
    start;
    setup;
    count:=0;
    Extend:=false;
    grip:=false;
    If (extend=false) and (grip=false) then
    port[base+2]:=0;
    pallet_choice;
  repeat
    IF (CHOICE='A') OR (CHOICE='a') THEN count:=count+1
    ELSE COUNT:=0;
    pallet_address;
    xaxis;
    yaxis;
    zaxis;
   If (grip=true) and (extend=true)then
     BEGIN
     port[base+2]:=1;
     DELAY(1000);
     END;
   If (grip=true) and (extend=false)then
      BEGIN
      port[base+2]:=2;
      DELAY(1000);
      END;
   If (grip=false) and (extend=true)then
```

```
storevalue,dz :longint;
dirz : string;
posz :boolean;

begin
z0:=0;
Read_rotary;
Get_value;
show_value;
if x3>204800 then x3:=0;
z0:=x3;
screen_write(message,'Busy...');
pallet_address;
dz:=round(z/50*512);
posz:=false;
repeat
  input:=port[base1+2];
  Read_rotary;
  get_value;
  Show_value;
  if x3>204800 then x3:=0;
  change_z:=x3-z0;
  change_z:=round((change_z/512)*50);
  change_dz:=dz-x3;
  change_dz:=round ((change_dz/512)*50);
  Read_rotary;
  get_value;
  Show_value;

 if (change_dz<0-50) then
          begin
            dirz :='cw';
            posz:=false;
          end;
 if (change_dz>0+50) then
          begin
            dirz:='ccw';
            posz:=false;
          end;
 if (change_dz<0+50) and (change_dz>0-50) then
          begin
            posz:=true;
            vz:=0;
          end;
if x3<2000 then begin
if (change_dz<0+200) and (change_dz>0-200) then
begin
case input of
88,72,104,8,12,40,44,24,28 : begin
                        posz:=true;
                        vz:=0;
                        x3:=0;
                        end;
end;
end;
end;

if (dirz='cw')and (posz=false) then
  begin
  vz:=53;
  end;
```

```
If (change_dy<-10) then
         begin
           diry :='cw';
           posy :=false;
         end;
If (change_dy>10) then
          begin
           diry:='ccw';
           posy :=false;
          end;
If (change_dy<=10) and (change_dy>=-10) then
         begin
           posy :=true;
           vy:=0;
         end;

If x2<600 then
begin
if (change_dy<0+150) and (change_dy>0-150) then
begin
case Input of
88,72,104,80,82,64,96,66,98 : begin
                              posy :=true;
                              vy:=0;
                              x2:=0;
                              end;
end;
end;
end;

If (diry='cw') and (posy=false)then
   pegin
    If (abs(change_y)<=1000)  then Vy:=10;
    If (abs(change_y)>1000) and (abs(change_dy)>=1000) then Vy:=30;
    If (abs(change_dy)<500) and (abs(change_dy)>300)and (abs(change_y)>200) then Vy:=20;
    If (abs(change_dy)<200) and (abs(change_y)>1000) then Vy:=8;
    If (abs(change_y)<1000) and (abs(change_dy)<1000) then Vy:=8;
   end;

If diry='ccw' then
   begin

    If abs(change_y)<=500 then Vy:=50;
    If (abs(change_y)>1000) and (abs(change_dy)>=1000) then Vy:=60;
    If (abs(change_dy)<600) and (abs(change_y)>500) then Vy:=39;
    If (abs(change_dy)<500) and (abs(change_y)>500) and (increasey=true) then Vy:=42;
    If (abs(change_y)<500) and (abs(change_dy)<600) then Vy:=40;
   und;
If vy>=0 then

ymotor;
until (posy=true);
vy:=0;
ymotor;
Read_rotary;
get_value;
Show_value;
end;

Procedure zaxis;

var
```

```
  if (abs(change_x)<500) and (abs(change_dx)<500) then Vx:=40;
  end;
If vx>=0 then
xmotor;
Increasex:=false;
until (pos=true);
vx:=31;
xmotor;
end;

Procedure yaxis;

var


diry : string;
posy,increasey:boolean;

begin
y0:=0;
cy:=0;
dy:=0;
increasey:=false;
Input:=port[base1+2];
Read_rotary;
Get_value;
show_value;
If x2>204800 then x2:=0;
y0:=x2;
screen_write(message,'Busy...');
pallet_address;
dy:=round(y/50*512);
posy:=false;
b:=0;
c:=0;
cy:=0;
repeat
  Input:=port[base1+2];
  b:=x2;
  Read_rotary;
  get_value;
  Show_value;
  Read_rotary;
  get_value;
  Show_value;
  Read_rotary;
  get_value;
  Show_value;
  Read_rotary;
  get_value;
  Show_value;
  Read_rotary;
  get_value;
  Show_value;
  c:=x2;
  if x2>504800 then x2:=0;
  change_y:=x2-y0;
  change_y:=round((change_y/512)*50);
  change_dy:=dy-x2;
  cy:=abs(c)-abs(b);
  if (b<>c) then increasey:=false else increasey:=true;
  change_dy:=round ((change_dy/512)*50);
```

```
repeat
  input:=port[base1+2];
  Read_rotary;
  get_value;
  Show_value;
  If x1>204800 then x1:=0;
  change_x:=x1-x0;
  change_x:=round((change_x/512)*50);
  a:=change_dx;
  change_dx:=dx-x1;
  cx:=change_dx-a;
  If cx=0 then increasex:=true;
  change_dx:=round ((change_dx/512)*50);
  Read_rotary;
  get_value;
  Show_value;
  If (change_dx<0-10) then
         begin
           dirx :='cw';
           pos :=false;
         end;
 If (change_dx>0+10) then
         begin
           dirx:='c
           pos :=false;
         end;
 If (change_dx<0+10) and (change_dx>0-10) then
         begin
           pos :=true;
           vx:=31;
         end;
If x1<300 then
begin
If (change_dx<0+150) and (change_dx>0-150) then

begin
case input of

88,16,18,20,22,80,82,24,28 : begin
                   pos :=true;
                   vx:=31;
                   x1:=0;
                   end;
end;
end;
end;

If (dirx='cw') and (pos=false) then
  begin
   If (abs(change_x)<=1000)  then Vx:=10;
   If (abs(change_x)>1000) and (abs(change_dx)>=600) then Vx:=30;
   If (abs(change_dx)<500) and (abs(change_dx)>300)and (abs(change_x)>200) then Vx:=20;
   If (abs(change_dx)<200) and (abs(change_x)>1000) then Vx:=10;
   If (abs(change_x)<1000) and (abs(change_dx)<1000) then Vx:=10;
  end;

If dirx='ccw' then
  begin
   If abs(change_x)<=500 then Vx:=43;
   If (abs(change_x)>500) and (abs(change_dx)>=500) then Vx:=60;

   If (abs(change_dx)<500) and (abs(change_x)>500) then Vx:=38;
   If ((abs(change_dx)<500) and (abs(change_x)>500) and) (increasex=true) then Vx:=42;
```

```
8 ,12,40,44 : begin
          Vx:=8;
          vy:=10;
          Vz:=0;
          end;

0,2,4,32,36,38,34,6 : begin
                    Vx:=8;
                    vy:=10;
                    Vz:=52;
                    end;
16,18,20,22 :  begin
           Vx:=0;
           vy:=10;
           Vz:=52;
           end;

80,82 :  begin
       Vx:=0;
       vy:=0;
       Vz:=52;
       end;

64,96,66,98 :  begin
          Vx:=8;
          Vy:=0;
          Vz:=52;
          end;

24,28 :  begin
     Vx:=0;
     vy:=10;
     Vz:=0;
     end;
end;
zmotor;
ymotor;
xmotor;
end;

Procedure xaxis;

var

a :longint;
dirx : string;
pos,increasex :boolean;

begin
x0:=0;
increasex:=false;
input:=port[base1+2];
Read_rotary;
Get_value;
show_value;
if x1>204800 then x1:=0;
x0:=x1;
screen_write (message,'Busy....');
pallet_address;
delay(100);
dx:=round(x/50*512);
pos:=false;
a:=0;
```

```
PROCEDURE start;

begin

   clrscr;
   inreg[1].=0;
   inreg[2]:=0;
   inreg[3]:=0;
   inreg[4]:=0;
   inreg[5]:=0;
   inreg[6]:=0;
   inreg[7]:=0;
   inreg[8]:=0;
   inreg[9]:=0;
   x0:=0;
   y0:=0;
   z0:=0;
   x1:=0;
   x2:=0;
   x3:=0;

   change_x:= 0;
   change_y:= 0;
   change_z:= 0;

   change_dx:= 0;
   change_dy:= 0;
   change_dz:= 0;

   port[base+3]:=128;
   port[base1+3]:=137;
   Port[base1+3]:=137;

   SET_ENCODER;
   DELAY(1000);
   set_encoder;
end;

Procedure Return_home;

begin

input :=port[base1+2];

homepos:=false;
case input of

88 :  begin
      Vx:=0;
      vy:=0;
      Vz:=0;
      homepos:=true;
      end;

72,104:  begin
      Vx:=8;
      vy:=0;
      Vz:=0;
      end;
```

```
Procedure Set_Encoder;

Begin
   x1:=0;
   x2:=0;
   x3:=0;
   x0:=0;
   Port[baser+0]:=$1;
   Port[baser+1]:=$1;
   Port[baser+2]:=$1;
   Port[baser+3]:=$0;
   Port[baser+4]:=$0;
   Port[baser+5]:=$0;
   Port[baser+6]:=$7;
   Port[baser+7]:=$7;
   Port[baser+8]:=$2;
End;

procedure GET_value;

begin
 x1 := inreg[3]*65536+inreg[2]*256+inreg[1];
 x2 := inreg[6]*65536+inreg[5]*256+inreg[4];
 x3 := inreg[9]*65536+inreg[8]*256+inreg[7];
END;

PROCEDURE SHOW_VALUE;

BEGIN
 change_value(5,11,5,'x1= ',x1);
 change_value(30,11,5,'x2= ',x2);
 change_value(55,11,5,'x3= ',x3);

 change_value(5,12,5,'Vx= ',vx);
 change_value(30,12,5,'Vy= ',vy);
 change_value(55,12,5,'Vz= ',vz);

 Change_value(5,13,5,'change_x= ',change_x);
 Change_value(30,13,5,'change_y= ',change_y);
 change_value(55,13,5,'change_z= ',change_z);

 Change_value(5,14,5,'change_dx= ',change_dx);
 Change_value(30,14,5,'change_dy= ',change_dy);
 change_value(55,14,5,'change_dz= ',change_dz);

  Change_value(5,15,5,'x0= ',x0);
  change_value(5,16,5,'input= ',input);
 Change_value(30,15,5,'y0= ',y0);
 Change_value(30,16,5,'cy= ',cy);
 change_value(55,15,5,'z0= ',z0);
end;
```

```
    until err=false;
    screen_write(message,'');
end;


procedure Xmotor;

begin

   Port[base]:=Vx;
end;

Procedure Ymotor;

begin

    port[base1+1]:=vy;
end;

Procedure Zmotor;

begin

    port[base1]:=vz;
end;


PROCEDURE Change_Value (xx,
                 yy,
                 box_width : INTEGER;chr:string;
                 value: REAL);
VAR
 digits: INTEGER;
BEGIN
 Gotoxy (xx+1,yy+2);
 WRITE (' ':box_width-2);
 IF (ABS(value) < 5E-3)
  THEN
   digits := 0
  ELSE
   digits := TRUNC (LN(ABS(value))/LN(10)) + 1;
 Gotoxy (xx+((box_width-(digits+3)) DIV 2), yy+2);
 write(chr);
 WRITE (value:(digits+3):2);
END;

Procedure Read_Rotary;

Begin

Inreg[3] := Port[baser+2];
Inreg[2] := Port[baser+1];
Inreg[1] := Port[baser];

Inreg[6] := Port[baser+6];
Inreg[5] := Port[baser+5];
Inreg[4] := Port[baser+4];

Inreg[9] := Port[baser+10];
Inreg[8] := Port[baser+9];
Inreg[7] := Port[baser+8];

End;
```

```
Procedure Pallet_address;

var

filevar1                : text;
extension,gripper       : char;
err                     : boolean;

begin
   IF COUNT=0 THEN
   filename:=filename;
   if count=1 then
   filename:=f;
   if count=2 then
   filename:=f1;
   if count=3 then
   filename:=f2;
   if count=4 then
   filename:=f3;
   if count=5 then
   filename:=f4;
   repeat
   err:=false;
   assign(filevar1,filename);
   reset(filevar1);
   while not eof(filevar1) do
     begin
      readln(filevar1,x);
      readln(filevar1,y);
      readln(filevar1,z);
      readln(filevar1,extension);
      readln(filevar1,gripper);

      case extension of
       'e','E' : extend :=true;
       'r','R' : extend :=false;
       end;

       case gripper of
       'y','Y' : grip :=true;
       'n','N' : grip :=false;
       end;

       if dx>80896 then begin
             screen_write(message,'Error 1'); {Exceeds max x stroke}
             err:=true;
             end;
       if dx<0 then begin
             screen_write(message,'Error 2');  {negative distance}
             err:=true;
             end;
  If (dy<0) then begin
          screen_write (message,'Error 4'); {negative y stroke}
           Err:=true;
           end;
  If (dz>1200) then begin
              screen_write(message,'Error 8'); {Exceeds maximum z stroke}
              err:=true;
              end;

  end;
   close(filevar1);
```

```
 WRITE ('Press any key to continue ....');
 Restore;
 ch := READKEY;
END;

PROCEDURE Setup; {Sets up the main screen}

BEGIN
 restore;
        Screen_Setup ('Command', 'Message');
        Screen_Clear (Main);
 Bold;
 Screen_Write (Main, '3001AS/RS PROGRAM');
 Restore;
END;

Procedure Automatic_pallet;

var

filevar2          : text;
extension,gripper  : char;
err               : boolean;


begin
   ASSIGN(FILEVAR2,filename2);
   reset(filevar2);
   while not eof(filevar2) do
   begin
   readln(filevar2,f);
   readln(filevar2,f1);
   readln(filevar2,f2);
   readln(filevar2,f3);
   readln(filevar2,f4);
   end;

   close(filevar2);
  end;

Procedure pallet_choice;

begin

screen_write (message,'');
screen_write (command,'Would you like a manual or automatic retrieval ? [A/M] ');
readln (choice);
case choice of
'm','M' : begin
        screen_write(message,'');
        screen_write(command,'Enter the pallet filename ');
        readln (filename);
        end;
'a','A' : begin
        screen_write(message,'');
        screen_write(command,'Enter the pallet filename ');
        readln(filename2);
        automatic_pallet;
        end;
end;
end;
```

Program ASRS (input,output);

```
uses crt,dos,library;

var

s,s1, a,count                   : integer;
Inreg                           : array[1..16] of longint;
x1,x2,x3,x0,y0,z0               : longint;
vx                              : integer;
vy                              : integer;
vz                              : integer;
Change_x,change_dx,dx,cx        : longint;
Change_y,change_dy,dy           : longint;
Change_z,change_dz,dz           : longint;
ans,filename,filename2          : string;
xhome,yhome,zhome,homepos       : boolean;
extend,grip                     : boolean;
input,x,y,z                     : longint;
filevar2                        : text;
choice                          : char;
f,f1,f2,f3,f4                   : string;
cy,b,c                          : longint;

const

baser=$200;
base1=$310;
base=$390;


PROCEDURE Front_Page; {Presents the first frontpage}

VAR
  s1,s2 : STRING[32];
  t,u   : INTEGER;
  ch    : char;

BEGIN
  RESTORE;
  Bold;
  Draw_Box(2,5,5,70,15,' ');
  s1 := 'AS/RS ROBOT';
  FOR t:=1 TO 11 DO
    BEGIN
      Goto_xy (31+t,8);
      WRITE (s1[t]);
      DELAY (100);
    END;
  Goto_xy (32,11);
  WRITE ('created by:');
  Restore;
  s2:='L.F CORSARO';
  Rvld;
  FOR u:=1 TO 11  DO
    BEGIN
      Goto_xy (31+u,13);
      WRITE (s2[u]);
      Bell (150,0.1);
    END;
  Restore;
  Goto_xy (2,24);
  Blink;
```

DIOPA - Port A of the 8255 (offset 0, read/write)

This register is port A of the 8255. It can be operated in one of three modes as described in Chapter 5 *Programming Guide*. The operating mode is set by writing to the DIOCTRL register, described below.

DIOPA Register

PA7	PA6	PA5	PA4	PA3	PA2	PA1	PA0

The bits PA7 (MSB) down to PA0 (LSB) reflect the status of the port's I/O lines. Depending on the programmed I/O mode of the port, the lines may be inputs, outputs or bidirectional.

DIOPB - Port B of the 8255 (offset 1, read/write)

This register is port B of the 8255. It can be operated in one of three modes as described in Chapter 5 *Programming Guide*. The operating mode is set by writing to the DIOCTRL register, described below.

DIOPB Register

PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0

The bits PB7 (MSB) down to PB0 (LSB) reflect the status of the port's I/O lines. Depending on the programmed I/O mode of the port, the lines may be inputs, outputs or bidirectional.

DIOPC - Port C of the 8255 (offset 2, read/write)

This register is port C of the 8255. It can be operated in one of three modes as described in Chapter 5 *Programming Guide*. The operating mode is set by writing to the DIOCTRL register, described below.

DIOPC Register

PC7	PC6	PC5	PC4	PC3	PC2	PC1	PC0

The bits PC7 (MSB) down to PC0 (LSB) reflect the status of the port's I/O lines. Depending on the programmed I/O mode of the port, the lines may be inputs, outputs or handshake lines.

4

Register Structure

At the lowest level, the PC-36 is programmed using I/O port input and output instructions. This chapter contains information on all of the PC-36's registers. Although programming the board is not difficult, it is time consuming and requires detailed knowledge of both the PC-36 and the host PC's operating system. This manual provides the former. As an alternative, a set of software library functions is provided. These cover all of the board's features and should suit most applications. The Driver Library is described in a companion manual to this. In case routines need to be custom written for a specific purpose, it is often quicker to base them on the driver system, by loading and modifying routines from the driver library source code. This chapter and Chapter 5: *Programming Guide* provide full information on how this is done.

The PC-36 occupies 4 consecutive addresses in the computer's I/O space. The layout of these registers in shown in Table 3: *PC-36 Register Structure*. The offset of the registers are given as offset addresses from the base address of the board. The board base address is set with the DIP switch as detailed in Chapter 2: *Installation*.

Offset	Write	Read
0	Port A (DIOPA)	Port A (DIOPA)
1	Port B (DIOPB)	Port B (DIOPB)
2	Port C (DIOPC)	Port C (DIOPC)
3	Control Register (DIOCTRL)	---

Table 3: PC-36 Register Structure.

The remainder of this chapter describes these registers in detail.

The symbol '/' indicates that a signal is active low.

When an 8255 is used in one of the handshaking modes, the /STB and IBF lines are used to synchronise input data transfers. The /OBF and /ACK lines are used to synchronise output transfers. The signals in the table above have the following functions:

Name	Type	Description
/STB	External Input	Strobe Input: A low on this handshaking line loads data from the peripheral bus into the input latch.
IBF	External Output	Input Buffer Full: A high on this line indicates that the external data has been loaded into the input latch. This is an input acknowledge signal.
/ACK	External Input	Acknowledge: The external device asserts this line low to indicate that the data written to the port by the program has been accepted.
/OBF	External Output	Output Buffer Full: The 8255 asserts this line low to indicate to the external device that the program has written data to the selected port. This line can be used to strobe the data into the external device.
INTR	External Output	Interrupt Request: This signal becomes active (high) when the 8255 requires service. For input operations, it indicates that there is data in the corresponding port to be read by the program. For output operations it indicates that the external device has accepted the data and thus the program can write another byte to the 8255.
/RD	Internal Input	Read Signal: This signal is generated by the control lines of the host computer. It is activated when the program executes an Input Instruction from any PC-36B register.
/WR	Internal Input	Write Signal: This signal is generated by the control lines of the host computer. It is activated when the program executes an Output Instruction to any PC-36B register.

Power supplies

The +12V, -12V, +5V and -5V power supplies are available, together with digital ground, user connector. These can be used to power external circuitry. As a rough guide, no more than about 250 mA should be drawn from these power supplies or the PC-36 board, the host computer or the power supply may be damaged permanently. Check the computer's power supply ratings for maximum current; this is especially important for the -12V and -5V supplies.

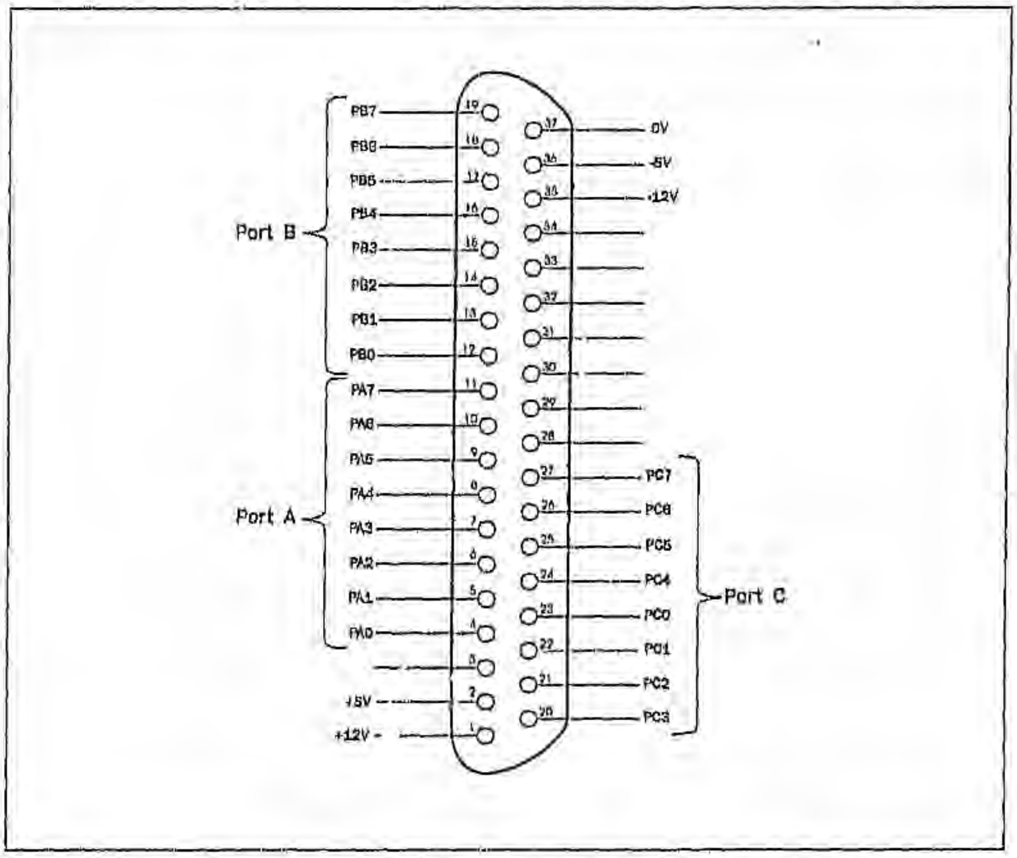


Figure 3: PC-36 connector, as seen from the rear of the PC.

Some of the lines of Port C take on different meanings when an 8255 is programmed to operate in strobed input or output mode or bidirectional bus mode. They are summarised in the following table and described below that. See Chapter 5: *Programming Guide* for full details on the use of these signals.

Port C Line	Simple I/O: Mode 0	Strobed Input: Mode 1	Strobed Output: Mode 1	Bidirectional Bus: Mode 2
C7	I/O	I/O	/OBF$_A$	/OBF$_A$
C6	I/O	I/O	/ACK$_A$	/ACK$_A$
C5	I/O	IBF$_A$	I/O	IBF$_A$
C4	I/O	/STB$_A$	I/O	/STB$_A$
C3	I/O	INTR$_A$	INTR$_A$	INTR$_A$
C2	I/O	/STB$_B$	/ACK$_B$	I/O
C1	I/O	IBF$_B$	/OBF$_B$	I/O
C0	I/O	INTR$_B$	INTR$_B$	I/O

Table 2: Port C Line Usage.

3

Interconnections

The PC-36 plugs into any of the computer's expansion slots, along the board's gold plated edge connector. The board communicates to the external world via a connector mounted in its bracket. This chapter describes these connectors.

Connections to the computer backplane

The PC-36 board may be plugged into any slot of the computer backplane (*with the exception of the J8 slot of IBM XT's*). All communication to and from the host computer is via this connector. The board forms part of the processor's I/O space.

If the PC-36 sometimes behaves erratically then there is the possibility that the gold plated contacts on the edge connector may have become dirty or abraded, especially if the card is installed and removed many times from various different computers. This condition can be corrected simply by cleaning the contacts with an ordinary pencil eraser.

User connector

The PC-36 interfaces to the external world via a 37 way D-type male connector mounted in the board's bracket.

The DB37 connector carries the following signals:

- The Port A, Port B and Port C digital input/output/handshake lines of the 8255.
- Power supplies of +5V, -5V, +12V, -12V and digital ground.

Figure 3 shows these connections, together with their pin assignments. Note that the pin connections refer to the pin numbers of the connector when looking into the connector from the rear of the computer. The pin numbers are embossed onto the connector itself.

Only a very small number of computers will require additional wait states. If the PC-36B card in your computer seems to be returning incorrect readings then increase the number of wait states until correct results are obtained. If the card does not produce correct results with the maximum number of additional wait states inserted then either the host computer or the card is faulty and should be serviced.

Installation

Installing the PC-36 is straightforward. You will need a screwdriver to match the screws on the computer's cover and expansion slot bracket.

a) Switch off the computer and all attached devices.

b) Unplug the power cord from the computer and all attached devices. Failure to do this may result in hazardous conditions, as there may be dangerous voltage levels present on externally connected cables.

c) Remove the top cover of the PC or the access port to the I/O channel. If you are not sure how to do this, consult the manual supplied with the system unit.

d) Cho[illegible]e any unused 8-bit or 16-bit expansion adapter slot and remove the screw from the top of the blank bracket corresponding to the chosen slot. Remove the bracket.

e) Align the gold plated edge connector of the PC-36 with the edge socket on the computer system b[illegible] and align the board bracket with the rear adapter slot on the computer's case. Firmly [illegible] the board down into the edge socket. Ensure that the board's edge connector is seated in [illegible] socket and has not slipped sideways past the socket.

f) Tighten the mounting bracket of the PC-36 to the back pa[illegible] rail of the computer.

g) Replace the computer's cover. Plug in all cords and cables. Switch on the power. The PC-36 is now installed and ready for operation.

I/O Addresses from 400h to 7FFh

Note that addresses from 400h to FFFh cannot normally be used because these addresses are not normally decoded by other I/O devices and cards in the 0h to 3FFh range.

The PC-36 however (and most other members of the PC-XX family) can use these additional addresses if (and only if) there is no board or device at address 400h less than the address of the PC-36 or the board at the address 400h less also decodes the extra addresses.

> A PC-36 may be installed at address 300h and another PC-36 at address 700h. (400h locations apart.) However it would not be advisable to install a PC-36 at address 778h because the printer port LPT1 uses a base address of 378h and does not normally decode the extra addresses.

Most other members of the PC-XX family of boards decode the extra addresses and may safely be installed 400h locations apart.

If your computer has boards not listed in Table 1 installed (such as LAN adapters, back-up boards or other engineering boards) then consult the manuals for these boards for information on the address ranges used. In most cases a base address of either 300h or 310h is a good choice. Address 310h is also the factory default address.

Generating additional wait states on the PC-36B

The number of additional wait states inserted in I/O bus cycles addressing the PC-36B is controlled by the position of the wait state jumper JP1. This is marked 'Wait State Selection' on the board. Refer to Figure 2 for the wait state jumper positions. The factory default setting is for zero wait states.

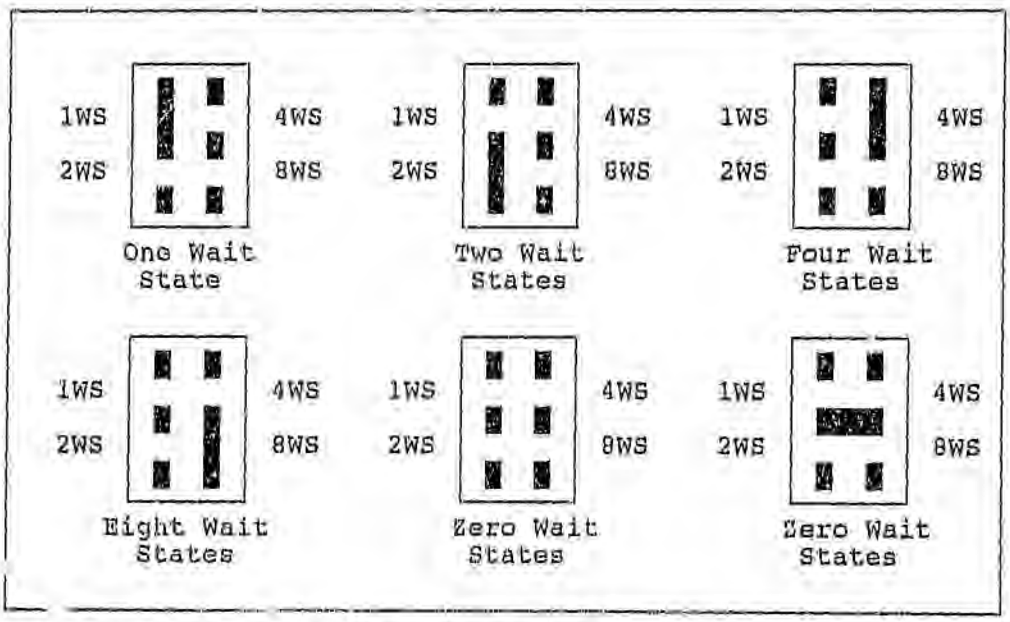


Figure 2: Wait State Jumper Settings.

Address (hex)	Standard Device
000-1FF	Internal system board
200-20F	Games port
210-217	Expansion unit
220-24F	Reserved
250-257	Not assigned
258-25F	Intel "Above Board"
260-277	Not assigned
278-26F	Reserved
280-2EF	Not assigned
2F0-2F7	LPT2
2F8-2FF	COM2
300-31F	Prototype board
320-32F	Hard disk
330-377	Not assigned
378-37F	LPT1
380-38F	SDLC communications
390-39F	Not assigned
3A0-3AF	Binary communications
3B0-3BF	Monochrome display adapter
3C0-3CF	Reserved
3D0-3DF	Colour graphics adapter
3E0-3E7	Reserved
3E3-3EF	Not assigned
3F0-3F7	Floppy disk
3F8-3FF	COM1
400-FFF	Not used; refer to text

Table 1: Standard I/O Addresses.

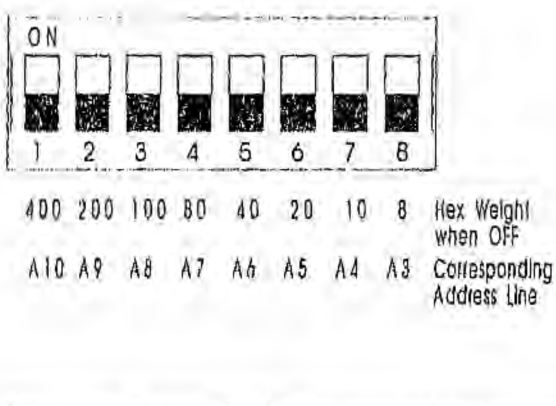


Figure 1: DIP Switch Address Weights (in hex).

2

Installation

Configuration

There are two aspects of the PC-36 that can be configured. These are:

- The base address. This is the address where the computer will find the board. It is set to an address between 0h and 7F8h with the eight switches on the DIP switch block. Note that this address is in the computer's I/O address space.
- PC-36B Wait state generation. If the host computer generates abnormally fast I/O bus cycles then it may be necessary to slow these down when the computer accesses the PC-36B. The board can do this without affecting any other I/O bus cycles. The number of additional wait states inserted in a PC-36B bus cycle is controlled by jumper on the board.

Setting the base address

The PC-36 uses a block of four I/O addresses. The base address setting controls the address where this block begins. This must be set so that the PC-36 does not use any addresses that are used by another device or card. If more than one PC-36 is to be installed in the computer then each card m , have a different base address setting.

The base address may be assigned to any location from 0h to 7F8h, on eight byte boundaries. The factory default base address is 310h. Refer to Table 1 below for a guide on addresses used by standard I/O devices and Table 4 in Appendix A for a list of the base address switch settings.

The base address is set by adjusting the eight switches in the DIP switch on the board. Switch number 1 is used to compare address line A10, number 2 for A9 and so on up to switch 8 /hich is used to compare address line A3. In general, if a switch is set to the off position, then its corresponding address weighting contributes to the base address. See Figure 1 for the DIP switch weightings.

For example switches 2 (corresponding to address line A9), 3 (corresponding to A8) and 7 (corresponding to A4) off yield a base address of 200h + 100h + 10h= 310h.

PC 36 CARD SPECIFICATIONS

Appendix C Process control cards.

```
    BEGIN
    port[base+2]:=3;
    DELAY(1000);
    END;
  if (grip=false) and (extend=false)then
  port[base+2]:=0;
 if (choice='m') or (choice='M') then begin
 screen_write (command,'again ? ');
 readln(ans);
 end;
  if (choice='m') or (choice='M') then pallet_choice;
  until (count=5) or (ans='n') or (ans='N');
  Read_rotary;
  get_value;
  show_value;

end.
```

2-pulse mode

In 2-pulse mode the PCL-833 uses two input pulses as counting sources: one for clockwise (CW) and one for counterclockwise (CCW) counting. The counter will decrement whenever a rising edge occurs on channel A. It will increment whenever a rising edge occurs on channel B.

Pulse/direction mode

In pulse/direction mode the PCL-833 uses one input line (A) for pulse input and one line (B) for direction. If channel B is high (1), the counter will decrement whenever a rising edge occurs on channel A. If channel B is low (0), the counter will increment whenever a rising edge occurs on channel A.

Disabled mode

PCL-833 will not accept input, but you can still access all its registers.

You select the mode by programming the card's registers: BASE+0 for CH1, BASE+1 for CH2 and BASE+2 for CH3. See Chapter 5 for more information.

Digital noise filter

Noise immunity is the most important requirement for reliable encoder interface operation. The PCL-833 conditions the input signals with a four stage digital filter. This filter reduces glitches (digital noise) or spikes by sampling the input at 2, 4 or 8 MHz. The filter output waveforms change only when an input has the same value for three consecutive sampling edges. The filter thus rejects noise or pulses shorter than two sampling clock periods. You can optimize noise immunity by selecting the lowest sampling frequency that compatible with the highest input rate you expect.

The PCL-833 accepts up to 1 MHz quadrature freq. at 8 MHz filter sampling speed. At 2 MHz sampling speed it can still accept up to 300 KHz quadrature input freq.

A 3600 rpm motor with 2000 ppr encoder will have a max. quadrature freq. of 3600 x 2000 ÷ 60 = 120 KHz. In the above example the 2 MHz sampling clock will have the best noise immunity and will meet the required input freq.

The following table shows the maximum noise pulse width that the filter will reject for each system clock frequency:

Clock freq.	Maximum width
8 MHz	375 nsec.
4 MHz	750 nsec.
2 MHz	1.5 msec.

Latch mode

When you read a counter, you are actually reading a value latched into a buffer. The PCL-833 provides five different latching modes, only one of which is active at any given time. Make sure that you know which latching mode is current whenever you read the counter. Otherwise, you may read an old value or one that was latched at a different time than you expect.

You select the latching mode for each channel individually. That is, you might select S/W latching on channel 1 and DIO latching for channels 2 and 3. Bits 0-2 of register BASE+3 control CH1, BASE+4 control CH2 and BASE+5 control CH3. See Chapter 5 for more information.

The PCL-833's latching modes are as follows:

S/W latch

Whenever you read a channel's data registers, the counter values will be latched in buffer. The S/W latch will only take effect when you read the high byte of the counter (C23-C16). Reading middle byte or low byte of a counter won't latch the counter values to the buffer. You should therefore read the high byte first, then the other two bytes of the counter.

Index latch

A rising edge on the channel's index input line will latch the channel's counter value.

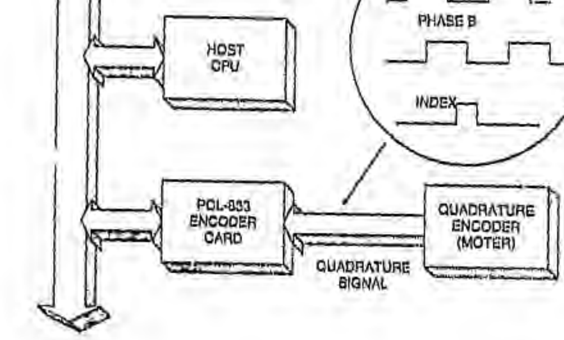
DIO latch

A rising edge on the board's DI0 line will latch the counter value for the channel.

Quadrature encoder introduction

In typical closed-loop control systems, also know as servo systems, the encoder interface senses motor position and sends a position signal to the controller. The diagram below shows a typical servo system.

The encoder generates pulses which indicate the shaft position. The encoder output includes two signals, commonly called channel A and channel B, which generate N pulses per revolution. The two signals are shifted by a quarter of a cycle, as shown below. The shift between the two signals enables the controller to determine the direction of rotation, depending on whether channel A leads channel B or vice versa.



Single-ended vs. differential input

Most encoders produce square wave signals with TTL levels. Industrial systems often use encoders with differential signals, i. e. channel A and B and their complements. Differential signals can reduce sensitivity to noise and allow longer transmission distances. Encoders may also produce a third signal once per revolution known as the index or marker. The encoder interface can use the index signal to reset the counter, allowing you to monitor the position within the current revolution.

Counter modes

The following table shows the maximum input rate for each input mode and system clock rate. Values are given for each system clock frequency.

Mode	Maximum input rate		
	8 MHz	4 MHz	2 MHz
Quadrature X1, X2, X4	1 MHz	600 KHz	300 KHz
2-pulse	2.4 MHz	1.2 MHz	600 KHz
Pulse/direction	2.4 MHz	1.2 MHz	600 KHz

Counter modes are as follows:

Quadrature input counter mode

Quadrature input consists of two square wave inputs (A and B) which are 90° out of phase. The PCL-833 counts the square wave transitions and determines the direction by comparing whether channel A is leading channel B or vice versa

There are three different counting methods in quadrature input mode:

X1 The counter will increment (or decrement) the counter whenever a rising edge occurs on input channel A.

X2 The counter will increment (or decrement) whenever a rising or falling edge occurs on input channel A.

X4 The counter will increment (or decrement) whenever a rising or falling edge occurs on input channel A or B.

Pin	Function
CH2B-	Channel 2 B differential negative - input
CH2B+	Channel 2 B differential positive - input
CH2Z-	Channel 2 Z differential negative - input
CH2Z+	Channel 2 Z differential positive - input
CH3A-	Channel 3 A differential negative - input
CH3A+	Channel 3 A differential positive - input
CH3B-	Channel 3 B differential negative - input
CH3B+	Channel 3 B differential positive - input
CH3Z-	Channel 3 Z differential negative - input
CH3Z+	Channel 3 Z differential positive - input
CDI0-	Digital input No. 0 differential negative - input
CDI0+	Digital input No. 0 differential positive - input
CDI1-	Digital input No. 1 differential negative - input
CDI1+	Digital input No. 1 differential positive - input

Connector wiring

External/internal power

If you use an external power supply, connect pins 1 and 13 to external ground and connect pin 25 to external V_{cc}.

If you use the card's internal power supply, place 0-Ω resistors (jumper wires) at locations L1 and L2 on board (see labels printed on board).

Differential/single-ended input

With differential inputs connect the negative wire to the negative pin and the positive wire to the positive pin. For example, with channel 3 A connect the negative input wire to CH3A- and the positive wire to CH3A+.

With single-ended inputs connect the input to the positive pin and leave the negative pin open.

AB phase encoder

In 2-pulse input mode A inputs (CH1A, CH2A, etc.) count up while their corresponding B inputs (CH1B, CH2B) count down.

In 1-pulse input mode A inputs (CH1A, etc.) count up or down and B inputs (CH1B, etc.) determine the direction to count. A logical high (1) on the B channel indicates that the pulse on the A channel is an up count, and a logical low (0) indicates that the pulse is a down count.

Hardware installation

Warning! Disconnect power from your PC whenever you install or remove the PCL-833 or its cables

Installing the card in your computer:

1. Turn off the computer and all peripheral devices (such as printers and monitors).
2. Disconnect the power cord and any other cables from the back of the computer. Turn the chassis so the back of the unit faces you.
3. Remove the chassis cover (see your computer users guide if necessary).
4. Locate the expansion slots at the rear of the unit and choose an unused slot.
5. Remove the screw that secures the expansion slot cover to the chassis. Save the screw to secure the PCL-833.
6. Carefully grasp the upper edge of the PCL-833 card. Align the hole in the retaining bracket with the hole on top of the expansion slot, and align the gold striped edge connector with the expansion slot socket. Press the board firmly into the socket.
7. Replace the screw in the expansion slot retaining bracket.
8. Attach necessary accessories to the card.
9. Replace the chassis cover. Connect the cables you removed in step 2. Turn on the computer.

Hardware installation is now complete. You can now install the software driver as described in the next section.

To use the interrupt you must install an interrupt service routine and program the PCL-833's on-board the 8259 interrupt controller.

Nine different conditions can enable the PCL-833's interrupt, but only one at a time.

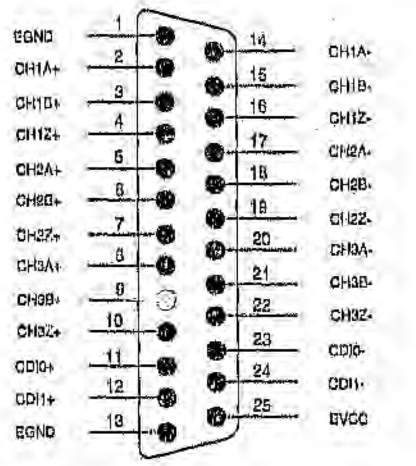
Interrupt source	Condition
0	CH1 overflow
1	CH2 overflow
2	CH3 overflow
3	CH1 ZIN
4	CH2 ZIN
5	CH3 ZIN
6	DI0
7	Shared by TIMER and DI1

Bit 3 of register BASE+9 switches interrupt source 7 between the card's TIMER and DI1. See Chapter 3 for details.

You should treat all the interrupt sources as positive-edge triggered when you program the 8259.

Connector pin assignments

You make all connections to the PCL-833 through a single DB-25 connector, shown below:



Connector pin assignments appear below:

Pin	Function
EGND	External ground
EVCC	External Vcc
CH1A-	Channel 1 A differential negative- input
CH1A+	Channel 1 A differential positive - input
CH1B-	Channel 1 B differential negative - input
CH1B+	Channel 1 B differential positive - input
CH1Z-	Channel 1 Z differential negative - input
CH1Z+	Channel 1 Z differential positive - input
CH2A-	Channel 2 A differential negative- input
CH2A+	Channel 2 A differential positive - input

Initial inspection

In addition to this manual the shipping container should contain the PCL-833 card and a utility diskette. We carefully inspected the PCL-833 mechanically and electrically before we shipped it. It should be free of marks and scratches and in perfect electrical order on receipt.

As you unpack the card, check it for signs of shipping damage (damaged box, scratches, dents, etc.). If it is damaged or fails to meet its specifications, notify our service department or your local sales representative immediately. You will need to contact the carrier so that it can inspect the shipping carton and packing material. We will then arrange to repair or replace the unit.

Remove the PCL-833 interface card from its protective packaging carefully. Keep the antistatic package. Whenever you are not using the board, please store it in the packaging for protection.

Warning! *Discharge any static electric charge on your body by touching grounded metal before you handle the board. You should avoid contact with materials that create static electricity such as plastic, vinyl, and styrofoam. Handle the board by its edges to avoid contacting the board's integrated circuits.*

Switch and jumper settings

DIP switch SW1 sets the card's I/O address and jumper JP1 sets the card's interrupt level.

Base I/O address (SW1)

The PCL-833 requires 16 consecutive I/O addresses. DIP switch SW1 (shown below) sets the base I/O address.

Choose a base address that is not in use by any other I/O device. A conflict with another device may cause one or both devices to fail. The factory address setting (hex 200) is usually free as it is reserved for PC prototype boards.

Jumper settings for various base addresses appear below:

Card I/O addresses (SW1)

Range (hex)	Switch position					
	1	2	3	4	5	6
*200 - 20F	●	O	O	O	O	O
210 - 21F	●	O	O	O	O	●
220 - 22F	●	O	O	O	●	O
230 - 23F	●	O		O	●	●
240 - 24F	●	O	O	●	O	O
⋮						
3F0 - 3FF	●	●	●	●	●	●

O = On ● = Off * = default

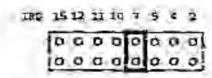
Note: Switches 1-6 control the PC bus address lines as follows:

Switch	1	2	3	4	5	6
Line	A9	A8	A7	A6	A5	A4

Interrupt level (JP1)

The jumper JP1 selects the card's interrupt level (2, 4, 5, 7, 10, 11, 12 15), as shown below:

Card interrupt (default = 7)



Do not select a level that is being used by another device unless you have performed special programming to share several devices on one interrupt.

PCL-833 CARD SPECIFICATIONS

Base Address	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	Base Address
600h	OFF	OFF	ON	ON	ON	ON	ON	ON	600h
608h	OFF	OFF	ON	ON	ON	ON	ON	OFF	608h
610h	OFF	OFF	ON	ON	ON	ON	OFF	ON	610h
618h	OFF	OFF	ON	ON	ON	ON	OFF	OFF	618h
620h	OFF	OFF	ON	ON	ON	OFF	ON	ON	620h
628h	OFF	OFF	ON	ON	ON	OFF	ON	OFF	628h
630h	OFF	OFF	ON	ON	ON	OFF	OFF	ON	630h
638h	OFF	OFF	ON	ON	ON	OFF	OFF	OFF	638h
640h	OFF	OFF	ON	ON	OFF	ON	ON	ON	640h
648h	OFF	OFF	ON	ON	OFF	ON	ON	OFF	648h
650h	OFF	OFF	ON	ON	OFF	ON	OFF	ON	650h
658h	OFF	OFF	ON	ON	OFF	ON	OFF	OFF	658h
660h	OFF	OFF	ON	ON	OFF	OFF	ON	ON	660h
668h	OFF	OFF	ON	ON	OFF	OFF	ON	OFF	668h
670h	OFF	OFF	ON	ON	OFF	OFF	OFF	ON	670h
678h	OFF	OFF	ON	ON	OFF	OFF	OFF	OFF	678h
680h	OFF	OFF	ON	OFF	ON	ON	ON	ON	680h
688h	OFF	OFF	ON	OFF	ON	ON	ON	OFF	688h
690h	OFF	OFF	ON	OFF	ON	ON	OFF	ON	690h
698h	OFF	OFF	ON	OFF	ON	ON	OFF	OFF	698h
6A0h	OFF	OFF	ON	OFF	ON	OFF	ON	ON	6A0h
6A8h	OFF	OFF	ON	OFF	ON	OFF	ON	OFF	6A8h
6B0h	OFF	OFF	ON	OFF	ON	OFF	OFF	ON	6B0h
6B8h	OFF	OFF	ON	OFF	ON	OFF	OFF	OFF	6B8h
6C0h	OFF	OFF	ON	OFF	OFF	ON	ON	ON	6C0h
6C8h	OFF	OFF	ON	OFF	OFF	ON	ON	OFF	6C8h
6D0h	OFF	OFF	ON	OFF	OFF	ON	OFF	ON	6D0h
6D8h	OFF	OFF	ON	OFF	OFF	ON	OFF	OFF	6D8h
6E0h	OFF	OFF	ON	OFF	OFF	OFF	ON	ON	6E0h
6E8h	OFF	OFF	ON	OFF	OFF	OFF	ON	OFF	6E8h
6F0h	OFF	OFF	ON	OFF	OFF	OFF	OFF	ON	6F0h
6F8h	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	6F8h
700h	OFF	OFF	OFF	ON	ON	ON	ON	ON	700h
708h	OFF	OFF	OFF	ON	ON	ON	ON	OFF	708h
710h	OFF	OFF	OFF	ON	ON	ON	OFF	ON	710h
718h	OFF	OFF	OFF	ON	ON	ON	OFF	OFF	718h
720h	OFF	OFF	OFF	ON	ON	OFF	ON	ON	720h
728h	OFF	OFF	OFF	ON	ON	OFF	ON	OFF	728h
730h	OFF	OFF	OFF	ON	ON	OFF	OFF	ON	730h
738h	OFF	OFF	OFF	ON	ON	OFF	OFF	OFF	738h
740h	OFF	OFF	OFF	ON	OFF	ON	ON	ON	740h
748h	OFF	OFF	OFF	ON	OFF	ON	ON	OFF	748h
750h	OFF	OFF	OFF	ON	OFF	ON	OFF	ON	750h
758h	OFF	OFF	OFF	ON	OFF	ON	OFF	OFF	758h
760h	OFF	OFF	OFF	ON	OFF	OFF	ON	ON	760h
768h	OFF	OFF	OFF	ON	OFF	OFF	ON	OFF	768h
770h	OFF	OFF	OFF	ON	OFF	OFF	OFF	ON	770h
778h	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	778h
780h	OFF	OFF	OFF	OFF	ON	ON	ON	ON	780h
788h	OFF	OFF	OFF	OFF	ON	ON	ON	OFF	788h
790h	OFF	OFF	OFF	OFF	ON	ON	OFF	ON	790h
798h	OFF	OFF	OFF	OFF	ON	ON	OFF	OFF	798h
7A0h	OFF	OFF	OFF	OFF	ON	OFF	ON	ON	7A0h
7A8h	OFF	OFF	OFF	OFF	ON	OFF	ON	OFF	7A8h
7B0h	OFF	OFF	OFF	OFF	ON	OFF	OFF	ON	7B0h
7B8h	OFF	OFF	OFF	OFF	ON	OFF	OFF	OFF	7B8h
7C0h	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	7C0h
7C8h	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF	7C8h
7D0h	OFF	OFF	OFF	OFF	OFF	ON	OFF	ON	7D0h
7D8h	OFF	OFF	OFF	OFF	OFF	ON	OFF	OFF	7D8h
7E0h	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	7E0h
7E8h	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF	7E8h
7F0h	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	7F0h
7F8h	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	7F8h

Table 4: Base Address Switch Settings (continued).

Base Address	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	Base Address
400h	OFF	ON	ON	ON	ON	ON	ON	ON	400h
408h	OFF	ON	ON	ON	ON	ON	ON	OFF	408h
410h	OFF	ON	ON	ON	ON	ON	OFF	ON	410h
418h	OFF	ON	ON	ON	ON	ON	OFF	OFF	418h
420h	OFF	ON	ON	ON	ON	OFF	ON	ON	420h
428h	OFF	ON	ON	ON	ON	OFF	ON	OFF	428h
430h	OFF	ON	ON	ON	ON	OFF	OFF	ON	430h
438h	OFF	ON	ON	ON	ON	OFF	OFF	OFF	438h
440h	OFF	ON	ON	ON	OFF	ON	ON	ON	440h
448h	OFF	ON	ON	ON	OFF	ON	ON	OFF	448h
450h	OFF	ON	ON	ON	OFF	ON	OFF	ON	450h
458h	OFF	ON	ON	ON	OFF	ON	OFF	OFF	458h
460h	OFF	ON	ON	ON	OFF	OFF	ON	ON	460h
468h	OFF	ON	ON	ON	OFF	OFF	ON	OFF	468h
470h	OFF	ON	ON	ON	OFF	OFF	OFF	ON	470h
478h	OFF	ON	ON	ON	OFF	OFF	OFF	OFF	478h
480h	OFF	ON	ON	OFF	ON	ON	ON	ON	480h
488h	OFF	ON	ON	OFF	ON	ON	ON	OFF	488h
490h	OFF	ON	ON	OFF	ON	ON	OFF	ON	490h
498h	OFF	ON	ON	OFF	ON	ON	OFF	OFF	498h
4A0h	OFF	ON	ON	OFF	ON	OFF	ON	ON	4A0h
4A8h	OFF	ON	ON	OFF	ON	OFF	ON	OFF	4A8h
4B0h	OFF	ON	ON	OFF	ON	OFF	OFF	ON	4B0h
4B8h	OFF	ON	ON	OFF	ON	OFF	OFF	OFF	4B8h
4C0h	OFF	ON	ON	OFF	OFF	ON	ON	ON	4C0h
4C8h	OFF	ON	ON	OFF	OFF	ON	ON	OFF	4C8h
4D0h	OFF	ON	ON	OFF	OFF	ON	OFF	ON	4D0h
4D8h	OFF	ON	ON	OFF	OFF	ON	OFF	OFF	4D8h
4E0h	OFF	ON	ON	OFF	OFF	OFF	ON	ON	4E0h
4E8h	OFF	ON	ON	OFF	OFF	OFF	ON	OFF	4E8h
4F0h	OFF	ON	ON	OFF	OFF	OFF	OFF	ON	4F0h
4F8h	OFF	ON	ON	OFF	OFF	OFF	OFF	OFF	4F8h
500h	OFF	ON	OFF	ON	ON	ON	ON	ON	500h
508h	OFF	ON	OFF	ON	ON	ON	ON	OFF	508h
510h	OFF	ON	OFF	ON	ON	ON	OFF	ON	510h
518h	OFF	ON	OFF	ON	ON	ON	OFF	OFF	518h
520h	OFF	ON	OFF	ON	ON	OFF	ON	ON	520h
528h	OFF	ON	OFF	ON	ON	OFF	ON	OFF	528h
530h	OFF	ON	OFF	ON	ON	OFF	OFF	ON	530h
538h	OFF	ON	OFF	ON	ON	OFF	OFF	OFF	538h
540h	OFF	ON	OFF	ON	OFF	ON	ON	ON	540h
548h	OFF	ON	OFF	ON	OFF	ON	ON	OFF	548h
550h	OFF	ON	OFF	ON	OFF	ON	OFF	ON	550h
558h	OFF	ON	OFF	ON	OFF	ON	OFF	OFF	558h
560h	OFF	ON	OFF	ON	OFF	OFF	ON	ON	560h
568h	OFF	ON	OFF	ON	OFF	OFF	ON	OFF	568h
570h	OFF	ON	OFF	ON	OFF	OFF	OFF	ON	570h
578h	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	578h
580h	OFF	ON	OFF	OFF	ON	ON	ON	ON	580h
588h	OFF	ON	OFF	OFF	ON	ON	ON	OFF	588h
590h	OFF	ON	OFF	OFF	ON	ON	OFF	ON	590h
598h	OFF	ON	OFF	OFF	ON	ON	OFF	OFF	598h
5A0h	OFF	ON	OFF	OFF	ON	OFF	ON	ON	5A0h
5A8h	OFF	ON	OFF	OFF	ON	OFF	ON	OFF	5A8h
5B0h	OFF	ON	OFF	OFF	ON	OFF	OFF	ON	5B0h
5B8h	OFF	ON	OFF	OFF	ON	OFF	OFF	OFF	5B8h
5C0h	OFF	ON	OFF	OFF	OFF	ON	ON	ON	5C0h
5C8h	OFF	ON	OFF	OFF	OFF	ON	ON	OFF	5C8h
5D0h	OFF	ON	OFF	OFF	OFF	ON	OFF	ON	5D0h
5D8h	OFF	ON	OFF	OFF	OFF	ON	OFF	OFF	5D8h
5E0h	OFF	ON	OFF	OFF	OFF	OFF	ON	ON	5E0h
5E8h	OFF	ON	OFF	OFF	OFF	OFF	ON	OFF	5E8h
5F0h	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	5F0h
5F8h	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	5F8h

Table 4: Base Address Switch Settings (continued).

Base Address	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	Base Address
200h	ON	OFF	ON	ON	ON	ON	ON	ON	200h
208h	ON	OFF	ON	ON	ON	ON	ON	OFF	208h
210h	ON	OFF	ON	ON	ON	ON	OFF	ON	210h
218h	ON	OFF	ON	ON	ON	ON	OFF	OFF	218h
220h	ON	OFF	ON	ON	ON	OFF	ON	ON	220h
228h	ON	OFF	ON	ON	ON	OFF	ON	OFF	228h
230h	ON	OFF	ON	ON	ON	OFF	OFF	ON	230h
238h	ON	OFF	ON	ON	ON	OFF	OFF	OFF	238h
240h	ON	OFF	ON	ON	OFF	ON	ON	ON	240h
248h	ON	OFF	ON	ON	OFF	ON	ON	OFF	248h
250h	ON	OFF	ON	ON	OFF	ON	OFF	ON	250h
258h	ON	OFF	ON	ON	OFF	ON	OFF	OFF	258h
260h	ON	OFF	ON	ON	OFF	OFF	ON	ON	260h
268h	ON	OFF	ON	ON	OFF	OFF	ON	OFF	268h
270h	ON	OFF	ON	ON	OFF	OFF	OFF	ON	270h
278h	ON	OFF	ON	ON	OFF	OFF	OFF	OFF	278h
280h	ON	OFF	ON	OFF	ON	ON	ON	ON	280h
288h	ON	OFF	ON	OFF	ON	ON	ON	OFF	288h
290h	ON	OFF	ON	OFF	ON	ON	OFF	ON	290h
298h	ON	OFF	ON	OFF	ON	ON	OFF	OFF	298h
2A0h	ON	OFF	ON	OFF	ON	OFF	ON	ON	2A0h
2A8h	ON	OFF	ON	OFF	ON	OFF	ON	OFF	2A8h
2B0h	ON	OFF	ON	OFF	ON	OFF	OFF	ON	2B0h
2B8h	ON	OFF	ON	OFF	ON	OFF	OFF	OFF	2B8h
2C0h	ON	OFF	ON	OFF	OFF	ON	ON	ON	2C0h
2C8h	ON	OFF	ON	OFF	OFF	ON	ON	OFF	2C8h
2D0h	ON	OFF	ON	OFF	OFF	ON	OFF	ON	2D0h
2D8h	ON	OFF	ON	OFF	OFF	ON	OFF	OFF	2D8h
2E0h	ON	OFF	ON	OFF	OFF	OFF	ON	ON	2E0h
2E8h	ON	OFF	ON	OFF	OFF	OFF	ON	OFF	2E8h
2F0h	ON	OFF	ON	OFF	OFF	OFF	OFF	ON	2F0h
2F8h	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF	2F8h
300h	ON	OFF	OFF	ON	ON	ON	ON	ON	300h
308h	ON	OFF	OFF	ON	ON	ON	ON	OFF	308h
310h	ON	OFF	OFF	ON	ON	ON	OFF	ON	310h
318h	ON	OFF	OFF	ON	ON	ON	OFF	OFF	318h
320h	ON	OFF	OFF	ON	ON	OFF	ON	ON	320h
328h	ON	OFF	OFF	ON	ON	OFF	ON	OFF	328h
330h	ON	OFF	OFF	ON	ON	OFF	OFF	ON	330h
338h	ON	OFF	OFF	ON	ON	OFF	OFF	OFF	338h
340h	ON	OFF	OFF	ON	OFF	ON	ON	ON	340h
348h	ON	OFF	OFF	ON	OFF	ON	ON	OFF	348h
350h	ON	OFF	OFF	ON	OFF	ON	OFF	ON	350h
358h	ON	OFF	OFF	ON	OFF	ON	OFF	OFF	358h
360h	ON	OFF	OFF	ON	OFF	OFF	ON	ON	360h
368h	ON	OFF	OFF	ON	OFF	OFF	ON	OFF	368h
370h	ON	OFF	OFF	ON	OFF	OFF	OFF	ON	370h
378h	ON	OFF	OFF	ON	OFF	OFF	OFF	OFF	378h
380h	ON	OFF	OFF	OFF	ON	ON	ON	ON	380h
388h	ON	OFF	OFF	OFF	ON	ON	ON	OFF	388h
390h	ON	OFF	OFF	OFF	ON	ON	OFF	ON	390h
398h	ON	OFF	OFF	OFF	ON	ON	OFF	OFF	398h
3A0h	ON	OFF	OFF	OFF	ON	OFF	ON	ON	3A0h
3A8h	ON	OFF	OFF	OFF	ON	OFF	ON	OFF	3A8h
3B0h	ON	OFF	OFF	OFF	ON	OFF	OFF	ON	3B0h
3B8h	ON	OFF	OFF	OFF	ON	OFF	OFF	OFF	3B8h
3C0h	ON	OFF	OFF	OFF	OFF	ON	ON	ON	3C0h
3C8h	ON	OFF	OFF	OFF	OFF	ON	ON	OFF	3C8h
3D0h	ON	OFF	OFF	OFF	OFF	ON	OFF	ON	3D0h
3D8h	ON	OFF	OFF	OFF	OFF	ON	OFF	OFF	3D8h
3E0h	ON	OFF	OFF	OFF	OFF	OFF	ON	ON	3E0h
3E8h	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF	3E8h
3F0h	ON	OFF	OFF	OFF	OFF	OFF	OFF	ON	3F0h
3F8h	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	3F8h

Table 4: Base Address Switch Settings (continued).

Appendix A

Base Address Switch Settings

Base Address	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	Base Address
0h	ON	ON	ON	ON	ON	ON	ON	ON	0h
8h	ON	ON	ON	ON	ON	ON	ON	OFF	8h
10h	ON	ON	ON	ON	ON	ON	OFF	ON	10h
18h	ON	ON	ON	ON	ON	ON	OFF	OFF	18h
20h	ON	ON	ON	ON	ON	OFF	ON	ON	20h
28h	ON	ON	ON	ON	ON	OFF	ON	OFF	28h
30h	ON	ON	ON	ON	ON	OFF	OFF	ON	30h
38h	ON	ON	ON	ON	ON	OFF	OFF	OFF	38h
40h	ON	ON	ON	ON	OFF	ON	ON	ON	40h
48h	ON	ON	ON	ON	OFF	ON	ON	OFF	48h
50h	ON	ON	ON	ON	OFF	ON	OFF	ON	50h
58h	ON	ON	ON	ON	OFF	ON	OFF	OFF	58h
60h	ON	ON	ON	ON	OFF	OFF	ON	ON	60h
68h	ON	ON	ON	ON	OFF	OFF	ON	OFF	68h
70h	ON	ON	ON	ON	OFF	OFF	OFF	ON	70h
78h	ON	ON	ON	ON	OFF	OFF	OFF	OFF	78h
80h	ON	ON	ON	OFF	ON	ON	ON	ON	80h
88h	ON	ON	ON	OFF	ON	ON	ON	OFF	88h
90h	ON	ON	ON	OFF	ON	ON	OFF	ON	90h
98h	ON	ON	ON	OFF	ON	ON	OFF	OFF	98h
A0h	ON	ON	ON	OFF	ON	OFF	ON	ON	A0h
A8h	ON	ON	ON	OFF	ON	OFF	ON	OFF	A8h
B0h	ON	ON	ON	OFF	ON	OFF	OFF	ON	B0h
B8h	ON	ON	ON	OFF	ON	OFF	OFF	OFF	B8h
C0h	ON	ON	ON	OFF	OFF	ON	ON	ON	C0h
C8h	ON	ON	ON	OFF	OFF	ON	ON	OFF	C8h
D0h	ON	ON	ON	OFF	OFF	ON	OFF	ON	D0h
D8h	ON	ON	ON	OFF	OFF	ON	OFF	OFF	D8h
E0h	ON	ON	ON	OFF	OFF	OFF	ON	ON	E0h
E8h	ON	ON	ON	OFF	OFF	OFF	ON	OFF	E8h
F0h	ON	ON	ON	OFF	OFF	OFF	OFF	ON	F0h
F8h	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	F8h
100h	ON	ON	OFF	ON	ON	ON	ON	ON	100h
108h	ON	ON	OFF	ON	ON	ON	ON	OFF	108h
110h	ON	ON	OFF	ON	ON	ON	OFF	ON	110h
118h	ON	ON	OFF	ON	ON	ON	OFF	OFF	118h
120h	ON	ON	OFF	ON	ON	OFF	ON	ON	120h
128h	ON	ON	OFF	ON	ON	OFF	ON	OFF	128h
130h	ON	ON	OFF	ON	ON	OFF	OFF	ON	130h
138h	ON	ON	OFF	ON	ON	OFF	OFF	OFF	138h
140h	ON	ON	OFF	ON	OFF	ON	ON	ON	140h
148h	ON	ON	OFF	ON	OFF	ON	ON	OFF	148h
150h	ON	ON	OFF	ON	OFF	ON	OFF	ON	150h
158h	ON	ON	OFF	ON	OFF	ON	OFF	OFF	158h
160h	ON	ON	OFF	ON	OFF	OFF	ON	ON	160h
168h	ON	ON	OFF	ON	OFF	OFF	ON	OFF	168h
170h	ON	ON	OFF	ON	OFF	OFF	OFF	ON	170h
178h	ON	ON	OFF	ON	OFF	OFF	OFF	OFF	178h
180h	ON	ON	OFF	OFF	ON	ON	ON	ON	180h
188h	ON	ON	OFF	OFF	ON	ON	ON	OFF	188h
190h	ON	ON	OFF	OFF	ON	ON	OFF	ON	190h
198h	ON	ON	OFF	OFF	ON	ON	OFF	OFF	198h
1A0h	ON	ON	OFF	OFF	ON	OFF	ON	ON	1A0h
1A8h	ON	ON	OFF	OFF	ON	OFF	ON	OFF	1A8h
1B0h	ON	ON	OFF	OFF	ON	OFF	OFF	ON	1B0h
1B8h	ON	ON	OFF	OFF	ON	OFF	OFF	OFF	1B8h
1C0h	ON	ON	OFF	OFF	OFF	ON	ON	ON	1C0h
1C8h	ON	ON	OFF	OFF	OFF	ON	ON	OFF	1C8h
1D0h	ON	ON	OFF	OFF	OFF	ON	OFF	ON	1D0h
1D8h	ON	ON	OFF	OFF	OFF	ON	OFF	OFF	1D8h
1E0h	ON	ON	OFF	OFF	OFF	OFF	ON	ON	1E0h
1E8h	ON	ON	OFF	OFF	OFF	OFF	ON	OFF	1E8h
1F0h	ON	ON	OFF	OFF	OFF	OFF	OFF	ON	1F0h
1F8h	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	1F8h

Table 4: Base Address Switch Settings.

Bit 2 : Group B mode select: This bit sets the mode of the group B ports. These are port B and the lower four lines of port C. The bit combinations are as follows:

MSB_0	Group B I/O Mode
0	Mode 0, simple I/O
1	Mode 1, strobed I/O

Note that group B can only be used for simple or strobed I/O.

Bit 1 : Port B I/O Mode: If this bit is set, then port B functions as an input. If it is 0, then port B is configured as an output.

Bit 0 : Port C Lower I/O Mode: If this bit is set, then the lower four lines of port C function as inputs. If the bit is 0, then the lines become outputs.

Bit Set/Reset Mode - Invoked when bit 7 is clear

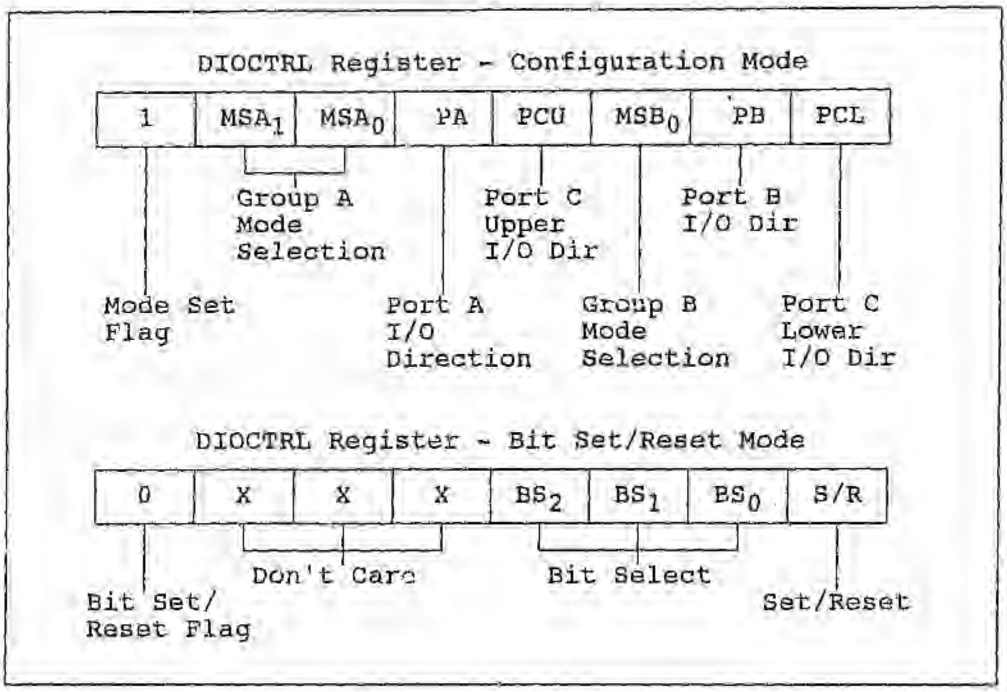
Bits 6-5 : These bits have no effect in this function.

Bits 3-1 : Bit Select: these bits select the bit in port C which is to be modified. A code of 000 selects port C line 0 to set or reset, 001 selects line 1 and so on up to 111 which selects line 7.

Bit 0 : Set/Reset: This bit specifies the state into which the selected port C line will be placed. Writing a 1 will make the line go high and a 0 makes it go low. This operation has no effect on the other lines of port C.

DIOCTRL - Control register of the 8255 (offset 3, write only)

This register is used to control the operating modes of the 8255 or to set and reset individual bits in port C of the device. The layout of this register is shown below. Note that the function and bit names of the register depend on the setting of bit 7.



Bit 7 : Function select: If this bit is set when the register is written to then the register is in configuration mode. If the bit is 0 then the register is in bit set/reset mode.

The functions of the remaining bits are described below, depending on the setting of bit 7.

Configuration Mode - Invoked when bit 7 is set

Bits 6-5 : Group A mode select: These two bits set the mode of the group A ports. These are port A and the upper four lines of port C. The bit combinations are as follows:

MSA_1	MSA_0	Group A I/O Mode
0	0	Mode 0, simple I/O
0	1	Mode 1, strobed I/O
1	X	Mode 2, bidirectional bus

Bit 4 : Port A I/O Mode: If this bit is set, then port A functions as an input. If it is 0, then port A is configured as an output.

Bit 3 : Port C Upper I/O Mode: If this bit is set, then the upper four lines of port C function as inputs. If the bit is 0, then the lines become outputs.

Criteria for Selection

The following factors should be considered in the selection of the ball screw assembly required for a given application:
- degree of accuracy required
- permissible clearance or desired preload (single or double nut)
- in-service load conditions
- desired life
- critical speed
- buckling load
- stiffness

The following points should be observed with a view to finding the optimum ball screw assembly from the point of view of design and economy:
- the lead is a decisive factor affecting the load-carrying capacity (via the maximum possible ball diameter) and the drive moment required;
- calculation of travel life should be based on average loads and average speeds and not on maximum values;
- to help us find a customized solution, enclose installation drawings or sketches of the vicinity of the nut with your enquiry;
- no special bearings are required for ball screw assemblies; bearings as for plain spindles will suffice. At least one bearing must be capable of taking up axial thrust forces. Where high stiffness is required, we recommend the use of combined radial and thrust bearings;
- the screw ends will be machined to the customer's specifications. The diameter of the screw ends should match the recommended dimensions for the end supports. Enclose a drawing with your enquiry.
- radial and eccentric forces relative to the screw must be avoided, as they reduce the life and adversely affect the functioning of the ball screw assembly.

Checklist

page 3.2.26

To enable us to find the ball screw assembly that best suits your application, please fill in the Checklist at the back of this brochure.

Please mark any questions you are unable to answer and any data you would like us to fill in.

Enquiry/Order Form

page 3.2.27

STAR Drive Screw

Nominal diameter .... d_0 = ______ mm

Lead ☐ right-hand thread ☐ left-hand thread ..... P = ______ mm

Precision-rolled quality .... ΔP_{300} = 25 µm ☐ / 50 µm ☐ / 100 µm ☐ / 200 µm ☐

Ground quality .... ΔP_{300} = 5 µm ☐ / 10 µm ☐ / 25 µm ☐ / 50 µm ☐

Overall length .... L = ______ mm

Threaded length .... L_1 = ______ mm

STAR Nut Type. .... Reference number 1512 – ☐ – ☐☐☐☐ / 1532 – ☐ – ☐☐☐☐ / 1502 – ☐ – ☐☐☐☐

Machining of screw ends .... ends not machined ☐ / ends annealed ☐/☐ mm ☐ / to customer's drawing ☐ / standard ☐

Please observe end bearing and support recommendations!

STAR End Bearing .... Reference number 159☐-☐-☐☐☐☐

Direction of mounting of nut: mounting dia D_1 towards fixed end ☐ / towards floating-bearing end ☐

STAR Housing for Flanged Nut. .. Reference number 1506 – ☐ – ☐☐☐☐

Product Range

Screw lengths
Screw diameters
Leads

Nominal dia. (mm) d_0	Precision-Rolled Thread: Lead P (mm) 2,5	5	10	16	20	25	32	40	Mill-cut lengths① (mm)	Ground Thread: Lead P (mm) 5	10	20	Max. screw length (mm)
8	●								3000–3500				
12		●							3000–3500				
16		●		●					3000–3500	●			1000
20		●			●				3000–3500	●			1200
25		●	●			●			4500–5000	●	●		1500
32		(●)	●		●		●		4500–5000	●	●		2000
40		●	●		●			●	4500–5000	●	●		4000
50		●	●		●			●	5000–5900	●	●		4000
63			●		●			●	5500–5900		●	●	5000
80			●		●				5500–5900		●	●	6000
100											●	●	6000
125											●	●	6000

Table 1

The nominal diameters and leads are standard to DIN 69 051, Part 2, and ISO 3408-2 (Draft).

Standard: Right-hand thread

Other leads, diameters and screw lengths can be manufactured on request. Please contact us for details.

① The ends (about 150 to 200 mm) are marked to show that they are not necessarily to tolerance.

Acceptance conditions

Accuracy classes

Ball screw assembly	Class	Accumulated lead deviation ΔP_{tot} (µm) over screw length l (mm): 300	600	900	1200	1500	2000	3000
Ground Thread	5	5	8	11	13	15	19	25
	10	10	16	22	26	31	38	50
	25	25	41	54	66	77	94	125
	50	50	81	108	132	154	189	250
Precision-Rolled Thread	25	25	50	75	100	125	167	250
	50	50	100	150	200	250	333	500
	100	100	200	300	400	500	666	1000
	200	200	400	600	800	1000	1333	2000

Table 2

The accuracy classes given in the table correspond roughly to the following tolerance classes to DIN 69051 Part 3:

Class 5 (5 µm/300 mm) ≈ tolerance class 1
Class 10 (10 µm/300 mm) ≈ tolerance class 3
Class 25 (25 µm/300 mm) ≈ tolerance class 5
Class 50 (50 µm/300 mm) ≈ tolerance class 7
Class 200 (200 µm/300 mm) ≈ tolerance class 10

Further purchase specifications to DIN 69051 Part 3

Machining of Screw Ends

Precision-Rolled Thread
- *not machined*
- ends soft annealed
- *standard screw ends*
- to customer's drawing
- *standard end supports and housings*

Ground Thread
- *always to customer's drawing*

STAR Precision Ball Screw Assemblies

General

ISO/DIS 3408-1 (Draft International Standard) defines a ball screw assembly as follows:

"An assembly comprising a ball screw shaft and ball nut and which is capable of converting rotary motion to linear motion and vice versa. The rolling elements of the assembly are balls."

Advantages over the conventional Acme screw drive

- The mechanical efficiency of the ball screw assembly is up to 98 % by comparison with a maximum of 50 % in the case of the Acme screw drive
- higher life expectancy thanks to negligible wear during operation
- less drive power required
- no stick-slip effect
- more precise positioning
- higher travel speed
- less heat-up

Because of their high mechanical efficiency, ball screw assemblies are not self-locking.

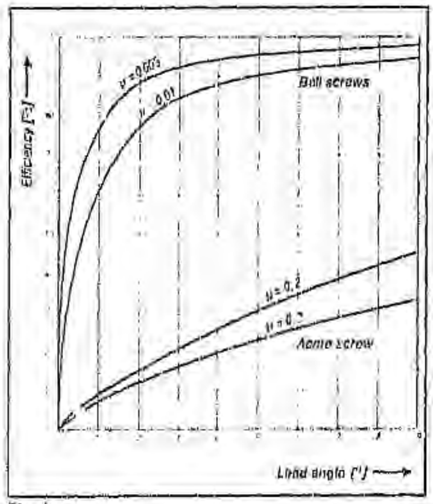


Fig. 1

Fields of Application

Ball screw assemblies have an excellent service record throughout the world in the following applications:

Machine tool engineering

General mechanical engineering
- paper-processing machines
- packaging machines
- printing machines
- plastics processing machines
- handling machines (robots)
- drawing machines
- lifting units (e.g. car lifts)
- valve actuators

Steel industry
- smelting plant
- slab lifting plant

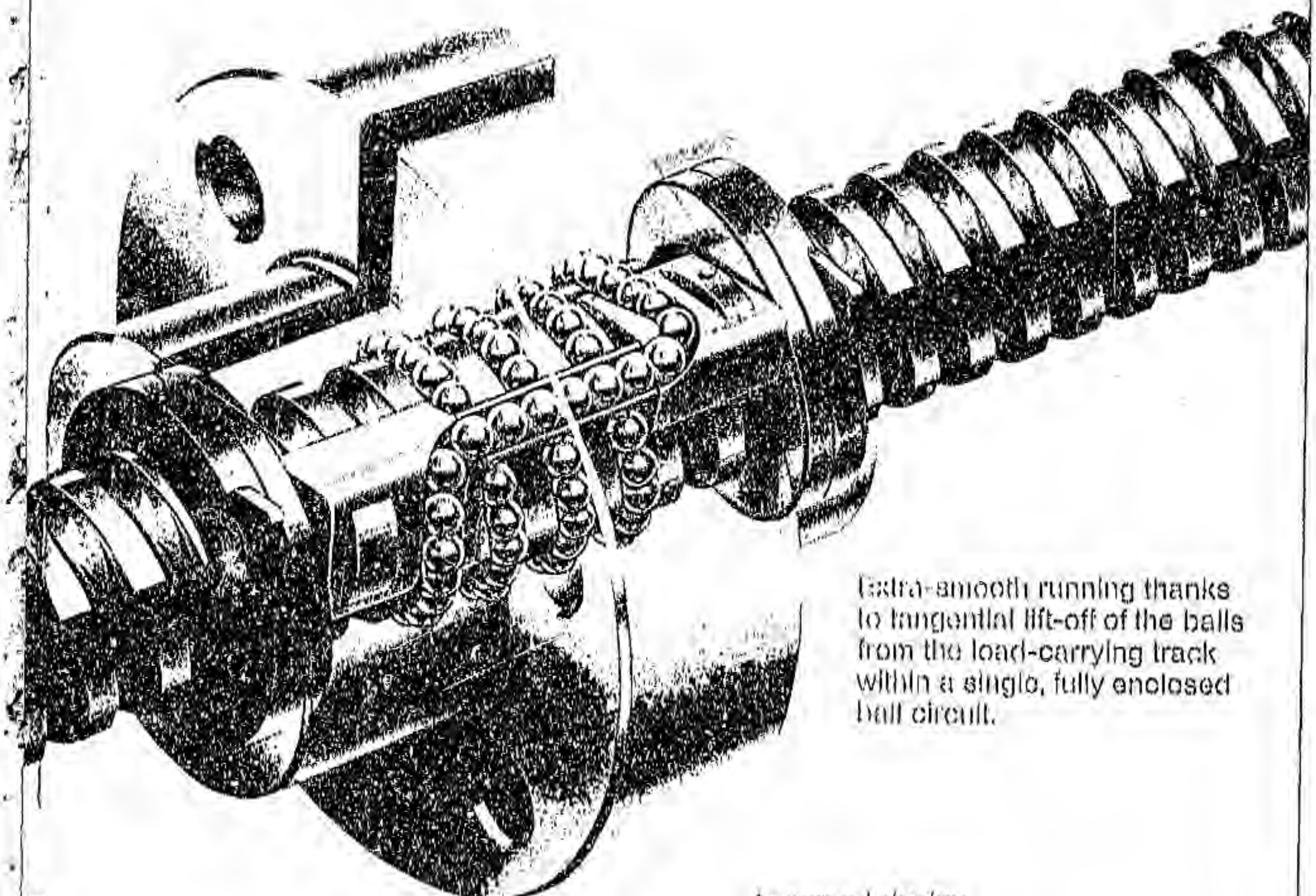
Automobile industry
- steering gears

Reactor technology
- refuelling machines
- control rod drive mechanisms

Aircraft industry
- aircraft landing flaps
- airport technology
- telescopic hoist spindles for landing equipment

Medical technology
- X-ray apparatus
- radiotherapy devices
- hospital beds

Semaphore technology
- signal arm movements


Short nut length
Extra-smooth running thanks to tangential lift-off of the balls from the load-carrying track within a single, fully enclosed ball circuit.
Compact design
No protruding parts: mounting the nut is no problem.

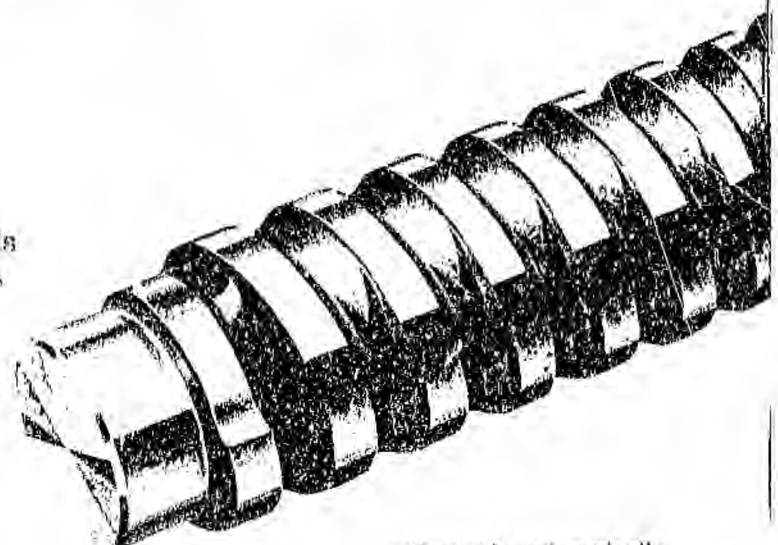
STAR Ball Screw Assemblies open up new potential in screw drive system design and application.
They are manufactured to the same high quality standards at STAR in Germany and at STAR's French subsidiary. Users benefit from STAR's know-how and decades of experience with anti-friction linear motion systems, from development to series-production.

For instance to replace the costly double-nut arrangements conventionally used in many applications.

STAR Adjustable-Preload Single Nuts

- Reduce system design cost
- Provide off-the-shelf availability:
  Ball Screw and nut need not be made to suit.

Large number of recirculating balls gives high load-carrying capacity.



Available at short notice

Smooth outer shell; internal ball recirculation system with precision moulded transition track for consistently smooth operation.

Appendix D Ballscrews

BASE+9	16C54 time base and interrupt control						
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	DI/TIMER	T-BASE2	T-BASE1	T-BASE0

T-BASE 2, 1, 0 16C54 time base control

0 0 0	0.1 msecond time base
0 0 1	1 msecond time base
0 1 0	10 msecond time base
0 1 1	100 msecond time base
1 0 0	1 second time base

DI/TIMER Interrupt by DI1 or timer control

0	Interrupt by DI1
1	Interrupt by timer

BASE+10 16C54 divider control								
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	DIV7	DIV6	DIV5	DIV4	DIV3	DIV2	DIV1	DIV0

BASE+12 8259

See Appendix A

BASE+13 8259

See Appendix A

APPENDIX A

8259A Data Sheet

BASE+3	CH1 counter latch source/counter latch on reset							
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	LC	S2	S1	S0

BASE+4	CH2 counter latch source/counter latch on reset							
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	LC	S2	S1	S0

BASE+5	CH3 counter latch source/counter latch on reset							
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	LC	S2	S1	S0

S2, S1, S0 The source of the signal to latch the counter data

- 0 0 0 S/W read latch data
- 0 0 1 Index-in latch data
- 0 1 0 DI0 latch data
- 0 1 1 DI1 latch data
- 1 0 0 Timer latch data

LC Reset/do not reset counter value after it is latched

- 0 Do not reset counter after it is latched
- 1 Reset counter after it is latched

BASE+6	Counter overflow lock control							
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	NA	OL3	OL2	OL1

OL3 ~ OL1 Counter overflow lock control (OL3 = CH3, OL2 = CH2, OL1 = CH1)

- 0 Counter value locked when counter overflows
- 1 Counter continues counting (wraps over) when counter overflows

BASE+7	Counter reset							
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	NA	CH3	CH2	CH1

CH3 ~ CH1 Reset counter

- 1 Reset corresponding counter
- 0 Counter not reset

BASE+8	System clock source / cascade mode control							
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	CAS1	CAS0	SYS1	SYS0

SYS1, SYS0 System clock source

- 0 0 8 MHz system clock
- 0 1 4 MHz system clock
- 1 0 2 MHz system clock
- 1 1 N/A

CAS1, CAS0 Cascade mode

- 0 0 24 bit (no cascade)
- 0 1 48 bit (CH1, CH2 cascade)
- 1 0 N/A
- 1 1 N/A

BASE+14 Status								
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	DI1	DI0	CH3 ZIN	CH2 ZIN	CH1 ZIN

D2 ~ D0 CH3 ~ CH1 Index status.

D3 Digital Input Channel 0 status.

D4 Digital Input Channel 1 status.

BASE+15 8259 INTA register
See Appendix A

Register format (write)

The following table gives the assignment of each of the card's write ports:

I/O port assignments - Write	
Port	Assignment
BASE+0	CH1 mode setting
BASE+1	CH2 mode setting
BASE+2	CH3 mode setting
BASE+3	CH1 counter latch source/counter latch on reset
BASE+4	CH2 counter latch source/counter latch on reset
BASE+5	CH3 counter latch source/counter latch on reset
BASE+6	Counter overflow lock control
BASE+7	Counter reset
BASE+8	System clock source / cascade mode control
BASE+9	16C54 time base and interrupt control
BASE+10	16C54 divider control
BASE+11	N/A
BASE+12	8259, see Appendix A
BASE+13	8259, see Appendix A

BASE+0 CH1 mode setting								
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	RF	M2	M1	M0

BASE+1 CH2 mode setting								
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	RF	M2	M1	M0

BASE+2 CH3 mode setting								
Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	NA	NA	NA	NA	RF	M2	M1	M0

M2 ~ M1 Input mode control

- 0 0 0 Disable
- 0 0 1 Quadrature input X1
- 0 1 0 Quadrature input X2
- 0 1 1 Quadrature input X4
- 1 0 0 2 pulse input
- 1 0 1 1 pulse input
- 1 1 0 N/A
- 1 1 1 Cascade

RF Reset value

- 1 The counter value will be set to 800000 when you reset the counter
- 0 The counter value will be set to 000000 when you reset the counter

The PCL-833 uses 16 consecutive addresses in the PC I/O address space. DIP switch SW1 sets the card's base, or beginning address. Specific I/O ports are referred to by their offset from the base address, BASE. For example, the address for the seventh register is BASE+6.

Register format (read)

The following table gives the assignment of each of the card's read ports.

I/O port assignments - Read

Port	Assignment
BASE+0	CH1 low byte
BASE+1	CH1 mid byte
BASE+2	CH1 high byte
BASE+3	CH1 overflow flag
BASE+4	CH2 low byte
BASE+5	CH2 mid byte
BASE+6	CH2 high byte
BASE+7	CH2 overflow flag
BASE+8	CH3 low byte
BASE+9	CH3 mid byte
BASE+10	CH3 high byte
BASE+11	CH3 overflow flag
BASE+12	8259 register, see Appendix A
BASE+13	8259 register, see Appendix A
BASE+14	Digital input status
BASE+15	8259 register, see Appendix A

BASE+0, 4, 8 CH1, CH2, CH3 low byte data

Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	C7	C6	C5	C4	C3	C2	C1	C0

BASE+1, 5, 9 CH1, CH2, CH3 mid byte data

Bit	D15	D14	D13	D12	D11	D10	D9	D8
Value	C15	C14	C13	C12	C11	C10	C9	C8

BASE+2, 6, 10 CH1, CH2, CH3 high byte data

Bit	D7	D6	D5	D4	D3	D2	D1	D0
Value	C23	C22	C21	C20	C19	C18	C17	C16

BASE+3, 7, 11 CH1, CH2, CH3 Overflow

Bit	D15	D14	D13	D12	D11	D10	D9	D8
Value	OV	NA	NA	NA	NA	NA	NA	NA

OV Overflow flag

1 Counter overflow has occurred

0 No overflow

BASE+12 8259 register

See Appendix A

BASE+13 8259 register

See Appendix A

Interrupt function

The PCL-833 can generate an interrupt to the PC for any of the following conditions:

1. Counter 1 overflow
2. Counter 2 overflow
3. Counter 3 overflow
4. Counter 1 index i.
5. Counter 2 index in
6. Counter 3 index in
7. DI0 input
8. DI1 input
9. Timer pulse

The card's 8259A interrupt controller chip combines these interrupts into a single PC interrupt, set by jumper JP1. Since the 8259A only has eight input channels, the DI1 and timer interrupts share a single interrupt line. Bit 3 of write register BASE+9 selects DI1 or timer.

Note that you can use only one of the card's interrupt sources at a given time, unless you specially program your interrupt service routine to handle multiple interrupt sources.

You enable the PCL-833 interrupt functions by programming the card's 8259 chip, accessed through the registers at BASE+12 and BASE+13. You will need to set the chip's interrupt mask register to exclude all but one of the interrupt lines.

Program the 8259 in 8086/8088 mode, single mode, edge-triggered mode. In 8086/8088 mode two INTA signals are needed. The PCL-833 generates the first INTA automatically. Your program generates the second INTA by reading BASE+15. This read returns the interrupt vector number which caused the request.

The hold time must be at least 1 usec. after a low-to-high transition of the interrupt source to ensure that the interrupt occurs.

See Appendix A for more information.

CHAPTER 4

Programming

DI1 latch
A rising edge on the DI1 line will latch the counter value for the channel.

Timer latch
The card latches the counter value on a rising edge of pulses from the card's on-board timer.

Counter reset value

Bit 3 (RF) of registers BASE+0, 1 and 2 control the initial (reset) value of for each counter. You can select either 000000 or 800000 (hex). When the counter is reset, it will take this value.

When RF = 0, the counter will reset to 000000h.

When RF = 1, the counter will reset to 800000h.

Reset after latch

Bit 3 (LC) of registers BASE+3, 4 and 5 determine whether the corresponding counter will reset to its initial value (see preceding section) when it is latched.

If LC = 1, the counter will reset to its initial value when it is latched.

If LC = 0, the counter will stay the same (keep its previous value) when it is latched.

Cascade mode

24 bits is enough for most counter applications. If you need to store larger values, you can cascade the output of one counter into the input of a second, giving 48 bits of storage. When the first counter overflows, the card increments the second counter.

The PCL-833 lets you cascade channel 1 into channel 2 to form a single 48-bit counter. (Channel 3 will not cascade.)

The mode settings of channel 1 control this 48-bit counter, except that the setting of channel 2 controls the initial (reset) value.

You set up the 48-bit counter as follows:

1. Set bits CAS1 and CAS0 of write register BASE+8 to 01h.
2. Set CH2 to cascade mode. (Set Bits 0-2 of register BASE+1 to "1 1 1".
3. Set the initial (reset) value in CH2.
4. Set remaining modes in CH1.

To read the total value, you must read both counters. Channel 1 holds the high 24-bits and channel 2 the low 24-bits.

Timer function

The PCL-833's on-board timer lets you monitor counter readings with extreme accuracy. The programmable timer generate pulses at regular intervals. The card can latch the readings in its counters and generate an interrupt to the PC.

You can set timer cycle periods from 1 msec. to 255 seconds. The cycle time is the product of the timer base period and a multiplier. Timer base periods are 1, 10, 100 or 1000 msec. The multiplier ranges from 1 to 255. The divider can range from 1 to 255.

For example, to set a timer period of 20 msec, you would set the timer base to 1 msec and the multiplier to 20. That is:

Timer period = Base period x multiplier
20 msec = 1 msec x 20

Set the timer period by programming registers BASE+9 and BASE+10.

You can use the timer to latch the counter values and/or to generate an interrupt to the PC. To use the timer latching set registers BASE+3, 4 and 5. To generate an interrupt with the timer set bit 3 of BASE+9 and program the card's 8259A interrupt controller. See the following sections for more information.

Direction of load and its influence on the load capacity of open STAR Super Linear Bearings

Load capacity factors f_ϱ and f_{ϱ_0}

The stated load capacities C and C_0 apply when the load is acting along the line $\varrho = 0°$ as shown in Figures 13 and 14. If the load is acting in any other direction, these load capacities must be multiplied by the factor f_ϱ (for dynamic load capacity C) or f_{ϱ_0} (for static load capacity C_0).

The reduction in load capacity can be minimized by selective circumferential positioning of the STAR Super Linear Bearing (see STAR Linear Set with Side Opening, pages 25 to 27).

Sizes 12 and 16

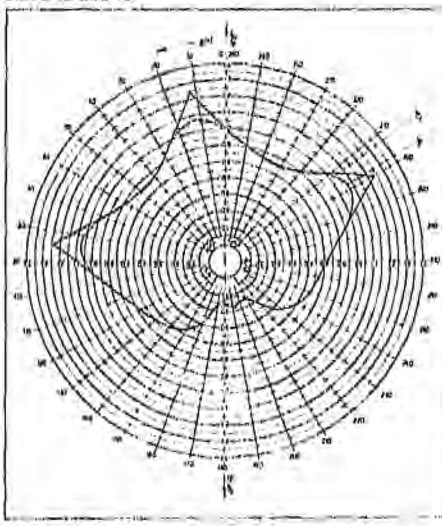


Figure 13

Sizes 20 to 50

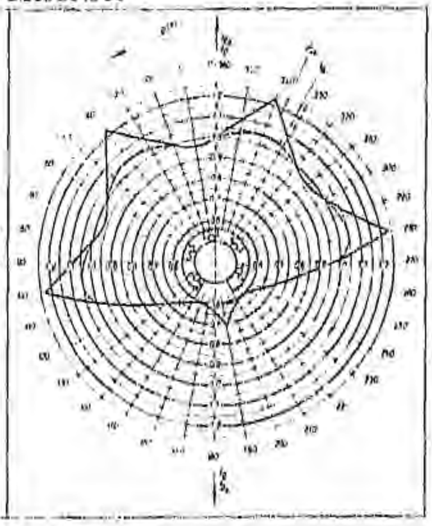


Figure 14

Reduced Load Capacity in Short-Stroke Applications

In short-stroke applications, the service life of the shafts is shorter than that of the STAR Super Linear Bearings.

For this reason, the load capacities C given in Tables 1 and 2 must be multiplied by the factor f_w (see Figure 15).

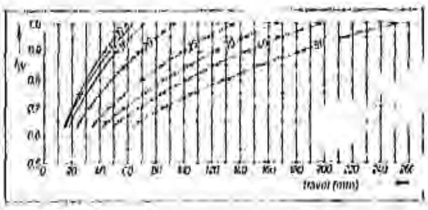


Figure 15

Separate Seals

The seal and holding rings can be used to give STAR Super Linear Bearings additional axial retention.
The choice of seal depends on the length of the housing bore. The following are examples of sealing arrangements for various bore lengths.

Material: Wiper-type seal ring made of polyurethane elastomer, metal case made of steel, holding ring made of polyamide 6.

Important to mounting: To prevent damage to the holding rings, these must not be allowed to tilt during mounting.

Bore length > B

Seal with Metal Case (closed type)

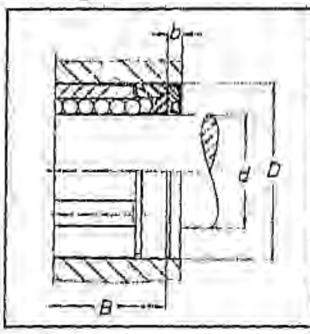


Figure 10

Reference No. Super Linear Bearing with 1 seal	with 2 seals	Spares: Seal with metal case	Metal case[1]	Dimensions (mm) d	D[2]	B	b +0,3
067.-110-00	067.-210-00	1331-610-00	0901-184-00	10	19	29	3
067.-112-00	067.-212-00	1331-612-00	0901-074-00	12	22	32	3
067.-116-00	067.-216-00	1331-616-00	0901-075-00	16	26	36	3
067.-120-00	067.-220-00	1331-620-00	0901-076-00	20	32	45	4
067.-125-00	067.-225-00	1331-625-00	0901-077-00	25	40	58	4
067.-130-00	067.-230-00	1331-630-00	0901-078-00	30	47	68	5
067.-140-00	067.-240-00	1331-640-00	0901-079-00	40	62	80	5
067.-150-00	067.-250-00	1331-650-00	0901-115-00	50	75	100	6

0 = Super Linear Bearing
2 = Super Linear Bearing, Type B

Table 7

Seal with Metal Case (open type)

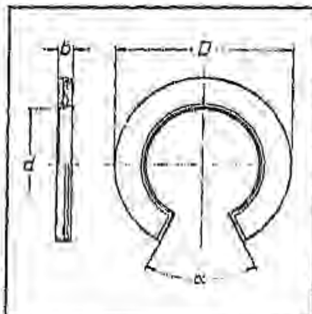


Figure 11

Reference No. Super Linear Bearing with 1 seal	with 2 seals	Spares: Seal with metal case	Dimensions (mm) d	D[2]	b +0,1 −0,2	Angle (°) α[3]
067.-112-00	067.-212-00	1331-712-60	12	22	3	66
067.-116-00	067.-216-00	1331-716-60	16	26	3	68
067.-120-00	067.-220-00	1331-720-60	20	32	4	66
067.-125-00	067.-225-00	1331-725-60	25	40	4	67
067.-130-00	067.-230-00	1331-730-60	30	47	5	67
067.-140-00	067.-240-00	1331-740-60	40	62	6	56
067.-150-00	067.-250-00	1331-750-60	50	75	6	54

1 = Super Linear Bearing, open
3 = Super Linear Bearing, Type B, open

Table 8

Bore length = B_1

Seal with Holding Ring (closed type)

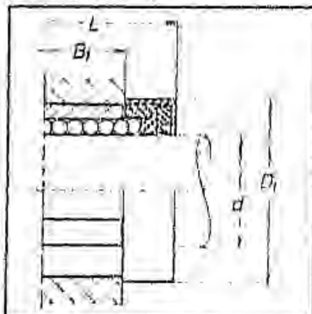


Figure 12

Reference No. Super Linear Bearing with 1 seal	with 2 seals	Spares: Seal with holding ring	Dimensions (mm) d	D_1	L	B_1
067.-112-10	067.-212-10	1331-812-10	12	23,5	39	20
067.-116-10	067.-216-10	1331-816-10	16	27,5	43	22
067.-120-10	067.-22 1-10	1331-820-10	20	33,5	54	28
067.-125-10	067.-225-10	1331-825-10	25	42	67	40
067.-130-10	067.-230-10	1331-830-10	30	49,5	89	48
067.-140-10	067.-240-10	1331-840-10	40	65	92	56
067.-150-10	067.-250-10	1331-850-10	50	78	115	72

0 = Super Linear L aring
2 = Super Linear Bearing, Type B

Table 9

[1] For axial retention
[2] Outside diameter D is about 0.1 mm oversize. No retaining elements required. Additional means of retention recommended for linear bearings with open seal in applications subject to vibration or high acceleration.
[3] Minimum when mounted in a bore of nominal diameter 'D'

Open type with all-round seal

For dimensions, load capacities and radial clearances, refer to Table 2 on page 4.

Reference No. Open Type	Reference No. Open Type B	d (mm)
0671-212-45	0673-212-45	12
0671-216-45	0673-216-45	16
0671-220-45	0673-220-45	20
0671-225-45	0673-225-45	25
0671-230-45	0673-230-45	30
0671-240-45	0673-240-45	40
0671-250-45	0673-250-45	50

Table 4a

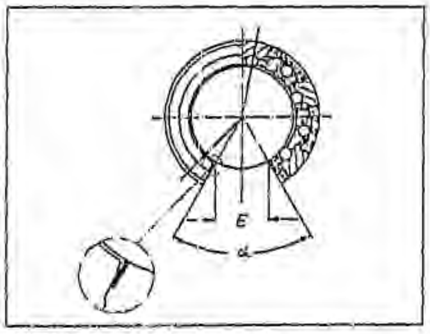


Figure 8a

Friction

The coefficient of friction μ of oil-lubricated STAR Super Linear Bearings without seals is 0.001 – 0.0025.

The coefficient of friction is at its lowest under heavy loads; conversely, under low-load conditions it may be somewhat higher than the range given above.

Table 5 gives the frictional resistance of STAR Super Linear Bearings with seals at both ends but without radial loading. The frictional resistance is a function of speed and lubrication.

Size code	Frictional Resistance Breakaway (N, approx.)	Frictional Resistance Rolling (N, approx.)
[illegible]	[illegible]	[illegible]
12	3	1,5
[illegible]	[illegible]	[illegible]
20	5	2,5
[illegible]	[illegible]	[illegible]
30	9	4
[illegible]	[illegible]	[illegible]
50	15	6

Table 5

Speed and Acceleration

(at approx. 20°C)

$v_{max} = 3\ ^{m}/_{s}$

$a_{max} = 150\ ^{m}/_{s^2}$

Please contact us for information on higher speed and acceleration levels.

Permissible Operating Temperatures

Linear bearings without seals: up to 100 °C.
Linear bearings with seals: up to 100 °C.

Load Capacity and Direction of Load

(closed type)

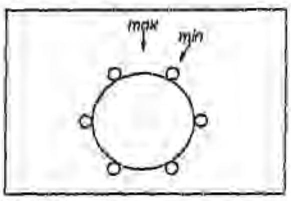


Figure 9

The load capacity ratings given in table 1 (page 4) refer to conditions when the linear bearing is in the "minimum" position relative to the direction of loading (fig. 9) and should be used in all calculations.

In applications where the direction of load is exactly known and where the linear bearings can be mounted in the "maximum" position (Fig. 9), the load capacity rating may be multiplied by the factor f_{max} (dynamic load capacity C) or $f_{o\,max}$ (static load capacity C_o) from Table 6.

Load capacity factors f_{max} and $f_{o\,max}$

Shaft diameter (mm)	f_{max}	$f_{o\,max}$
10, 12, 16,	1,25	1,46
20, 25, 30, 40	1,09	1,28

Table 6

This type likewise affords 3 times the load-carrying capacity or 27 times the service life of STAR Standard Linear Bearings. Because the surfaces of the steel bearing plates are plane, however, the self-alignment feature does not apply.

The designer who has no need for this special feature can still use this type of STAR Super Linear Bearing to gain all the other advantages described on pages 2 and 3.

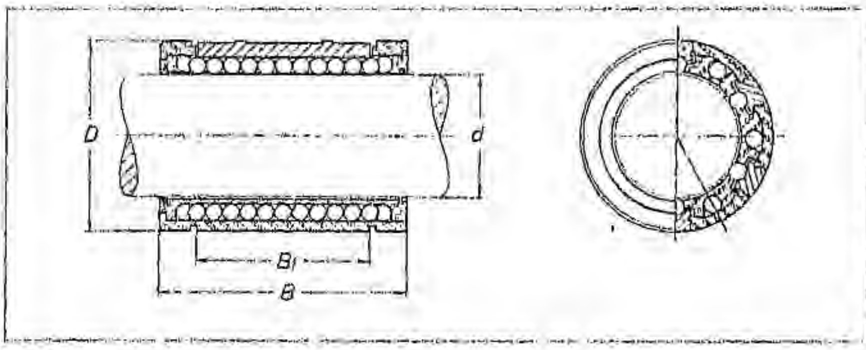


Figure 5

Type B, Closed

Reference Number without seal	Reference Number with integral seals[2]	d (mm)
0672-010-00	0672-.10-40	10
0672-012-00	0672-.12-40	12
0672-016-00	0672-.16-40	16
0672-020-00	0672-.20-40	20
0672-025-00	0672-.25-40	25
0672-030-00	0672-.30-40	30
0672-040-00	0672-.40-40	40
0672-050-00	0672-.50-40	50

Table 3

1 = with 1 seal
2 = with 2 seals

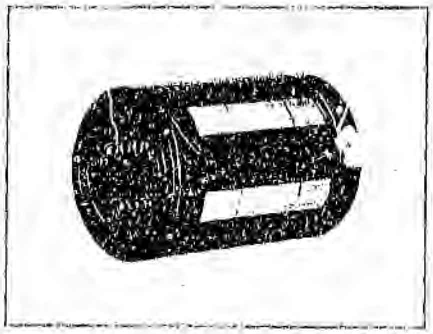


Figure 6

[2] For separate seals refer to page 7.

Type B, Open

For dimensions, load capacities and radial clearances, refer to table 2 on page 4.

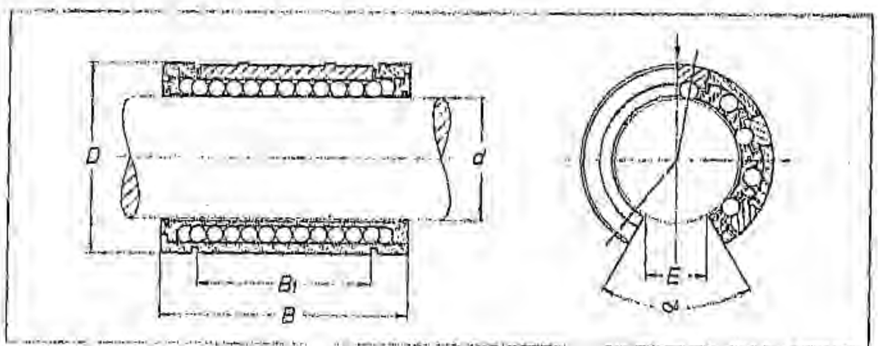


Figure 7

Reference Number without seal	Reference Number with integral seals[2]	d (mm)
0673-012-00	0673-.12-40	12
0673-016-00	0673-.16-40	16
0673-020-00	0673-.20-40	20
0673-025-00	0673-.25-40	25
0673-030-00	0673-.30-40	30
0673-040-00	0673-.40-40	40
0673-050-00	0673-.50-40	50

Table 4

1 = with 1 seal
2 = with 2 seals

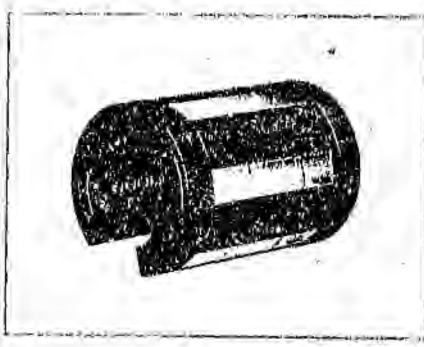


Figure 8

[2] For separate seals refer to page 7.

STAR Super Linear Bearings with Self-Alignment Feature

Closed Type

When this type is used, the self-alignment feature requires two STAR Super Linear Bearings to be mounted on at least one of the shafts of the assembly.

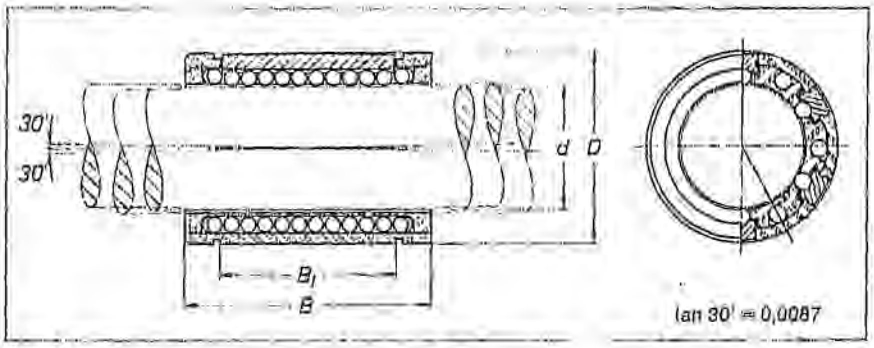


Figure 3

Reference Number: without seal	with one seal[3]	with two seals[3]	d	D	B ±0,2	B_1 +0,2	No. of ball circuits	Load Capacities (N) dyn. C[2]	stat. C_0	Radial Clearance (µm) (shaft/bore) h7/H7	h7/JS7	h6/JS6	h6/K6	Weight (kg)
0670-010-00	0670-110-40	0670-210-40	10	19	29	18	5	500	390	$^{+30}_{+8}$	$^{+29}_{-2}$	$^{+20}_{-1}$	$^{+16}_{-6}$	0,017
0670-012-00	0670-112-40	0670-212-40	12	22	32	20	5	650	520	$^{+40}_{+8}$	$^{+30}_{-2}$	$^{+21}_{-1}$	$^{+16}_{-6}$	0,023
0670-016-00	0670-116-40	0670-216-40	16	26	36	22	5	800	630	$^{+30}_{+8}$	$^{+30}_{-2}$	$^{+21}_{-1}$	$^{+16}_{-6}$	0,028
0670-020-00	0670-120-40	0670-220-40	20	32	45	28	6	1500	1250	$^{+45}_{+8}$	$^{+33}_{-4}$	$^{+23}_{-3}$	$^{+18}_{-8}$	0,061
0670-025-00	0670-125-40	0670-225-40	25	40	58	40	6	2500	2200	$^{+45}_{+8}$	$^{+33}_{-4}$	$^{+23}_{-3}$	$^{+16}_{-8}$	0,122
0670-030-00	0670-130-40	0670-230-40	30	47	68	48	6	3200	2800	$^{+45}_{+8}$	$^{+33}_{-4}$	$^{+23}_{-3}$	$^{+18}_{-8}$	0,185
0670-040-00	0670-140-40	0670-240-40	40	62	80	56	6	5500	4900	$^{+50}_{+8}$	$^{+36}_{-7}$	$^{+25}_{-6}$	$^{+19}_{-11}$	0,360
0670-050-00	0670-150-40	0670-250-40	50	75	100	72	6	8600	7100	$^{+50}_{+8}$	$^{+35}_{-7}$	$^{+25}_{-6}$	$^{+19}_{-11}$	0,580

Table 1

[2] In short-stroke applications, please observe reduction factor f_w from page 8, fig. 15. [3] For separate seals refer to page 7.

Open Type

STAR Shaft Support Rails are available for all shaft diameters (refer to pages 38 to 44, tables 1 to 4). The user may also use the mating dimensions given in the tables to design his own shaft supports. When this type is used, the self-alignment feature requires two STAR Super Linear Bearings to be mounted on at least one of the shafts of the assembly.

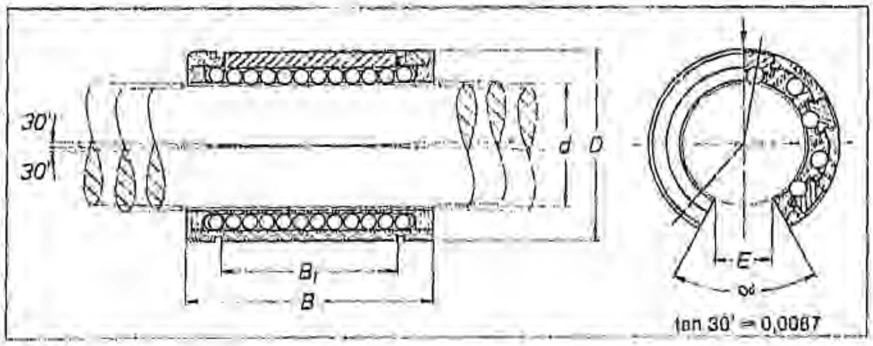


Figure 4

Reference Number: without seal	with one seal[3]	with two seals[3]	d	D	B ±0,2	B_1 +0,2	E[4]	Angle α (°)	No. of ball circuits	Load Cap. (N)[5] dyn. C[2]	stat. C_0	Radial Clearance (µm) (shaft/bore) h7/H7	h7/JS7	h6/JS6	h6/K6	Weight (kg)
0671-012-00	0671-112-40	0671-212-40	12	22	32	20	6,5	66	4	750	600	$^{+40}_{+8}$	$^{+30}_{-2}$	$^{+21}_{-1}$	$^{+18}_{-6}$	0,018
0671-016-00	0671-116-40	0671-216-40	16	26	36	22	9	68	4	920	730	$^{+40}_{+8}$	$^{+30}_{-2}$	$^{+21}_{-1}$	$^{+16}_{-6}$	0,022
0671-020-00	0671-120-40	0671-220-40	20	32	45	28	9	65	5	1560	1300	$^{+45}_{+8}$	$^{+33}_{-4}$	$^{+23}_{-3}$	$^{+18}_{-8}$	0,051
0671-025-00	0671-125-40	0671-225-40	25	40	58	40	11,5	67	5	2600	2290	$^{+45}_{+8}$	$^{+33}_{-4}$	$^{+23}_{-3}$	$^{+18}_{-8}$	0,102
0671-030-00	0671-130-40	0671-230-40	30	47	68	48	14	57	5	3330	2910	$^{+45}_{+8}$	$^{+33}_{-4}$	$^{+23}_{-3}$	$^{+18}_{-8}$	0,156
0671-040-00	0671-140-40	0671-240-40	40	62	80	56	19,5	56	5	5720	5100	$^{+50}_{+8}$	$^{+36}_{-7}$	$^{+25}_{-6}$	$^{+19}_{-11}$	0,300
0671-050-00	0671-150-40	0671-250-40	50	75	100	72	22,5	54	5	8940	7380	$^{+50}_{+8}$	$^{+36}_{-7}$	$^{+25}_{-6}$	$^{+19}_{-11}$	0,480

Table 2

[2] In short-stroke applications, please observe reduction factor f_w from page 8, fig. 15
[3] For separate seals refer to page 7.
[4] Lower limit relative to shaft diameter 'd'
[5] See page 5, figures 13 and 14

Unbeaten Smooth Running

Self-alignment of the bearing plates and the ground-quality finish of the ball tracks result in extremely smooth operation. The running diagram below shows a com arison with a conventional linear bearing for a load of 800 N and alignment error of about 8′ (due to shaft deflection).

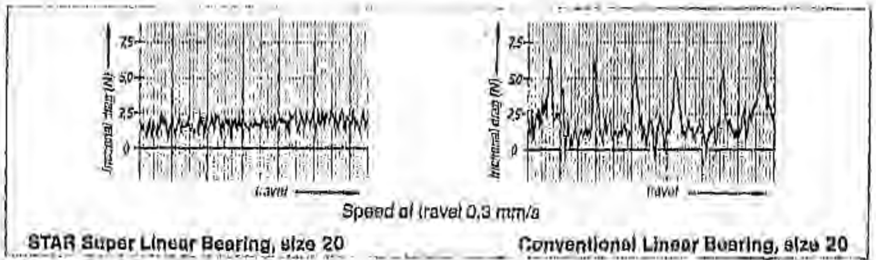


Figure 2

High Running Speed

Precision guidance of the balls in the ball grooves permits faster acceleration and higher running speeds.

Long Travel Life

The STAR Super Linear Bearing affords the designer a substantially longer travel life than other types of bearing with the same as-installed dimensions. Given a shaft diameter of 20 mm under the service conditions a = 150 mm, b = 200 mm, l = 500 mm, and F = 800 N, the shaft deflection would be about 8′ (see running diagram, Figure 2, and loading condition 1, Part 1A, page 62). Under these service conditions, the travel life of a conventional linear bearing would be lower by about 90 % than that of a STAR Super Linear Bearing.

Cost-Effective Design

The high load capacity and its high utilization factor thanks to the self-alignment feature permit the use of smaller components (shaft, linear bearing, housing) and thus money-saving design of all elements.

Structural Design

The STAR Super Linear Bearing consists of:
- a ball retainer with outer sleeve (of polyamide 6.6)
- the hardened steel segmental bearing plates and
- high-carbon chrome alloy steel balls.

The steel bearing plates, which serve to take up the external load, have grooves along their sides which snap into the outer sleeve. This snap fit permits slight radial movement of the bearing plates, enough to allow them to make perfect contact with the contour of the housing bore for exact and easy adjustment of radial clearance.

Sealing

STAR Super Linear Bearings are available with integral or with separate wiper-type seals. Use of separate seals is advisable where there is a high risk of foreign-body soiling. The STAR Super Linear Bearing's versatility makes it suitable for use in a wide range of applications, some of which may make additional sealing (e.g. bellows-type dust boots or telescoping sleeves) necessary.

STAR Super Linear Bearings

STAR Super Linear Bearings with ground ball track grooves automatically compensate for alignment errors. In combination with ideal track geometry in the ball return zone, these features ensure unbeaten smooth running. Even where shaft deflection would cause rough running and stutter and severely reduce the service life of conventional linear bearings.

STAR Super Linear Bearings – patented experience in the construction of ball-bearing linear motion systems.

Self-alignment

STAR Super Linear Bearings automatically compensate for alignment errors of up to 30′. No reduction in load-carrying capacity due to pressure between bearing edge and shaft.

The outer surface of the steel bearing plates is designed with the central portion slightly thicker than its ends. The central portion serves as a rocking fulcrum which allows each individual bearing plate to compensate for minor errors in alignment between shaft and housing bore that might be caused by inaccurate machining[1)], mounting errors or shaft deflection. This self-alignment feature assures smooth entry and exit of the balls into and out of the load-carrying area and uniform load distribution over the entire row of balls.

Result: much smoother running, much higher load capacity, and substantially longer travel life than conventional linear bearings subject to bearing edge pressure due to axially off-centre loading.

[1)] The self-alignment feature is not able to compensate for poor parallelism between the two shafts of a table assembly.

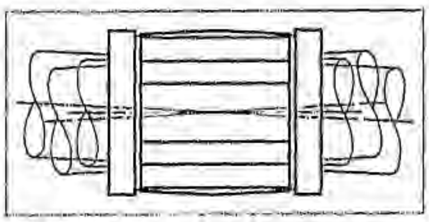


Figure 1

Ground Ball Tracks, High Load Capacities

Each bearing plate has a groove, the ball track, in which the balls roll. These ball grooves are ground for extra smoothness. The smooth, close-contact running between balls and ball track thus achieved yields, in combination with the long ball tracks, high load-carrying capacities.

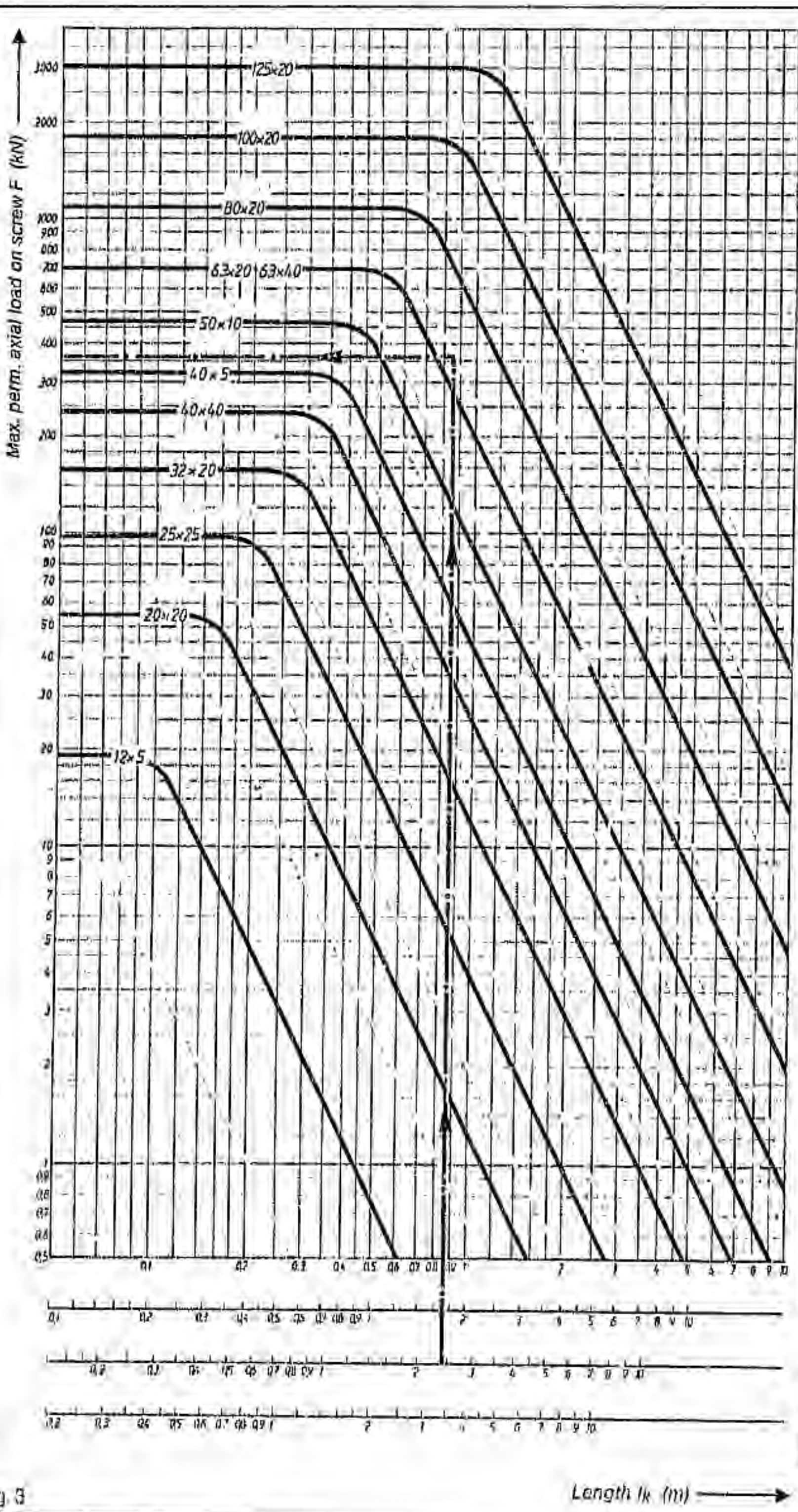


Fig. 3

Permissible axial load on screw (Buckling Load)

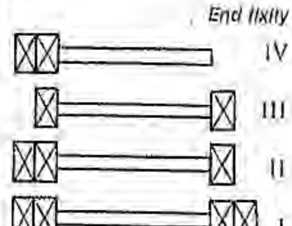
The permissible axial load on the screw depends on the diameter of the screw, the type of end fixity, and the effective (=unsupported) length l_k of the screw.
Allowance should be made for a safety factor of $\gamma \geqq 2$ in the determination of the permissible axial load.

Example:

Screw diameter	63 mm
Lead	10 mm
Length l_K	2.4 m

End fixity Type II (fixed – simple)

According to the figure, the theoretical maximum permissible axial load is 360 kN. Applying a safety factor of 2, we obtain a permissible axial service load of
360 kN : 2 = 180 kN.
This lies above the maximum operating load of F_1 = 50kN actually occurring in service as used in our example of calculation.



Critical Speed

The critical speed depends on the diameter of the screw, the type of end fixity, and the free length l_n of the screw. No allowance may be made for guidance by the nut. The operating speed should not be greater than 80 % of the critical speed.

Example:
Screw diameter 63 mm
Length l_n 2.4 m
End fixity Type II (fixed – simple)

According to the figure, the critical speed is 1850 min⁻¹. The *safe operating speed* is thus 1850 min⁻¹ x 0.8 = **1480 min⁻¹**.

The maximum operating speed in our example of calculation, n_a = 1000 min⁻¹, is thus below the safe operating speed.

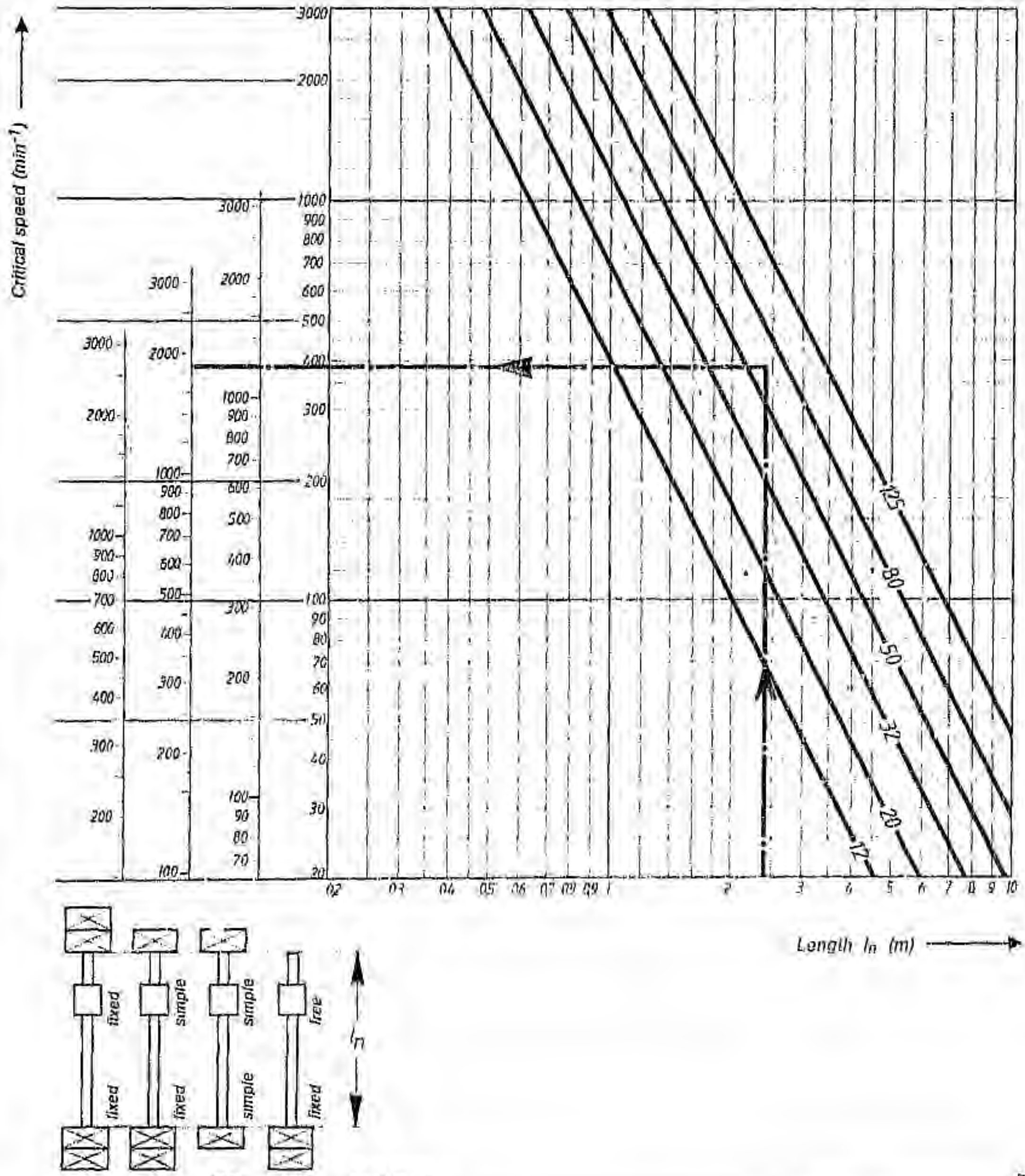


Fig. 2

Example of calculation

Ball screw assembly, $d_o = 63$ mm, $P = 10$ mm

Service conditions

$F_1 = 50\,000$ N at $n_1 = 10$ min^{-1} für $q_1 = 6\,\%$ of the duty cycle
$F_2 = 25\,000$ N at $n_2 = 30$ min^{-1} für $q_2 = 22\,\%$ of the duty cycle
$F_3 = 8\,000$ N at $n_3 = 100$ min^{-1} für $q_3 = 47\,\%$ of the duty cycle
$F_4 = 2\,000$ N at $n_4 = 1000$ min^{-1} für $q_4 = 25\,\%$ of the duty cycle
100 %

The service life of the machine is required to be 40 000 operating hours with the ball screw operating 60 % of the time.

Calculation procedure:

Average speed
(applying formula [illegible])

$$n_m = \frac{6}{100}\cdot 10 + \frac{22}{100}\cdot 30 + \frac{47}{100}\cdot 100 + \frac{25}{100}\cdot 1000$$

$n_m \approx$ **304 min^{-1}**

Average load under variable load and variable speed
(applying formula [illegible])

$$F_m = \sqrt[3]{50\,000^3\cdot\frac{10}{304}\cdot\frac{6}{100} + 25\,000^3\cdot\frac{30}{304}\cdot\frac{22}{100} + 8\,000^3\cdot\frac{100}{304}\cdot\frac{47}{100} + 2\,000^3\cdot\frac{1000}{304}\cdot\frac{25}{100}}$$

$F_m \approx$ **8757 N**

Required life L in revolutions

The life L can be calculated by transformation of formulas [illegible] and [illegible] as follows:

$L = L_h \cdot n_m \cdot 60$

$$L_h = \text{Machine service life} \cdot \frac{\text{Ball screw operating hours}}{\text{Machine operating hours}}$$

$$L_h = 40\,000 \cdot \frac{60}{100} = \mathbf{24\,000\ h}$$

$L = 24\,000 \cdot 304 \cdot 60$

$L =$ **437 760 000 revolutions**

Dynamic load capacity C
(applying formula [illegible])

$$C = 8757 \cdot \sqrt[3]{\frac{437\,760\,000}{10^6}}$$

$C \approx$ **66492 N**

The following ball screw assembly can now be selected from the Tables of Dimensions:
63 · 10; 6 turns (C = 78 500 N); e.g. nut unit, reference number 1502-6-4024.

Cross check:

Life of the selected ball screw assembly in revolutions
(applying formula [illegible])

$$L = \left(\frac{78\,500}{8757}\right)^3 \cdot 10^6$$

$L \approx$ **720 · 10^6 revolutions**

life in hours
(applying formula [illegible])

$$L_h = \frac{720\cdot 10^6}{304\cdot 60} \qquad L_h \approx \mathbf{39\,470\ hours}$$

The life of the ball screw assembly is thus greater than the required life of 24.000 hours.

Average speed and average load

Where both speed and load fluctuate, calculation of life expectancy must be based on the averages F_m and n_m.

– Where speed fluctuates, the average speed n_m is calculated as follows:

$$n_m = \frac{q_1}{100} \cdot n_1 + \frac{q_2}{100} \cdot n_2 + \ldots + \frac{q_n}{100} \cdot n_n$$

n_m = average speed (min^{-1})
q = time fraction (%)

– Where load fluctuates but speed is constant, the average load F_m is calculated as follows:

$$F_m = \sqrt[3]{F_1^3 \cdot \frac{q_1}{100} + F_2^3 \cdot \frac{q_2}{100} + \ldots + F_n^3 \cdot \frac{q_n}{100}}$$

F_m = average load (N)
q = time fraction (%)

– Where both load and speed fluctuate, the average load F_m is calculated as follows:

$$F_m = \sqrt[3]{F_1^3 \cdot \frac{n_1}{n_m} \cdot \frac{q_1}{100} + F_2^3 \cdot \frac{n_2}{n_m} \cdot \frac{q_2}{100} + \ldots + F_n^3 \cdot \frac{n_n}{n_m} \cdot \frac{q_n}{100}}$$

F_m = average load (N)
q = time fraction (%)

Nominal Life

L in revolutions

$$L = \left(\frac{C}{F_m}\right)^3 \cdot 10^6 \Rightarrow C = F_m \cdot \sqrt[3]{\frac{L}{10^6}} \Rightarrow F_m = \frac{C}{\sqrt[3]{\frac{L}{10^6}}}$$

L = nominal life (in revolutions)
C = dynamic load-carrying capacity (N)
F_m = average load (N)

L_h in hours

$$L_h = \frac{L}{n_m \cdot 60}$$

L_h = nominal life in hours (h)
L = nominal life (in revolutions)
n_m = average speed (min^{-1})

$$\text{Machine service life} = L_h \cdot \frac{\text{Machine operating hours}}{\text{Ball screw operating hours}}$$

Drive torque and drive power requirement

Drive torque M_{ta} for conversion of rotational into linear motion:

$$M_{ta} = \frac{F \cdot P}{2000 \cdot \pi \cdot \eta}$$

Transmitted torque M_{te} for conversion of linear into rotational motion:

$$M_{te} = \frac{F \cdot P \cdot \eta'}{2000 \cdot \pi}$$

M_{ta} = drive torque (Nm)
M_{te} = transmitted torque (Nm)
F = operating load (N)
P = lead (mm)
η = mechanical efficiency (approx. 0.9)
η' = mechanical efficiency (approx. 0.8)

In preloaded nuts, allowance must be made for idle-running torque.

Drive power requirement P_a

$$P_a = \frac{M_{ta} \cdot n}{9\,550}$$

P_a = drive power requirement (kW)
M_{ta} = drive torque (Nm)
n = speed (min^{-1})

Material, Hardness

Our ball screw assemblies are made of high-quality heat-treatable steels, carbon chrome alloy steels or case-hardened ste... The raceways in the screws and nuts ha... a Rockwell hardness number of HRC 58 + 4.

Ball screw assemblies made of stainless ...el are also available on request. ...ess otherwise specified, ...e ends of the ...v are not hardened.

Sealing

Ball screw assemblies are precision devices and require protection against foreign-body contamination. Flat protective covers and bellows-type dust boots are particularly suitable for this purpose.
Since there are many applications in which these methods do not afford adequate protection, however, we have developed a wiper-type seal which, thanks to the extremely low friction between its lip edges and the screw, yields a good sealing effect without noticeably reducing the high efficiency of the assembly. Because of this excellent sealing performance, our screw assemblies are supplied with seals as a standard feature. The seals can, however, be omitted at the customer's special request.

Permissible operating temperatures

Ball screw assemblies are suitable for continuous operation at temperatures up to 100°C.

Load-carrying capacity and life expectancy

to DIN 69 051 Part 4 (June 1978 Draft).

Static load capacity C_0

The static load capacity is an axial, concentrically acting force which induces a permanent deformation of **0.0001 x the ball diameter** between the ball and the raceway.

Dynamic load capacity C

The dynamic load capacity is an axial, concentrically acting force of constant magnitude a... ...rection under which a representative sample of identical ball screw assemblies will attain a nominal life of **one million revolutions.**

Life expectancy

The nominal life is expressed by that number of revolutions (or number of operating hours at constant speed) which 90% of a representative sample of identical ball screw assemblies will attain or exceed before the first signs of material fatigue appear. The nominal life is designated as L or L_h, depending on whether it is given in revolutions or in hours.

Critical speed Buckling load

Check against the figures in the following to ensure that there is a safe margin to critical speed and buckling load.

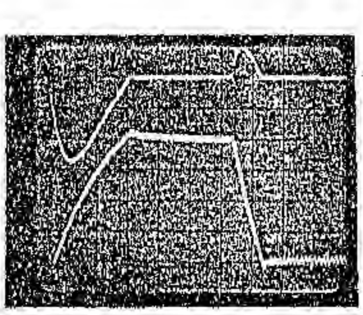
APPLICATION INFORMATION (continued)

b) Large signal response

The large step signal response is limited by slew-rate and inductive load.
In this case, during the rise-time of the motor current, the L292 works in open-loop condition, as can be seen from the photograph of fig. 10.

Fig. 10 - Motor current and pin 7 voltage waveforms (application of fig. 6) Large signal response.

V_7 1V/div.
I_M 0.5A/div.
t 500 μs/div.



The voltage at pin 7 (inverting input of the error amplifier) departs from the reference voltage V_R present at the non-inverting input and the feedback loop is open.
The feedback loop is on when the motor current reaches its steady-state value (2A).

Closed loop system bandwidth

A good choise for ξ is the value $1/\sqrt{2}$. In this case:

$$\frac{I_M}{V_i}(s) = \frac{0.048}{R_s} \cdot \frac{1 + s\,R_F C_F}{1 + 2s\,R_F C_F + 2s^2\,R_F^2 C_F^2} \qquad (8)$$

The module of the transfer function is:

$$\left|\frac{I_M}{V_i}\right| = \frac{0.048}{R_s} \cdot \frac{2\sqrt{1 + \omega^2 R_F^2 C_F^2}}{\sqrt{[(1 + 2\,\omega R_F C_F)^2 + 1] \cdot [(1 - 2\,\omega R_F C_F)^2 + 1]}} \qquad (9)$$

The cutoff frequency is derived by the expression (9) by putting $\left|\frac{I_M}{V_i}\right| = 0.707$ (-3 dB), from which:

$$\omega_T = \frac{0.9}{R_F C_F} \qquad f_T = \frac{0.9}{2\pi R_F C_F}$$

APPLICATION INFORMATION (continued)

Example:

a) Data
- Motor characteristics: $L_M = 5$ mH, $R_M = 5\Omega$, $L_M/R_M = 1$ msec
- Voltage and current characteristics: $V_s = 20V$ $I_M = 2A$ $V_1 = 8.3V$
- Closed loop bandwidth: 6 KHz.

b) Calculation
- From relationship (4):

$$R_s = \ldots = 0.2\Omega$$

and from (1):

$$G_{\ldots} = \frac{2\,V_s}{R_M\,V_R} = 1\,\Omega^{-1}$$

- RC = 1 msec [from expression (2)].
- Assuming $\xi = 1/\sqrt{2}$; from (7) follows:

$$\xi^2 = \frac{1}{2} = \frac{200\,C}{4\,R_F C_F \cdot 0.2}$$

- The cutoff frequency is:

$$f_T = \frac{143 \cdot 10^{-3}}{R_F C_F} = 6\text{ KHz}$$

c) Summarising
- $RC = 1 \cdot 10^{-3}$ sec
- $\frac{500\,C}{R_F C_F} = 1$
- $R_F C_F \cong 24$ μsec

C = 47 nF
R = 22 KΩ
For $R_F = 510\,\Omega \rightarrow C_F = 47$ nF.

APPLICATION INFORMATION (continued)

Neglecting the V_{CEsat} of the bridge transistors and the V_{BE} of the diodes:

$$G_{mo} = \frac{1}{R_M} \frac{2 V_s}{V_R} \qquad \text{where: } V_s = \text{supply voltage}, \; V_R = 8V \text{ (reference voltage)} \tag{1}$$

DC transfer function

In order to be sure that the current loop is stable the following condition is imposed:

$$1 + sRC = 1 + s \cdot \frac{L_M}{R_M} \qquad \text{(pole cancellation)} \tag{2}$$

$$\text{from which } RC = \frac{L_M}{R_M} \qquad \text{(Note that in practice R must be greater than 5.6 K}\Omega\text{)}$$

The transfer function is then,

$$\frac{I_M}{V_i}(s) = \frac{R_2 R_4}{R_1 R_3} G_{mo} \frac{1 + sR_FC_F}{G_{mo} R_s + s R_4 C + s^2 R_F C_F R_4 C} \tag{3}$$

In DC condition, this is reduced to

$$\frac{I_M}{V_i}(o) = \frac{R_2 R_4}{R_1 R_3} \cdot \frac{1}{R_s} = \frac{0.048}{R_s} \left[\frac{A}{V}\right] \tag{4}$$

Open-loop gain and stability criterion

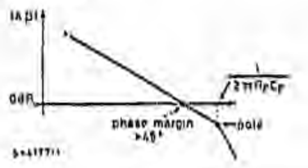
For $RC = L_M/R_M$, the open loop gain is:

$$A\beta = \frac{1}{sR_FC} \cdot G_{mo} \frac{R_s}{R_4} \frac{R_F}{1 + sR_FC_F} = \frac{G_{mo} R_s}{R_4 C} \frac{1}{s(1 + sR_FC_F)} \tag{5}$$

In order to achieve good stability, the phase margin must be greater than 45° when $|A\beta| = 1$.
That means that, at $f_F = \frac{1}{2\pi R_F C_F}$, must be $|A\beta| < 1$ (see fig. 7), that is

$$|A\beta|_{f = \frac{1}{2\pi R_F C_F}} = \frac{G_{mo} R_s}{R_4 C} \frac{R_F C_F}{\sqrt{2}} < 1 \tag{6}$$

Fig. 7 - Open-loop frequency response



APPLICATION INFORMATION (continued)

Closed-loop system step response

a) Small-signals analysis.

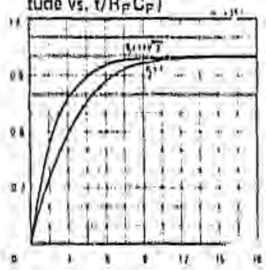
The transfer function (3) can be written as follows:

$$\frac{I_M}{V_i}(s) = \frac{0.048}{R_s} \frac{1 + \frac{s}{2\xi\omega_o}}{1 + \frac{2\xi s}{\omega_o} + \frac{s^2}{\omega_o^2}} \tag{7}$$

where: $\omega_o = \sqrt{\frac{G_{mo} R_s}{R_4 C R_F C_F}}$ is the cutoff frequency

$\xi = \sqrt{\frac{R_4 C}{4 R_F C_F G_{mo} R_s}}$ is the dumping factor

Fig. 8 - Small signal step response (normalized amplitude vs. t/R_FC_F)



By choosing the ξ value, it is possible to determine the system *response to an input step signal. Examples:*

1) $\xi = 1$ from which

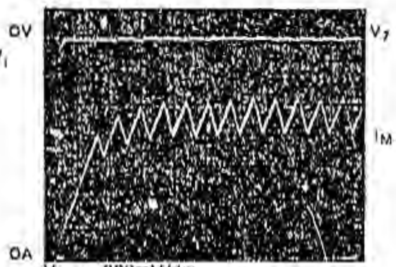
$$I_M(t) = \frac{0.048}{R_s} \left[1 - e^{-\frac{t}{2R_FC_F}} \left(1 + \frac{t}{4 R_F C_F}\right)\right] \cdot V_i$$

(where V_i is the amplitude of the input step).

2) $\xi = \frac{1}{\sqrt{2}}$ from which

$$I_M(t) = \frac{0.048}{R_s} \left(1 - \cos \frac{t}{2R_FC_F} e^{-\frac{t}{2R_FC_F}}\right) V_i$$

Fig. 9 - Motor current and pin 7 voltage waveforms (application of fig. 5). Small signal response



V_7 = 200mV/div.
I_M = 100mA/div.
t = 100µs/div.
with V_i = 1.6 Vp.

From fig. 9, it is possible to verify that the L292 works in "closed-loop" conditions during the entire motor current rise-time: the voltage at pin 7 (inverting input of the error amplifier) is locked to the reference voltage V_R, present at the non-inverting input of the same amplifier.
The previous linear analysis is correct for this example.
Decreasing the ξ value, the rise-time of the current decreases. But for a good stability, from relationship (8), the minimum value of ξ is:

$$\xi_{min} = \frac{1}{2\sqrt[4]{2}} \qquad \text{(phase margin = 45°)}$$

SYSTEM DESCRIPTION (continued)

Thus the output stage may be inhibited by taking pin 12 high or by taking pin 13 low. The output will also be inhibited if the supply voltage falls below 18V.
The enable inputs were implemented in this way because they are intended to be driven directly by a microprocessor. Currently available microprocessors may generates spikes as high as 1.5V during power-up. These inputs may be used for a variety of applications such as motor inhibit during reset of the logical system and power-on reset (see fig. 3).

Fig. 3

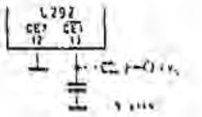
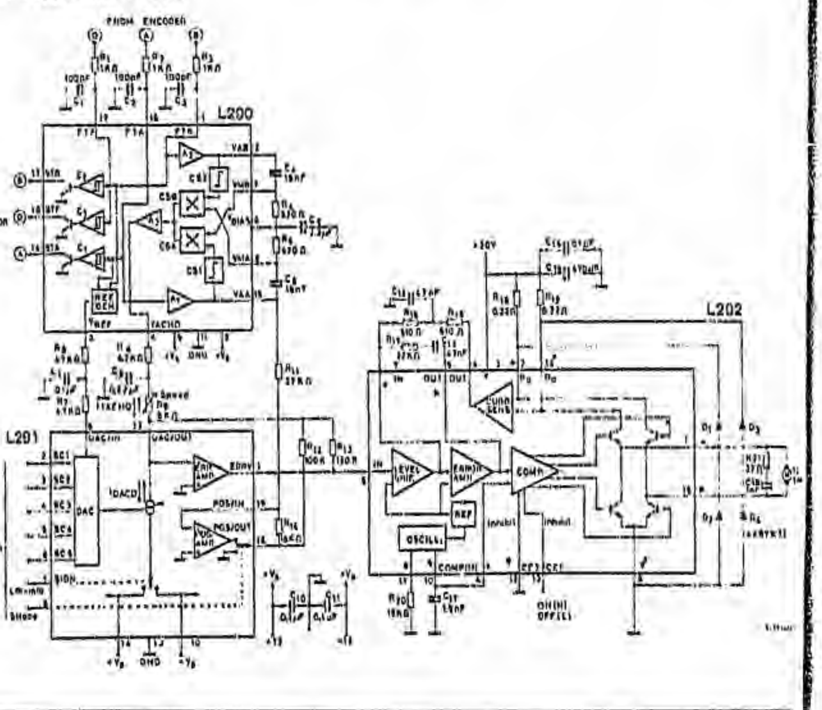


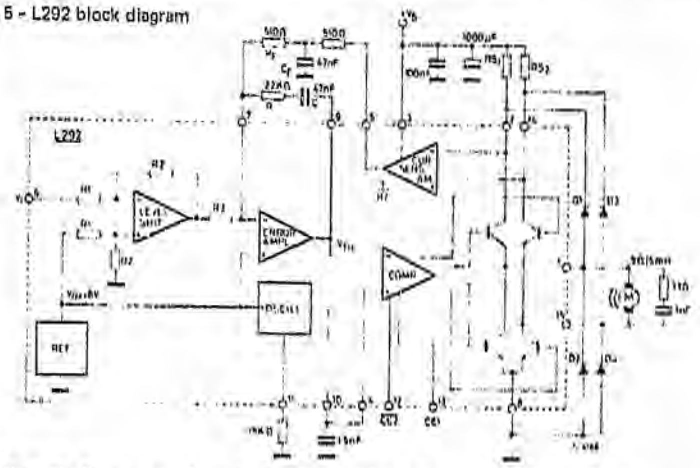
Fig. 4 - Application circuit



APPLICATION INFORMATION

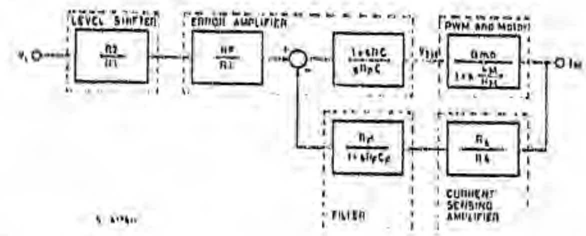
This section has been added in order to help the designer for the best choise of the values of external components.

Fig. 5 - L292 block diagram



The schematic diagram used for the Laplace analysis of the system is shown in fig. 6.

Fig. 6



$R_{S1} = R_{S2} = R_S$ (sensing resistors)

$\frac{1}{R_A} = 0.005\ \Omega^{-1}$ (current sensing amplifier transconductance)

L_M = Motor inductance

R_M = Motor resistance

I_M = Motor current

$G_{mo} = \left.\frac{I_M}{V_{TH}}\right|_{s=0}$ (DC transfer function from the input of the comparator (V_{TH}) to the motor current (I_M)).

SYSTEM DESCRIPTION (continued)

The mechanical/electrical interface consists of an optical encoder which generates two sinusoidal signals 90° out of phase (leading or lagging according to the motor direction) and proportional in frequency to the speed of rotation. The optical encoder also provides an output at one position on the disk which is used to set the initial position.
The opto encoder signals, FTA and FTB are filtered by the networks R_2 C_2 and R_3 C_3 (referring to Fig. 4) and are supplied to the FTA/FTB inputs on the L290.
The main function of the L290 is to implement the following expression:

$$\text{Output signal (TACHO)} = \frac{dV_{AA}}{dt} \cdot \frac{FTB}{|FTB|} - \frac{dV_{AB}}{dt} \cdot \frac{FTA}{|FTA|}$$

Thus the mean value of TACHO is proportional to the rotation speed and its polarity indicates the direction of rotation.
The above function is performed by amplifying the input signals in A_1 and A_2 to obtain V_{AA} and V_{AB} (typ. 7 V_p). From V_{AA} and V_{AB} the external differentiator RC networks R_5 C_5 and R_4C_4 give the signals V_{MA} and V_{MB} which are fed to the multipliers.
The second input to each multiplier consists of the sign of the first input of the other multiplier before differentiation, these are obtained using the comparators C_{S1} and C_{S2}. The multiplier outputs, C_{SA} and C_{SB}, are summed by A_3 to give the final output signal TACHO. The peak-to-peak ripple signal of the TACHO can be found from the following expression:

$$V_{ripple\ p\text{-}p} = \frac{\pi}{4}(\sqrt{2} - 1) \cdot V_{tacho\ DC}$$

The max value of TACHO is:

$$V_{tacho}\ max = \frac{\pi}{4}\sqrt{2} \cdot V_{tacho\ DC}$$

Using the comparators C_1 and C_2 another two signals from V_{AA} and V_{AB} are derived – the logic signals STA and STB.
These signals are used by the microprocessor to determine the position by counting the pulses.
The L290 internal reference voltage is also derived from V_{AA} and V_{AB}:

$$V_{ref} = |V_{AA}| + |V_{AB}|$$

This reference is used by the D/A converter in the L291 to compensate for variations in input levels, temperature changes and ageing.
The "one pulse per rotation" opto encoder output is connected to pin 12 of the L290 (FTF) where it is squared to give the STF logic output for the microprocessor.
The TACHO signal and V_{ref} are sent to the L291 via filter networks R_8 C_8 R_9 and R_6 C_7 R_7 respectively. Pin 12 of this chip is the main summing point of the system where TACHO and the D/A converter output are compared.
The input to the D/A converter consists of 5 bit word plus a sign bit supplied by the microprocessor. The sign bit represents the direction of motor rotation. The (analogue) output of the D/A converter - DAC/OUT – is compared with the TACHO signal and the resulting error signal is amplified by the error amplifier, and subsequently appears on pin 1.

SYSTEM DESCRIPTION (continued)

The ERRV signal (from pin 1, L291) is fed to pin 6 of the final chip, the L292 H-bridge motor-driver. This input signal is bidirectional so it must be converted to a positive signal because the L292 uses a single supply voltage. This is accomplished by the first stage – the level shifter, which uses an internally generated 8V reference.
This same reference voltage supplies the triangle wave oscillator whose frequency is fixed by the external RC network (R_{20}, C_{17} – pins 11 and 10) where:

$$f_{osc} = \frac{1}{2RC} \qquad \text{(with } R \geq 8.2\ K\Omega)$$

The oscillator determines the switching frequency of the output stage and should be in the range 1 to 30 KHz.
Motor current is regulated by an internal loop in the L292 which is performed by the resistors R_{18}, R_{19} and the differential current sense amplifier, the output of which is filtered by an external RC network and fed back to the error amplifier.
The choice of the external components in these RC network (pins 5, 7, 9) is determined by the motor type and the bandwidth requirements. The values shown in the diagram are for a 5Ω, 5 mH motor. (See L292 Transfer Function Calculation in Application Information).
The error signal obtained by the addition of the input and the current feedback signals (pin 7) is used to pulse width modulate the oscillator signal by means of the comparator. The pulse width modulated signal controls the duty cycle of the H-bridge to give an output current corresponding to the L292 input signal.
The interval between one side of the bridge switching off and the other switching on, τ, is programmed by C_{17} in conjunction with an internal resistor R_T.
This can be found from:

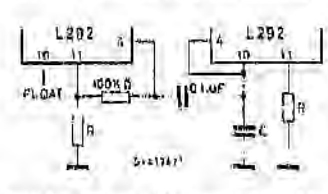
$$\tau = R_T \cdot C_{pin\ 10} \quad (C_{17} \text{ in the diagram})$$

Since R_T is approximately 1.5 KΩ and the recommended τ to avoid simultaneous conduction is 2.5 μs $C_{pin\ 10}$ should be around 1.5 nF.
The current sense resistors R_{18} and R_{19} should be high precision types (maximum tolerance ± 2%) and the recommended value is given by:

$$R_{max} \cdot I_{o\ max} \leq 0.44V$$

It is possible to synchronize two L292's, if desired, using the network shown in fig. 2.

Fig. 2



Finally, two enable inputs are provided on the L292 (pins 12 and 13-active low and high respectively).

THERMAL DATA

$R_{th\ j\text{-}case}$	Thermal resistance junction-case	max	3	°C/W

ELECTRICAL CHARACTERISTICS (T_{amb} = 25°C, f_{osc} = 20 KHz unless otherwise specified)

	Parameter	Test conditions		Min.	Typ.	Max.	Unit
V_s	Supply voltage			18		36	V
I_d	Quiescent drain current	V_s = 20V (offset null)			30	50	mA
V_{os}	Input offset voltage (pin 6)	V_s = 36V	I_o = 0			±350	mV
$V_{inh.}$	Inhibit low level (pin 12, 13)					2	V
	Inhibit high level (pin 12, 13)			3.2			V
$I_{inh.}$	Low voltage condition	$V_{inh.}$ (L) = 0.4V				-100	μA
	High voltage conditions	$V_{inh.}$ (H) = 3.2V				10	μA
	Input current (pin 6)	V_i = -8.8V V_i = +8.8V				-1.8 0.5	mA mA
V_i	Input voltage (pin 6)	R_{s1} = R_{s2} = 0.2Ω	I_o = 2A		8.3		V
			I_o = -2A		-8.3		V
I_o	Output current	V_i = ±5.8V R_{s1} = R_{s2} = 0.2Ω		±2			A
V_D	Total drop out voltage	(Inluding sensing resistors)	I_o = 2A			5	V
			I_o = 1A			3.6	V
V_{RS}	Sensing resistor voltage drop	T_j = 150°C	I_o = 2A			0.44	V
$\frac{I_o}{V_i}$	Transconductance	R_{s1} = R_{s2} = 0.2Ω		220	240	260	mA/V
		R_{s1} = R_{s2} = 0.4Ω			120		mA/V
f_{osc}	Frequency range (pin 10)			1		30	KHz

TRUTH TABLE

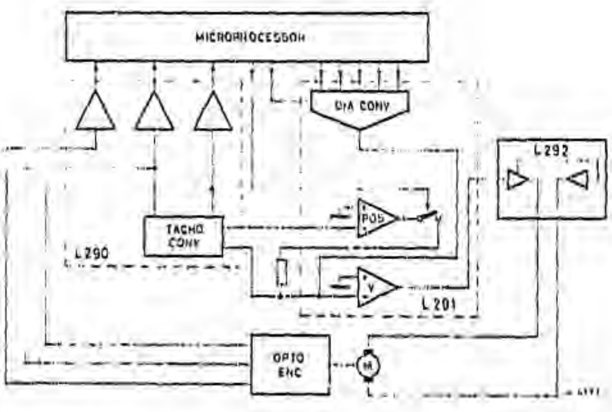
$V_{inhibit}$		Output stage condition
Pin 12	Pin 13	
L	L	Disabled
L	H	Normal operation
H	L	Disabled
H	H	Disabled

Note: The output stage is also disabled if the supply voltage falls below 18V.

SYSTEM DESCRIPTION

The L290, L291 and L292 are intended to be used as a 3-chip microprocessor controlled positioning system. These devices may be used separately - particularly the L292 motor driver - but since they will usually be used together, a description of a typical L290/1/2 system follows.

Fig. 1 - System block diagram



The system operates in two modes to achieve high-speed, high-accuracy positioning.
Speed commands for the system originate in the microprocessor. It is continuously updated on the motor position by means of pulses from the L290 tachometer chip, which in turn gets its information from the optical encoder. From this basic input, the microprocessor computes a 5-bit control word that sets the system speed dependent on the distance to travel.
When the motor is stopped and the microprocessor orders it to a new position, the system operates initially in an open-loop configuration as there is no feedback from the tachometer generator. Therefore maximum current is fed to the motor. As maximum speed is reached, the tachometer chip output backs off the processor signal thus reducing accelerating torque.
The motor continues to run at top speed but under closed-loop control.
As the target position is approached, the microprocessor lowers the value of the speed-demand word; this reduces the voltage at the main summing point, in effect braking the motor. The braking is applied progressively until the motor is running at minimum speed.
At that time, the microprocessor orders a switch to the position mode, (strobe signal at pin 8 of L291) and within 3 to 4 ms the L292 drives the motor to a null position, where it is held by electronic "detenting".

L 292

LINEAR INTEGRATED CIRCUIT

PRELIMINARY DATA

SWITCH-MODE DRIVER FOR DC MOTORS

The L292 is a monolithic LSI circuit in 15-lead MULTIWATT® package. It is intended for use, together with L290 and L291, as a complete 3-chip DC motor positioning system for applications such as carriage/daisy-wheel position control in typewriters.
The L290/1/2 system can be directly controlled by a microprocessor. The outstanding characteristics of the L292 are:

- Driving capability: 2A, 36V, 30 KHz.
- 2 Logic chip enable.
- External loop gain adjustment.
- Single power supply (18 to 36V).
- Input signal symmetric to ground.
- Thermal protection.

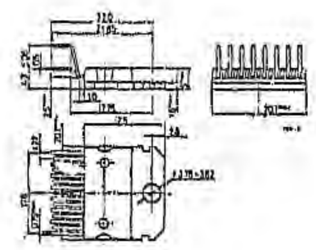
ABSOLUTE MAXIMUM RATINGS

V_s	Power supply	36	V
V_i	Input voltage	-15 to $+V_s$	V
$V_{inhibit}$	Inhibit voltage	0 to V_s	V
P_{tot}	Total power dissipation ($T_{case} = 75°C$)	25	W
T_{stg}	Storage and junction temperature	-40 to $+150$	°C

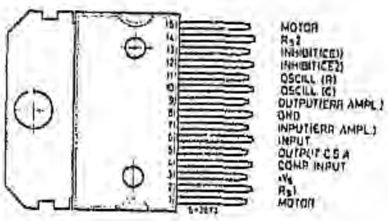
ORDERING NUMBER: L292

MECHANICAL DATA

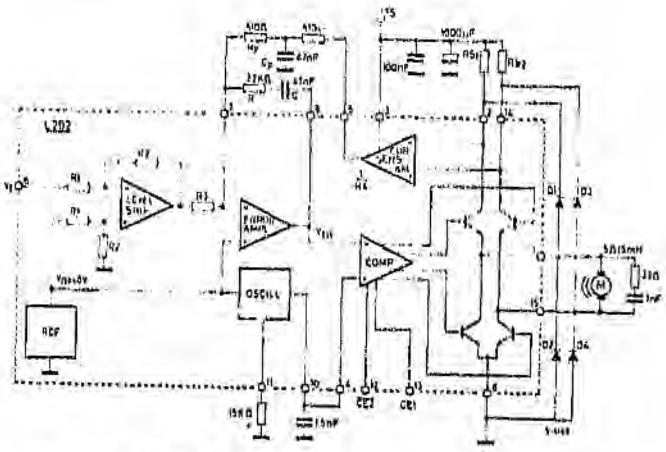
Dimension in mm



CONNECTION DIAGRAM
(top view)



BLOCK DIAGRAM



$D_1 \cdot D_2 \cdot D_3 \cdot D_4$ = High speed diodes (BYW 72 or equivalent)

D/A converter logic function (I_{ref} = 0.516 mA)

DIGITAL WORD (From µ Processor)						Commands
$\overline{SIGN}$	$\overline{SC_5}$	$\overline{SC_4}$	$\overline{SC_3}$	$\overline{SC_2}$	$\overline{SC_1}$	
X	H	H	H	H	H	Speed = Zero
L	L	L	L	L	L	Speed = Max CK wise
L	H	H	H	H	L	Speed = Min CK wise
H	H	H	H	H	L	Speed = Min ACK wise
H	L	L	L	L	L	Speed = Max ACK

X = indifferent L = low H = high.

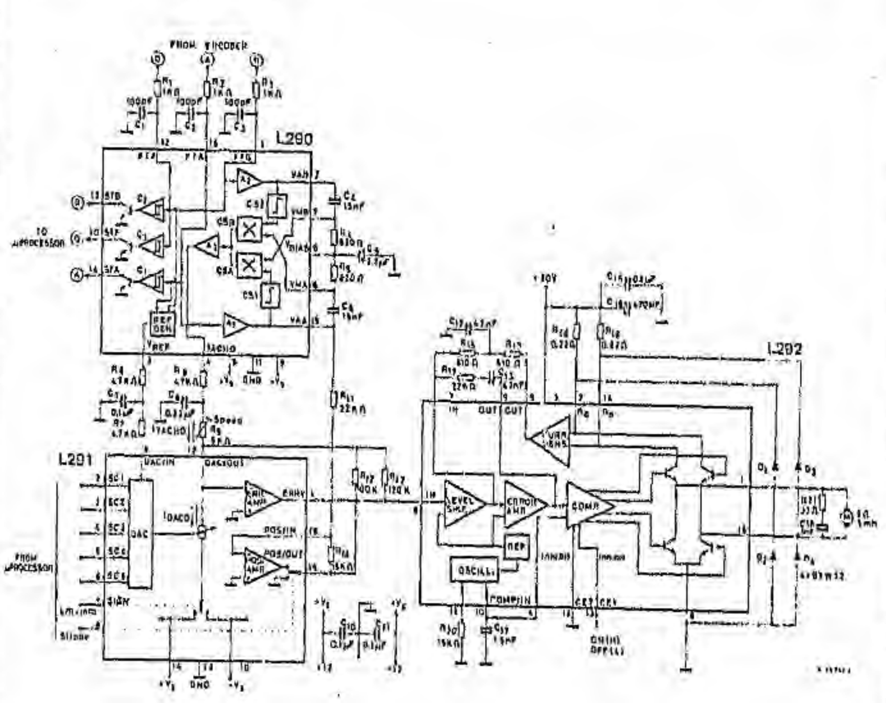
Looking from the typewriter keyboard the clockwise rotation of the motors move the carriage from left to right and the daisy clockwise.

Error amplifier

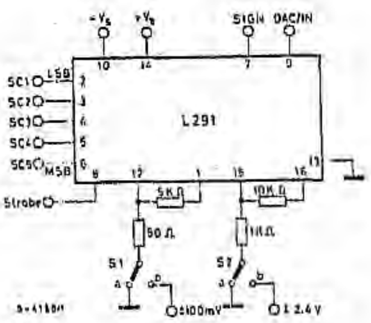
In order to have a good stability, the error amplifier must work with a closed loop gain greater than 20 dB.

SYSTEM DESCRIPTION: refer to the L292 data sheet

Fig. 1 - Complete application circuit



TEST CIRCUIT



THERMAL DATA

$R_{th\ j\text{-}amb}$	Thermal resistance junction-ambient	max	80	°C/W

ELECTRICAL CHARACTERISTICS (Refer to the test circuit, S_1 and S_2 in (a), V_s = + 12V (± 10%), T_{amb} = 25°C, unless otherwise specified)

Parameters		Test conditions	Min.	Typ.	Max.	Unit
V_s	Supply voltage		±10		±15	V
I_d	Quiescent drain current			6.5	10	mA

POSITION AMPLIFIER

Parameters		Test conditions	Min.	Typ.	Max.	Unit
V_{strobe}	Enable voltage level	V_L (S in (a)) *	0		0.8	V
		V_H (S in (b)) *	2.4		$+V_s$	V
V_{os}	Output offset voltage (pin 16)	$V_{strobe} = V_L$			±50	mV
I_b	Input bias current (pin 15)	$V_{strobe} = V_L$			0.3	µA
V_o	Output voltage swing (pin 16)	$V_{strobe} = V_L$ S_2 in (b)	± 9			V
V_R	Residual output voltage (pin 16)	$V_{strobe} = V_H$			± 20	mV

* See block diagram.

ELECTRICAL CHARACTERISTICS (continued)

Parameters		Test conditions	Min.	Typ.	Max.	Unit
D/A CONVERTER						
I_{ref}	Current reference input range (pin 9)	All inputs low	0.3		1	mA
V_{os}	Current reference offset voltage (pin 9 to GND)	I_{ref} = 0.3 to 1 mA All inputs high			± 20	mV
I_o	Output current range (pin 12)		0.7		1.4	mA
		I_{ref} = 0.516 mA all inputs low	0.98		1.02	mA
I_{os}	Output offset current (pin 12)	All inputs high			0.4	µA
V_L	Low voltage level (digital inputs)	SC1 = LSB SC5 = MSB	0		0.8	V
V_H	High voltage level (digital inputs)		2.4		$+V_S$	V
I_L	Digital inputs current (low state)	V_L = 0.4V			-50	µA
I_H	Digital inputs current (high state)	V_H = 5V			1	µA
ERROR AMPLIFIER						
V_{os}	Output offset voltage (pin 1)	I_{ref} = 0.5 mA; All inputs high			± 200	mV
I_o	Output current (pin 1)				5	mA
V_o	Output voltage swing (pin 1)	All inputs high S_1 in (b); R_L = 10 KΩ	±7.4		±8.4	Vp

LINEAR INTEGRATED CIRCUIT

PRELIMINARY DATA

5 BIT - D/A CONVERTER AND POSITION AMPLIFIER

The L291, a monolithic LSI circuit in a 16 lead dual in-line plastic package, is intended for use with the L290 and L292 to form a complete 3 chip DC motor positioning system for applications such as carriage/daisy-wheel position control in typewriters.
The L290/1/2 system can be directly controlled by a microprocessor.
The L291 integrates the following functions:
- 5 bit D/A converter (½ LSB max linearity error)
- error amplifier
- position amplifier

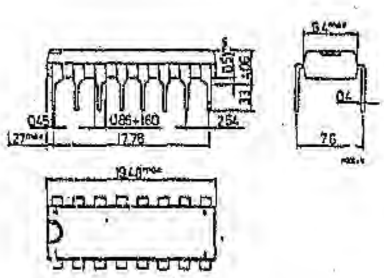
ABSOLUTE MAXIMUM RATINGS

V_s	Supply voltage	± 15	V
P_{tot}	Total power dissipation T_{amb} = 70°C	1	W
T_{stg}, T_j	Storage and junction temperature	-40 to 150	°C

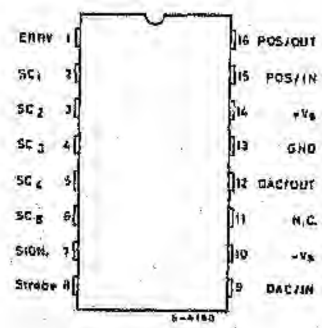
ORDERING NUMBER: L291 B

MECHANICAL DATA

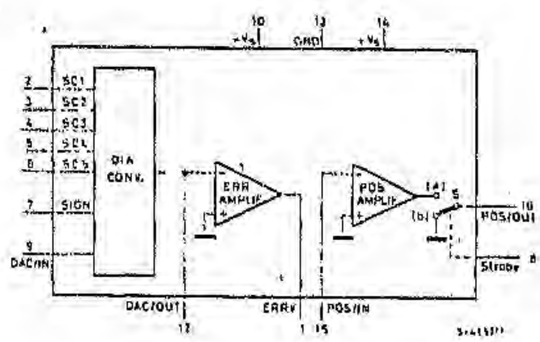
Dimensions in mm



CONNECTION DIAGRAM
(top view)

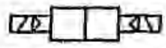


BLOCK DIAGRAM



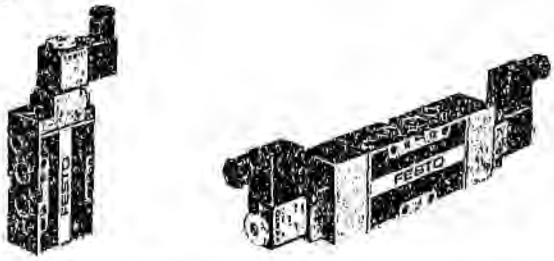
Appendix F Electronics

Solenoid Actuated Valves



The "Tiger 2000" Valves – Free Voltage Range

FESTO PNEUMATIC



Type MFH-...
JMFH-...

These valves are part of a new family offering high flow rates and improved mounting options.

Note: These valves are not directly interchangeable with Tiger Classic Valves.

- Range of coil voltages
- G 1/8 to G 1/4
- Non-lubricated operation
- Versatile mountings

Accessories:

Solenoid coils (see page 94)

	DC	AC
Type	MSFG-12-OD	MSFW-24-OD
	MSFG-24-OD	MSFW-110-OD
		MSFW-220-50/60-OD
		MSFW-240-OD

Socket without cable
Type MSSD-F

Socket with cable
Type KMF-1-24-2.5-LED, cable 2.5 m, 24 DC
KMF-1-24-5-LED, cable 5 m, 24 DC
KMF-1-220-2.5, cable 2.5 m, 220 V to 240 V
KMF-1-220-5, cable 5 m, 220 V to 240 V

Illuminating seal
Type MF-LD-12-24, for status indication

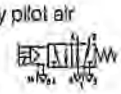
Manifold Systems: See pages 96, 97

Voltage and power consumption see page 94.

5/2-Configuration

without auxiliary pilot air — with auxiliary pilot air

Type MFH-5/2-...

Type JMFH-5/2-...


5/3-Configuration

Type MFH-5/3G-...
Mode: Mid position closed


Type MFH-5/3E-...
Mode: Mid position exhausted


Type MFH-5/3B-...
Mode: Mid position pressurized

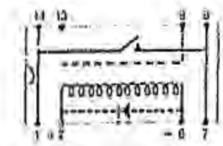

Options:
All types are also available with auxiliary pilot air connection to allow low pressure operation and vacuum.

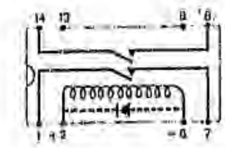
How to order: Select valve type required and quote type code. Select voltage and quote coil no. (2 pieces off for type JMFH). Select electrical connection required and quote type code.	**Example:** Single solenoid, G 1/8 connection with 240 V AC coil, connector without cable = quote MFH-5-1/8-B + MSFW-240-OD + MSSD-F
For further information see back page	Dims. and technical data: Tech. cat. page 2.520 to 2.529

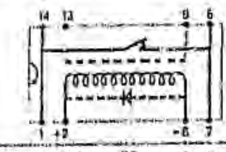
Appendix E Pneumatics

	Référence contact normal / Reference standard contact / Referenzen standard Typ	Référence contact H. Fiabilité / High reliability contact / Hochzuverlässiger Kontakt	Tension nominale / Nominal Voltage / Nenn Spannung	Tension fonction. / Must operate Voltage / Ansprech spannung max	Tension relâch. / Must release Voltage / Abfall spannung min	Tension max / Max Voltage / Spannung max	Résistance bobine Ω ± 10% / Coil Ω ± 10% / Spule Ω ± 10%	Pouvoir de coupure / Contact rating / Kontaktbelastbarkeit W	V	mA	N° Fiche / Data Sheet / Katalog Blatt
	AR11	AR21	interrupteur reed / Reed switch / Schliesser								
D31A	D31A21	D31A22	5	3,7	1	8	200	10	100	600	1100
	D31A31	D31A32	5	3,7	1	18	500				
	D31A51	D31A52	12	8	2	[illegible]	1000				
	D31A61	D31A62	15	11,5	4	37	2150				
	D31A71	D31A72	24	16	4	37	2150				
	D31A81	D31A82	48	32	8	75	8000				
D32A	D32A21	D32A22	5	4,2	0,8	9	125	10	100	250	1300
	D32A41	D32A42	6	5	1	12	200				
	D32A51	D32A52	12	9,6	2	18	600				
	D32A61	D32A62	15	11,5	4	22	850				
	D32A71	D32A72	24	20	4	37	2150				
	D32A81	D32A82	48	40	8	50	6000				
D31B	D31B31	D31B32	5	3,7	1	8	500	10	100	250	1200
	D31B51	D31B52	12	8	2	18	1000				
	D31B61	D31B62	15	11,5	4	32	2150				
	D31B71	D31B72	24	16	4	32	2150				
	D31B81	D31B82	48	32	8	55	6000				
D31L	D31L31	D31L32	5	3,7	3,7	8	2x410	10 /	100	250	1500
	D31L51	D31L52	12	8	8	16	2x1500				
*	Distance minimum entre 2 relais 1 cm / Minimum distance between 2 relais 1 cm / Minimale Abstand zwischen 2 Relais 1 cm				Durée minimum de l'impulsion de commande 5 ms / Minimum length of input pulse / Minimale Zeit von Steuer-Impuls						
	CM11	CM21	inverseur reed / SPDT / Wechsler								
D31C	D31C21	D31C22	5	3,7	1	12	200	3	28	250	1400
	D31C51	D31C52	12	8	2	18	500				
	D31C61	D31C62	15	11,5	4	22	850				
	D31C71	D31C72	24	16	4	37	2150				
	D31C81	D31C82	48	[illegible]	8	50	9000				
D31R		D31R31	5	3,7	3,7	8	2x410	3	28	250	1600
		D31R51	12	8	8	16	2x1500				
*	Idem D31L										
	AR41		interrupteur Haute tension / High voltage Switch / Hoch - Spannung schalter								
D31A	D31A24		5	3,7	1	12	[illegible]	10	220	600	1140
	D31A54		12	8	2	18	500				
	D31A74		24	16	4	37	2150				
	D31A84		48	32	8	60	6000				
	AP51		interrupteur Mercure / Mercury wetted / Hg Benetzt								
D31A	D31A25		5	4,2	0,5	10	65	3	28	100	1150
	D31A55		12	9,1	1	16	236				
	D31A75		24	18	2	25	1000				
	D31A85		48	36	4	[illegible]	[illegible]				

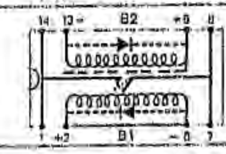
Vues de dessus pas de 2,54 mm
Top view 0,1 inch step
Von oben gesehen Rastermass 2,54 mm

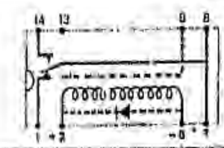


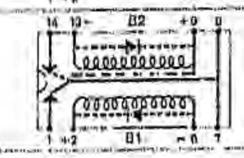


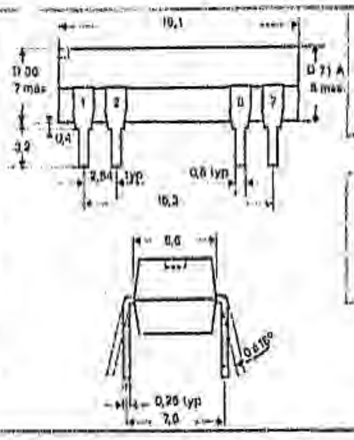


B









Forme B et L, respecter la polarité en l'absence de diode - distance minimum, voire fiche particulière
Form B and L, without diode respect polarity - proximity between relays see data sheet.
Form B und L, ohne diode polarität beachten - abstand mini siehe sonder datenblatt

B1 Bobine de fermeture / Coil to close / Schliesspule
B2 Bobine d'ouverture / Coil to open / Offnerspule

Observations
Remarques

Remarks

Notiz

Toutes options possibles
All options available
Alle optionen möglich

Ecran statique
non disponible
Electrostatic shield
not available
Elektrostatische
Abschirmung nicht lieferbar

Toutes options possibles
All options available
Alle optionen möglich

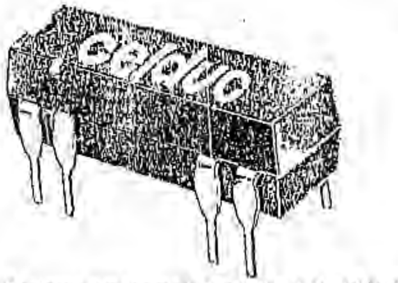
Ecran magnétique inclus
dans la version standard
Magnetic shield included
in this model
Magnetische Abschirmung
in der Normalausführung

Toutes options possibles
All options available
Alle optionen möglich

Ecran magnétique inclus
dans la version standard
Magnetic shield included
in this model
Magnetische Abschirmung
in der Normalausführung

Toutes options possibles
All options available
Alle optionen möglich

Position indifférente
Operable in any position
Lunbetriebsanglelenlage



Relais Reed / Boîtier DIP

DIP Reed Relay

Reed Relais / Typ DIP

Conforme aux normes / Qualified to / Nach MIL S 004.MA, MIL R 5757

D 30

De format DIP, la conception et le procédé de moulage par transfert des relais D sont semblables à ceux des circuits intégrés avec lesquels ils sont compatibles mécaniquement et électriquement.
Notre gamme est la plus étendue de toutes celles produites actuellement.
Cette sélection devrait satisfaire les besoins les plus divers. Notre équipe d'étude est à votre disposition pour choisir ou même conce[illegible] elais spécial correspondant à votre application.

The Reed-Relay D 30 in a DIP-package is similar to integrated circuits in design, shape and the transfert mold process. They are mechanically and electrically compatible with integrated circuits.
Our serie of Dual-In-Line packaged relays is the widest available today. This choice makes them indispensable for various applications.
Our engineering department is at your disposal to choose or even design your special relay.

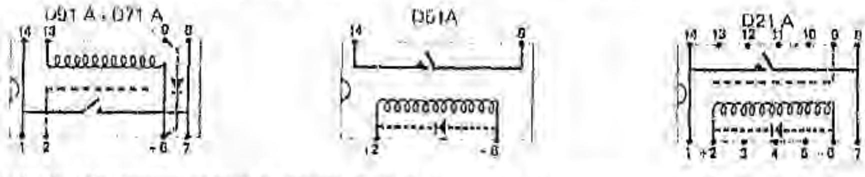
Die Reed-Relay D 30 im DIP-Gehäuse gleichem im Aussehen, in der KonZeption und der Herstellungsmethode integrierten Schaltungen. Sie sind mechanisch und elektrish mit diesen Kompatibel.
Das vorliegende Programm stellt das kompletteste Spektrum an Reed-Relais im "Dual-In-Line" Gehäuse dar.
Diese grosse Auswahl macht unsere Relais unentbehrlich für die verschiedensten Anwendungen.
Für die Wahl oder Auslegung des für Ihren Fall am besten geeigneten Relais steht Ihnen unsere Entwicklungsabteilung zur Verfügung.

REFERENCES - REFERENCES - REFERENZEN

D • • • • • • 0

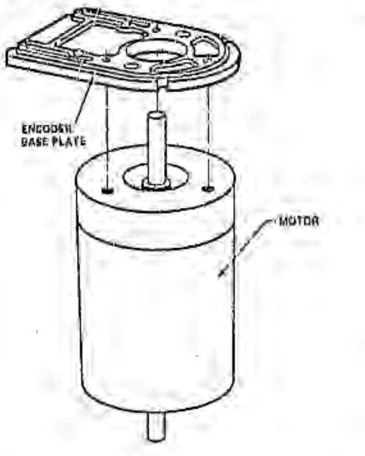
Brochage / pin configuration / Stiftbelegung	Nb de contact / contact number / Kontaktzahl	Forme du contact / Form / Ausführung	Tension nominale / nominal Voltage / Nennspannung	Qualité contact / contact quality / Kontakt Qualität	Option / Option / Optionen
2 = 14 pins	1 = 1	A = Normal ouvert N.O. Schliesser	0 = Spécial	1 = Normal	0 = Sans without Ohne
5 = 8 pins	2 = 2	B = Normal fermé N.C. Öffner	2 = 5 V	2 = Haute fiabilité High reliability Hohe Zuverlässigkeit	1 = Diode D
6 = 4 pins		C = Inverseur SPDT Wechsler	3 = 6 V	4 = Haute tension High voltage Hochspannung	2 = Ecran stat. E Elec. shield Elec. schirm
9 = 8 pins		L = Bistable A Latching Bistabil	4 = 9 V	8 = Hg	3 = Ecran mag. M Mag. shield Mag. schirm
		R = Bistable C Latching contact	5 = 12 V		4 = D + E
			6 = 16 V		6 = D + M
			7 = 24 V		7 = D + E + M
			8 = 48 V		

Les brochages 5 et 9 n'existent qu'en D51A et D91A / 5 and 9 pin configuration only available with D51A and D91A / Stiftbelegung 5 und 9 nur in Ausführung D51A und D91A

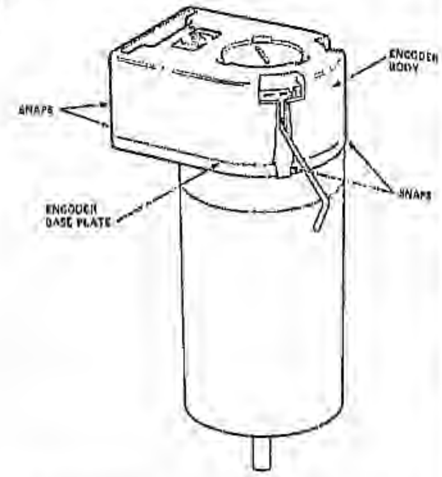


En 48 V, l'option écran magnétique entraîne une réduction de la résistance de la bobine.
For 48 V relay with magnetic shield, coil resistance is lower.
Bei 48 V ausführungen mit magnetischer Schirm, sind die angegebene Spulenwiderstände niedriger.

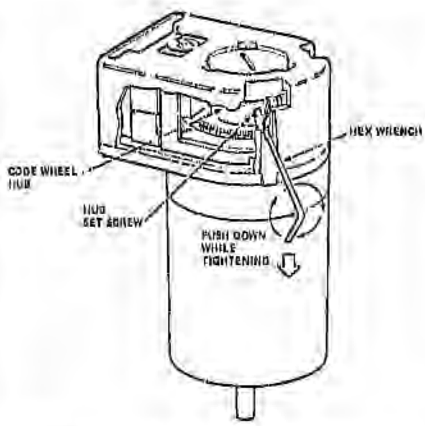
Encoder Mounting and Assembly



1. Mount encoder base plate onto motor. Tighten screws. (Reference page 8 for mounting considerations).



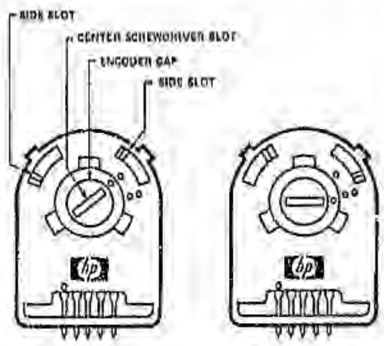
2. Snap encoder body onto base plate locking all 4 snaps.



3a. Push the hex wrench into the body of the encoder to ensure that it is properly seated into the code wheel hub set screw. Then apply a downward force on the end of the hex wrench. This sets the code wheel gap by levering the code wheel hub to its upper position.

3b. While continuing to apply a downward force, rotate the hex wrench in the clockwise direction until the hub set screw is tight against the motor shaft. The hub set screw attaches the code wheel to the motor's shaft.

3c. Remove the hex wrench by pulling it straight out of the encoder body.



ONE DOT POSITION TWO DOT POSITION

4. Use the center screwdriver slot, or either of the two side slots, to rotate the encoder cap dot clockwise from the one dot position to the two dot position. Do not rotate the encoder cap counter-clockwise beyond the one dot position.

The encoder is ready for use!

HEWLETT PACKARD

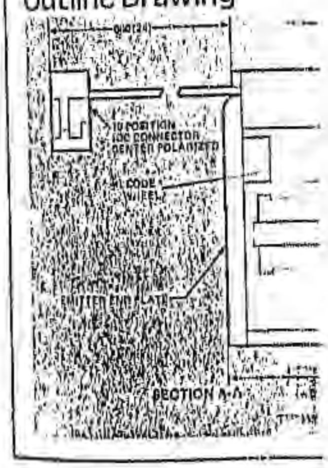
Features

- SMALL SIZE — 28 mm DIAMET
- 100-512 CYCLES/REVOLUTIO
- MANY RESOLUTIONS STAND
- LOW INERTIA
- QUICK ASSEMBLY
- 0.25 mm (.010 INCHES) END PL ALLOWANCE
- TTL COMPATIBLE DIGITAL
- SINGLE 5V SUPPLY
- WIDE TEMPERATURE RANGE
- INDEX PULSE AVAILABLE

Description

The HEDS-5000 series is a high resolu cal encoder kit emphasizing reliability The 28 mm diameter package con encoder body, a metal code wheel, an An LED source and lens transmit co emitter module through a precision phase plate into a bifurcated detector The light is focused onto pairs of clos detectors which output two square wa ture and an optional index pulse custom photodetector configuration bility by reducing sensitivity to eccentricity and LED degradation. supply input of the HEDS-5000 are pin connector mounted on a .8 metri

Outline Drawing



Ordering Information

HEDS-5500 Option □ □□

Resolution	(Cycles per revolution)	
K - 96 CPR	E - 200 CPR	H - 400 CPR
C - 100 CPR	F - 256 CPR	A - 500 CPR
D - 192 CPR	G - 360 CPR	I - 512 CPR

Shaft Diameter	
01 - 2 mm	[illegible] 1/4 in.
02 - 3 mm	[illegible] mm
03 - 1/8 in.	[illegible] mm
05 - 3/16 in.	[illegible] 6 mm
04 - 5/32 in.	

Note:
1. Other code wheel resolutions are available. Please consult your Hewlett-Packard sales representative for further information.

Mounting Considerations

The HEDS - 5500 can be mounted to a motor using either the two screw or three screw mounting option as shown in figure 1. If the encoder is attached to the motor with the screw sizes and mounting tolerances specified in the encoding characteristics section without any additional mounting bosses, the encoder output errors will be within the maximums specified in the encoding characteristics section.

The optional alignment pins shown in figure 2 can be used with either the two or three screw mounting option to improve the alignment of the encoder to the motor. This improved alignment will result in better encoder performance.

The best encoder performance will be obtained by mounting the encoder onto the motor using the optional motor boss with either the two or three screw mounting option as shown in figure 2.

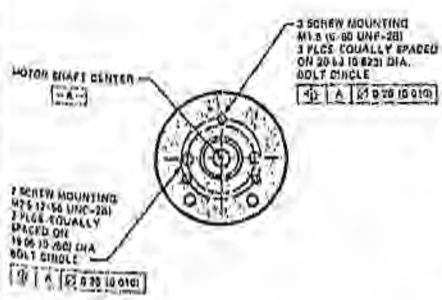


Figure 1. Mounting Holes

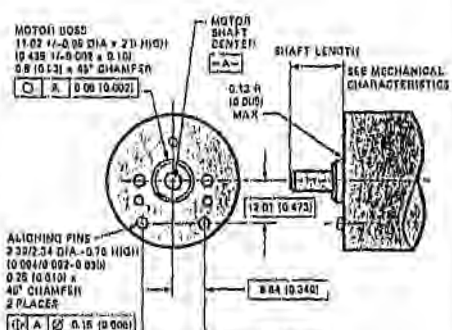


Figure 2. Optional Mounting Aids

MOTOR SENSING AND CONTROL

r shafts. Please consult your

ommended.

Mechanical Characteristics

Parameter	Symbol	Dimension	Tolerance	Units
Standard Shaft Diameters		2 3 4 5 3	+0.000 -0.015	mm
		5/32 1/8 3/16 1/4	+0.0000 -0.0007	inches
Moment of Inertia	J	0.6 (8.0 x 10^-6)		gcm² (oz-in-s²)
Required Shaft Length[3]		14.0 (0.55)	±0.5 (±0.02)	mm (inches)
Bolt Circle	2 screw mounting	19.05 (0.750)	±0.13 (±0.005)	mm (inches)
	3 screw mounting	20.90 (0.823)	±0.13 (±0.005)	mm (inches)
Mounting Screw Size	2 screw mounting	M 2.5 or (2-56)		mm (inches)
	3 screw mounting	M 1.6 or (0-80)		mm (inches)
Encoder Base Plate Thickness		0.33 (0.130)		mm (inches)
Hub Set Screw		(2-56)		(inches)

Note:
3. An 8.0 mm (0.36") diameter hole through the housing of the HEDS-5500 is available for extended motor shafts. Please consult your Hewlett-Packard sales representative for further information.

Electrical Characteristics

Electrical Characteristics over Recommended Operating Range, typical at 25°C.

Parameter	Symbol	Min.	Typ.	Max.	Units	Notes
Supply Current	I_{CC}		17	40	mA	
High Level Output Voltage	V_{OH}	2.4			Volts	I_{OH} = -40 μA Max.
Low Level Output Voltage	V_{OL}			0.4	Volts	I_{OL} = 3.2 mA
Rise Time	t_r		200		ns	C_L = 25 pF, R_L = 11 kΩ Pull-up
Fall Time	t_f		50		ns	

Note:
1. For improved performance in noisy environments or high speed applications, a 3.3 kΩ pull-up resistor is recommended.

Suggested Connectors

Manufacturer	Part Number
AMP	103686-4
	640442-5
Berg	65039-032 with 4825X-000 terminals
	65801-034
Molex	2695 series with 2759 series terminals

Ordering

Note:
1. Other code who

Mountin

The HEDS-550 the two screw o figure 1. If the screw sizes and coding charac mounting base the maximums section.

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Figure 1. Moun

Absolute Maximum Ratings

Parameter	Symbol	Min.	Typ.	Max.	Units	Notes
Storage Temperature	T_S	-40		100	Celsius	
Operating Temperature	T_A	-40		100	Celsius	
Supply Voltage	V_{CC}	-0.5		7	Volts	
Output Voltage	V_O	-0.5		V_{CC}	Volts	
Output Current per Channel	I_O	-1.0		5	mA	
Vibration				20	g	5 to 1000 Hz
Shaft Axial Play				±0.25 ±(0.010)	mm (inch)	
Shaft Eccentricity Plus Radial Play				0.1 (0.004)	mm (inch) TIR	
Velocity				30 K	R.P.M.	
Acceleration				250 K	Rad/Sec^2	

Recommended Operating Conditions

Parameter	Symbol	Min.	Max.	Units	Notes
Temperature	T_A	-40	100	Celsius	
Supply Voltage	V_{CC}	4.5	5.5	Volts	Ripple ≤ 100 mV_{p-p}
Load Capacitance	C_L		100	pF	3.2 K pull-up resistor
Count Frequency[1]	f		100	kHz	$\frac{\text{Velocity (rpm)} \times N}{60}$
Shaft Perpendicularity Plus Axial Play			±0.25 ±(0.010)	mm (inch)	6.9 mm (0.27 inch) from mounting surface
Shaft Eccentricity Plus Radial Play			0.04 (0.0016)	mm (inch) TIR	6.9 mm (0.27 inch) from mounting surface

Note:
1. The encoder performance is guaranteed to 100 kHz but can operate at higher frequencies.

Encoding Characteristics

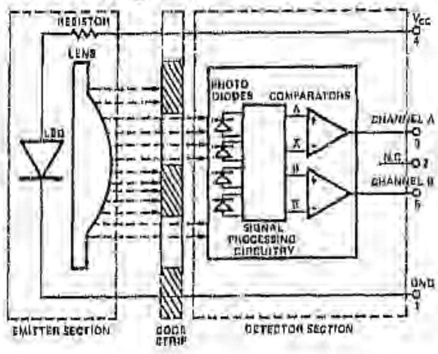
Encoding characteristics over Recommended Operating range and recommended mounting tolerances. Values are for the worst error over the full rotation.

Parameter	Symbol	Typ.[2]	Max.	Units	Notes
Pulse Width Error	ΔP	7	45	elec. deg.	
Logic State Width Error	ΔS	5	45	elec. deg.	
Phase Error	$\Delta\phi$	2	20	elec. deg.	
Position Error	$\Delta\Theta$	10	40	minutes of arc	
Cycle Error	ΔC	3	5.5	elec. deg.	

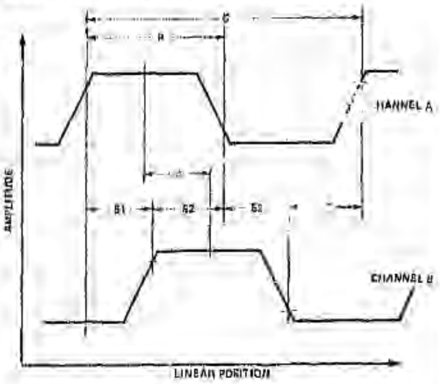
Note:
2. Typical errors are computed as the absolute value of the mean error.

MOTION SENSING AND CONTROL

Block Diagram



Output Waveforms



Theory of Operation

The HEDS-5500 translates rotary motion of a shaft into a two channel digital quadrature output.

As seen in the block diagram, the HEDS-5500 encoder contains a single Light Emitting Diode (LED) as its emitter. The light is collimated into a parallel beam by means of a single lens located directly over the LED. Opposite the emitter is an integrated detector circuit. This IC consists of multiple sets of photodetectors and the signal processing circuitry necessary to produce the digital waveforms.

The code wheel rotates between the emitter and detector, causing the light beam to be interrupted by the code wheel's pattern of spaces and bars. The photodiodes which detect these interruptions are arranged in a pattern that corresponds to the radius and design of the code wheel. These detectors are also spaced such that a light period on one pair of detectors corresponds to a dark period on the adjacent pair of detectors. The photodiode outputs are then fed through the signal processing circuitry resulting in A, $\bar{A}$, B and $\bar{B}$. Two comparators receive these signals and produce the final outputs for channels A and B. Due to this integrated phasing technique, the digital output of channel A is in quadrature with that of channel B (90 degrees out of phase).

Definitions

Count (N): The number of bar and window pairs or counts per revolution (CPR) of the code wheel.

Electrical Degree (°e): The dimension of one bar and window pair divided by 360.

1 Cycle (C): 360 electrical degrees (°e), 1 bar and window pair.

1 Shaft Rotation: 360 mechanical degrees, N cycles.

Position Error (ΔΘ): The normalized angular difference between the actual shaft position and the position as indicated by the encoder cycle count.

Cycle Error (ΔC): An indication of cycle uniformity. The difference between an observed shaft angle which gives rise to one electrical cycle, and the nominal angular increment of 1/N of a revolution.

Pulse Width (P): The number of electrical degrees that an output is high during 1 cycle. This value is nominally 180°e or 1/2 cycle.

Pulse Width Error (ΔP): The deviation, in electrical degrees, of the pulse width from its ideal value of 180°e.

State Width (S): The number of electrical degrees between a transition in the output of channel A and the neighboring transition in the output of channel B. There are 4 states per cycle, each nominally 90°e.

State Width Error (ΔS): The deviation, in electrical degrees, of each state width from its ideal value of 90°e.

Phase (φ): The number of electrical degrees between the center of the high state of channel A and the center of the high state of channel B. This value is nominally 90°e for quadrature output.

Phase Error (Δφ): The deviation of the phase from its ideal value of 90°e.

Direction of Rotation: When the code wheel rotates in the counterclockwise direction (as viewed from the encoder end of the motor), channel A will lead channel B. When the code wheel rotates in the clockwise direction, channel B will lead channel A.

HEWLETT PACKARD

QUICK ASSEMBLY OPTICAL ENCODER

HEDS-5500 SERIES

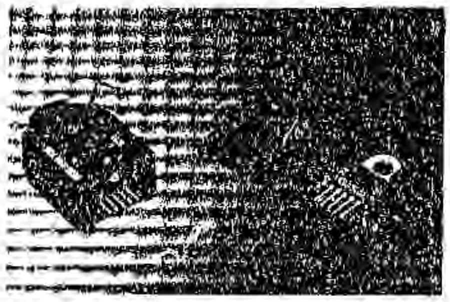
Features

- QUICK AND EASY ASSEMBLY
- NO SIGNAL ADJUSTMENT REQUIRED
- LOW COST
- SMALL SIZE
- HIGH PERFORMANCE
- HIGH RESOLUTION
- INSENSITIVE TO RADIAL AND AXIAL PLAY
- -40°C TO 100°C OPERATING TEMPERATURE
- TWO CHANNEL QUADRATURE OUTPUT
- TTL COMPATIBLE OUTPUTS
- SINGLE 5 V SUPPLY

Description

The HEDS-5500 is a high performance, low cost, optical incremental encoder which emphasizes high reliability, high resolution and easy assembly.

The encoder contains a lensed LED light source, an integrated circuit with detectors and output circuitry, and a code wheel which rotates between the emitter and detector IC. The outputs of the encoder are two square waves in quadrature. The collimated light and special photodetector configuration allow for high resolution and excellent encoding performance as well as increased long life reliability.



The encoder may be quickly and easily mounted onto a motor. No mechanical or electrical adjustments are required.

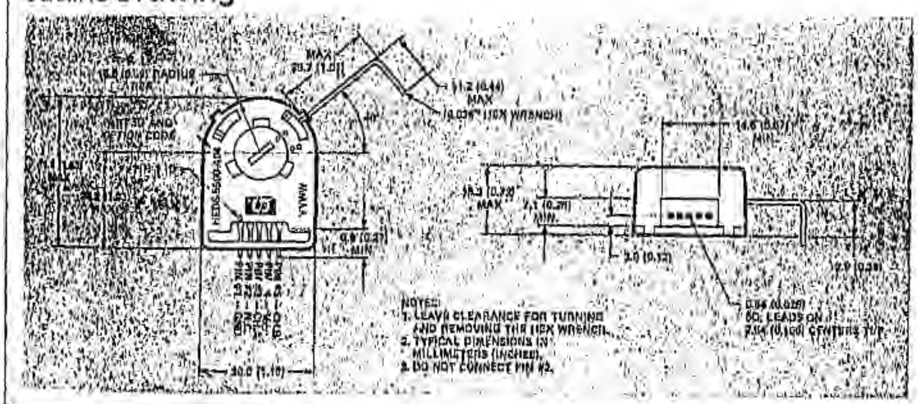
The two channel digital outputs and the single 5 V supply input are accessed through 0.025 inch square pins located on 0.1 inch centers.

Applications

The HEDS-5500 provides motion detection at a low cost, making it ideal for high volume applications. Typical applications include printers, plotters, tape drives, positioning tables and automatic handlers.

ESD WARNING: NORMAL HANDLING PRECAUTIONS SHOULD BE TAKEN TO AVOID STATIC DISCHARGE.

Outline Drawing



MOTION SENSING AND CONTROL

MAXIMUM SAFE OPERATING AREA

MAXIMUM COLLECTOR CURRENT
vs
COLLECTOR-EMITTER VOLTAGE

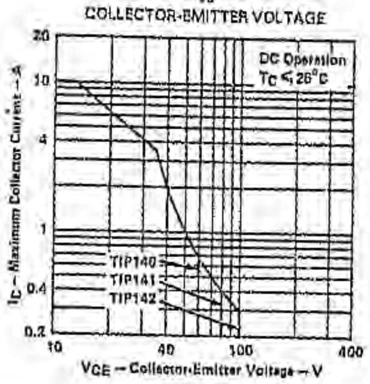


FIGURE 7

MAXIMUM COLLECTOR CURRENT
vs
UNCLAMPED INDUCTIVE LOAD

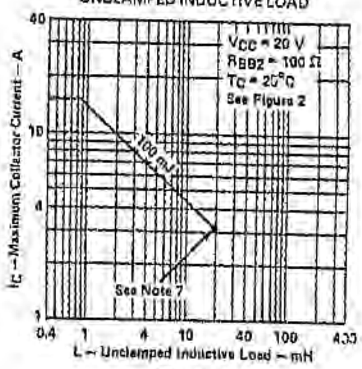


FIGURE 8

NOTE 7: Above this point the safe operating area has not been defined.

THERMAL INFORMATION

CASE TEMPERATURE
DISSIPATION DERATING CURVE

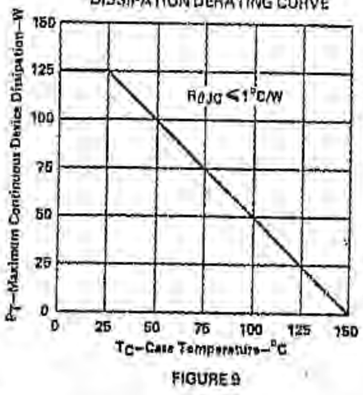


FIGURE 9

FREE-AIR TEMPERATURE
DISSIPATION DERATING CURVE

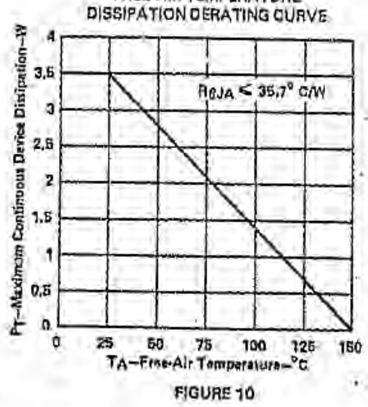


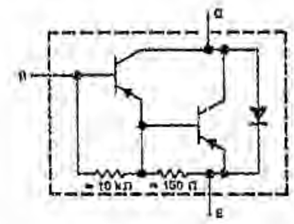
FIGURE 10

TEXAS INSTRUMENTS
POST OFFICE BOX 225012 • DALLAS, TEXAS 75265

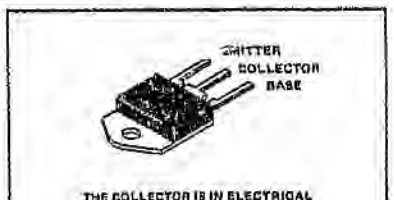
REVISED OCTOBER 1984

- Designed for Complementary Use With TIP140, TIP141, TIP142
- 125 W at 25°C Case Temperature
- 10 A Rated Collector Current
- Min h_{FE} of 1000 at 4 V, 5 A
- 100 mJ Reverse Energy Rating

device schematic



TO-218AA PACKAGE



THE COLLECTOR IS IN ELECTRICAL CONTACT WITH THE MOUNTING TAB

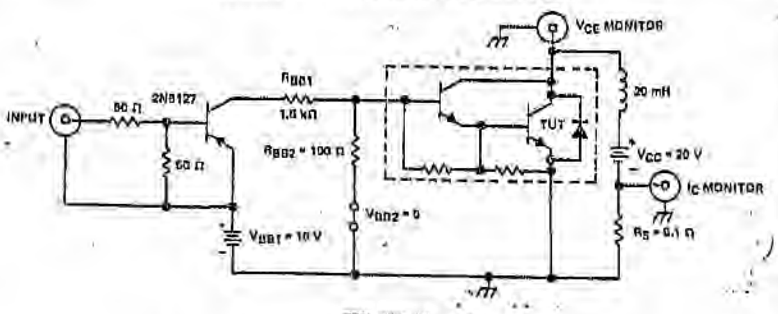
absolute maximum ratings at 25°C case temperature (unless otherwise noted)

	TIP145	TIP146	TIP147
Collector-base voltage	−60 V	−80 V	−100 V
Collector-emitter voltage (I_B = 0)	−60 V	−80 V	−100 V
Emitter-base voltage	−5 V		
Continuous collector current	−10 A		
Peak collector current (see Note 1)	−15 A		
Continuous base current	−0.5 A		
Safe operating areas at (or below) 25°C case temperature	See Figures 7 and 8		
Continuous device dissipation at (or below) 25°C case temperature (see Note 2)	125 W		
Continuous device dissipation at (or below) 25°C free-air temperature (see Note 3)	3.5 W		
Unclamped inductive load energy (see Note 4)	100 mJ		
Operating collector junction and storage temperature range	−65°C to 150°C		
Lead temperature 3.2 mm (0.125 inch) from case for 10 seconds	260°C		

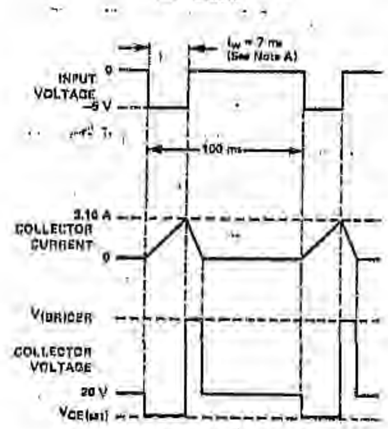
NOTES: 1. This value applies for $t_w \leq 0.3$ ms, duty cycle ≤ 10%.
2. Derate linearly to 150°C case temperature at the rate of 1 W/°C or refer to Dissipation Derating Curve, Figure 9.
3. Derate linearly to 150°C free-air temperature at the rate of 28 mW/°C or refer to Dissipation Derating Curve, Figure 10.
4. This rating is based on the capability of the transistors to operate safely in the circuit of Figure 2, L = 20 mH, R_{BB2} = 100 Ω, V_{BB2} = 0 V, R_S = 0.1 Ω, V_{CC} = 20 V, Energy ≈ $I_C^2L/2$.

TEXAS INSTRUMENTS

PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT



VOLTAGE AND CURRENT WAVEFORMS

NOTE A: Input pulse duration is increased until I_{CM} = 3.16 A.

FIGURE 2. INDUCTIVE-LOAD SWITCHING

TYPICAL CHARACTERISTICS

STATIC FORWARD CURRENT TRANSFER RATIO
vs
COLLECTOR CURRENT

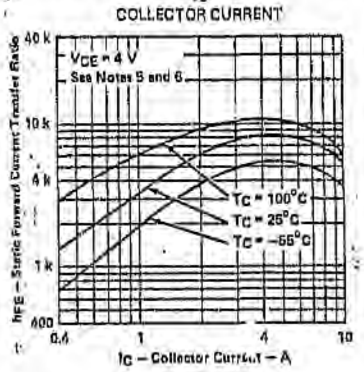


FIGURE 3

BASE-EMITTER VOLTAGE
vs
CASE TEMPERATURE

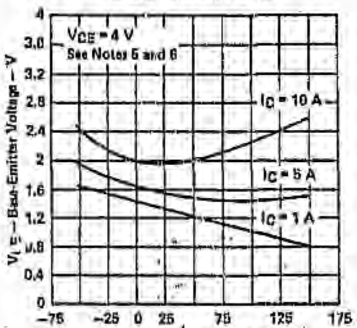


FIGURE 4

COLLECTOR-EMITTER SATURATION VOLTAGE
vs
CASE TEMPERATURE

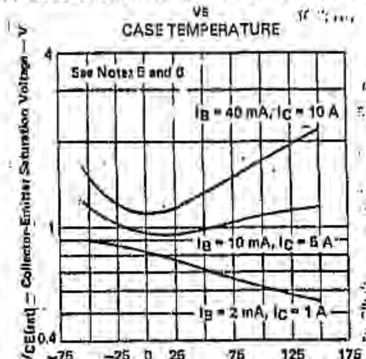


FIGURE 5

SMALL-SIGNAL COMMON-EMITTER
FORWARD CURRENT TRANSFER RATIO
vs
FREQUENCY

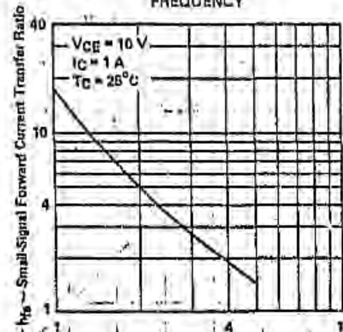


FIGURE 6

NOTES: 5. These parameters must be measured using pulse techniques, t_w = 300 μs, duty cycle ≤ 2 %.
6. These parameters are measured with voltage-sensing contacts separate from the current-carrying contacts and located within 3.2 mm (0.125 inch) from the device body.

electrical characteristics at 25°C case temperature

PARAMETER	TEST CONDITIONS	TIP140 MIN	TIP140 TYP	TIP140 MAX	TIP141 MIN	TIP141 TYP	TIP141 MAX	TIP142 MIN	TIP142 TYP	TIP142 MAX	UNIT
$V_{(BR)CEO}$	I_C = 30 mA, I_B = 0, See Note 5	60			80			100			V
I_{CEO}	V_{CE} = 30 V, I_B = 0			2							mA
	V_{CE} = 40 V, I_B = 0						2				
	V_{CE} = 50 V, I_B = 0									2	
I_{CBO}	V_{CB} = 60 V, I_E = 0			1							mA
	V_{CB} = 80 V, I_E = 0						1				
	V_{CB} = 100 V, I_E = 0									1	
I_{EBO}	V_{EB} = 5 V, I_C = 0			2			2			2	mA
h_{FE}	V_{CE} = 4 V, I_C = 5 A, See Notes 5 and 6	1000			1000			1000			
	V_{CE} = 4 V, I_C = 10 A, See Notes 5 and 6	500			500			500			
V_{BE}	V_{CE} = 4 V, I_C = 10 A, See Notes 5 and 6			3			3			3	V
$V_{CE(sat)}$	I_B = 10 mA, I_C = 5 A, See Notes 5 and 6			2			2			2	V
	I_B = 40 mA, I_C = 10 A, See Notes 5 and 6			3			3			3	
V_F	I_F = 10 A, See Notes 5 and 6			3.5			3.5			3.5	V

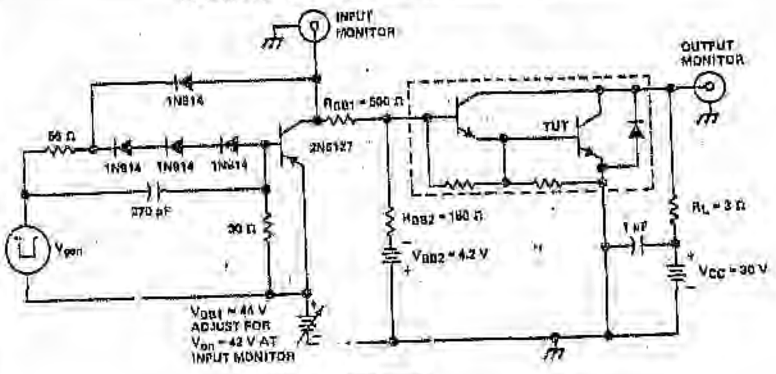
NOTES: 5. These parameters must be measured using pulse techniques, t_w = 300 µs, duty cycle ≤ 2%.
6. These parameters are measured with voltage-sensing contacts separate from the current-carrying contacts and located within 3,2mm (0.125 inch) from the device body.

resistive-load switching characteristics at 25°C case temperature

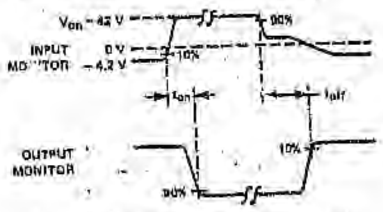
PARAMETER	TEST CONDITIONS †	MIN	TYP	MAX	UNIT
t_{on}	I_C = 10 A, I_{B1} = 40 mA, I_{B2} = −40 mA, $V_{BE(off)}$ = −4.2 V, R_L = 3 Ω, See Figure 1		0.9		µs
t_{off}			11		

† Voltage and current values shown are nominal, exact values vary slightly with transistor parameters.

PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT



VOLTAGE WAVEFORMS

NOTES: A. V_{gen} is a − 30-V pulse into a 50 Ω termination.
B. The V_{gen} waveform is supplied by a generator with the following characteristics: t_r ≤ 15 ns, t_f ≤ 15 ns, Z_{out} = 50 Ω, t_w = 20 µs, duty cycle ≤ 2 %.
C. Waveforms are monitored on an oscilloscope with the following characteristics: t_r ≤ 15 ns, R_{in} ≥ 10 MΩ, C_{in} ≤ 11.5 pF.
D. Resistors must be noninductive types.
E. The d-c power supplies may require additional bypassing in order to minimize ringing.

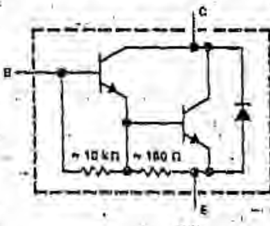
FIGURE 1. RESISTIVE-LOAD SWITCHING

5 TIP Devices

REVISED OCTOBER 1984

- Designed For Complementary Use With TIP145, TIP146, TIP147
- 125 W at 25°C Case Temperature
- 10 A Rated Collector Current
- Min h_{FE} of 1000 at 4 V, 5 A
- 100 mJ Reverse Energy Rating

device schematic



TO-218AA PACKAGE

THE COLLECTOR IS IN ELECTRICAL CONTACT WITH THE MOUNTING TAB

absolute maximum ratings at 25°C case temperature (unless otherwise noted)

	TIP140	TIP141	TIP142
Collector-base voltage	60 V	80 V	100 V
Collector-emitter voltage (I_B = 0)	60 V	80 V	100 V
Emitter-base voltage	5 V		
Continuous collector current	10 A		
Peak collector current (see Note 1)	15 A		
Continuous base current	0.5 A		
Safe operating areas at (or below) 25°C case temperature	See Figures 7 and 8		
Continuous device dissipation at (or below) 25°C case temperature (see Note 2)	125 W		
Continuous device dissipation at (or below) 25°C free-air temperature (see Note 3)	3.5 W		
Unclamped inductiv[illegible]gy (see Note 4)	100 mJ		
Operating co[illegible] junctio[illegible] and storage temperature range	− 65°C to 150°C		
Lead temperatur[illegible]m (0.125 inch) from case for 10 seconds	260°C		

NOTES: 1. This value applies for $t_w \leq 0.3$ ms, duty cycle ≤ 10 %.
2. Derate linearly to 150°C case temperature at the rate of 1 W/°C or refer to Dissipation Derating Curve, Figure 9.
3. Derate linearly to 150°C free-air temperature at the rate of 28 mW/°C or refer to Dissipation Derating Curve, Figure 10.
4. This rating is based on the capability of the transistors to operate [illegible]ly in the circuit of Figure 2. L = 20mH, R_{BB2} = 100 Ω, V_{BB2} = 0 V, R_S = 0.1 Ω, V_{CC} = 20 V, Energy = $I_C^2L/2$.

This section aims to resolve any system malfunctions that may occur during operation.

Symptom : The z-axis does not reverse when instructed.

This is due that the pinout (see description of the control circuit) of the PC36 has not reset itself. The problem generally only occurs on start-up. Inside the electric panel there is a microswitch that connects the pin to ground via a high impedance. Pressing the microswitch forces the pin to ground and resolves the problem. If the problem still persists then rebooting the PC and switching everything off will help.

Symptom : The x-axis and y-axis moves slow at first, then speeds up after a period of operation.

This is due to the non linear operation of the power transistors with increasing case temperature. At first the power transistors allow a certain current to pass, and thereafter, as they heat up, allow more current to pass.

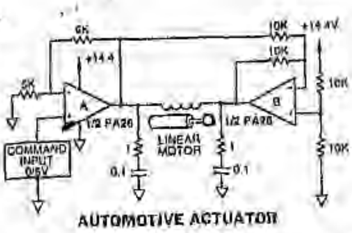
Symptom : The y-axis vibrates when in motion.

This is due to the ballscrews have been machined off centre and thus do not rotate about their centre. A seeder block is required to be placed in the bearing housing to absorb the vibrations.

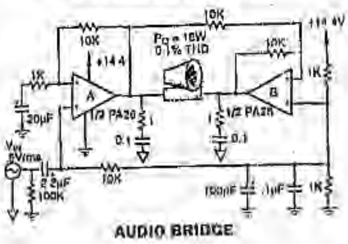
Symptom : The Z-axis fails to position itself correctly for the pick operation.

This is due to the power supply to drive the Z-motor is rated at 24 V when the in fact the power supply required is 16 V, and thus the RPM of the Z-motor are too high for the successful stopping of the Z-motor.

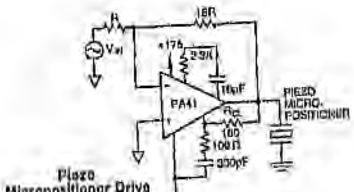
Appendix G Troubleshooting



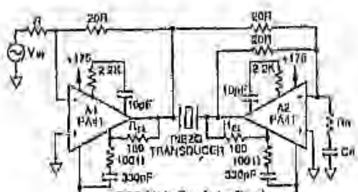
AUTOMOTIVE ACTUATOR



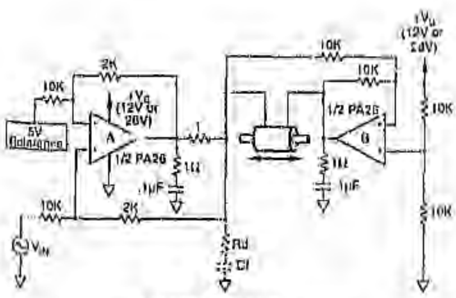
AUDIO BRIDGE



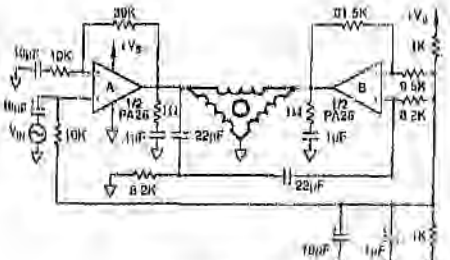
Piezo Micropositioner Drive



660 Volt Peak to Peak Low Cost Piezo Drive



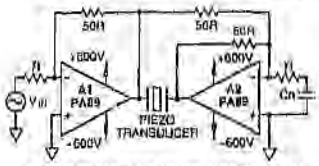
CURRENT CONTROL
SOLENOID OR LINEAR ACTUATOR DRIVE
±200mA/V current output



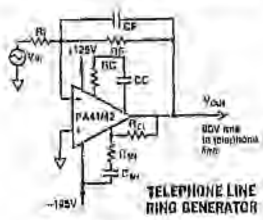
60Hz 3 PHASE MOTOR DRIVE
Single Supply

PA89 Industry's Highest Voltage

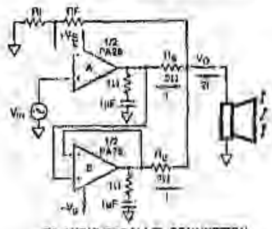
- ±600V supply
- 75mA output
- 3kHz power bandwidth
- 6.0mA max quiescent current
- Input Offset Voltage 2mV max



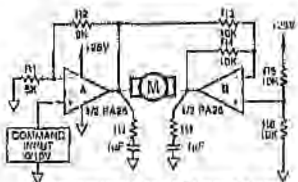
±1100V SINGLE AXIS MICRO-POSITIONING



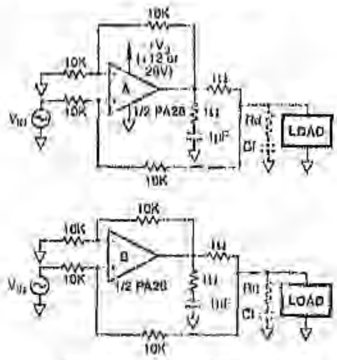
TELEPHONE LINE RING GENERATOR



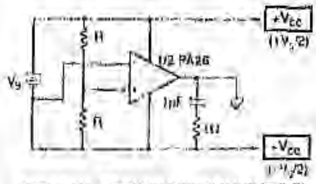
5A AUDIO PARALLEL CONNECTION



BIDIRECTIONAL SMALL MOTOR DRIVE



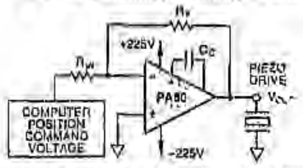
DUAL UNIPOLAR SOLENOID DRIVER
1A/V current output



ARTIFICIAL GROUND (SUPPLY SPLITTER)

PA88/PA88M—High Voltage, Low Quiescent Current

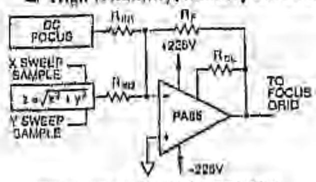
- ±225V supply
- 100mA output
- 2.0mA max quiescent current
- Programmable current limit
- High reliability, military version



±210V LOW POWER, PIEZOELECTRIC POSITIONING

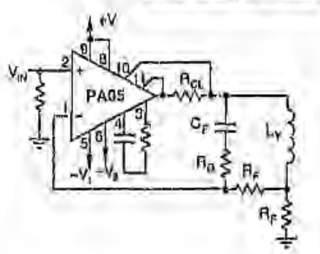
PA85/PA85M—High Voltage, High Power Bandwidth

- ±225V supply
- 200mA output
- 550kHz power bandwidth
- 1000V/µs
- High reliability, military version

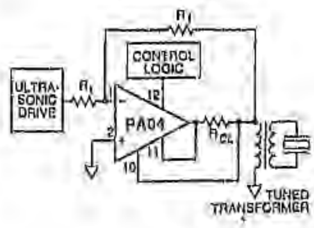


HIGH VOLTAGE DYNAMIC FOCUSING

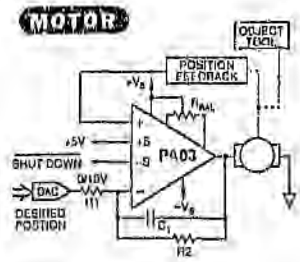
DEFLECTION

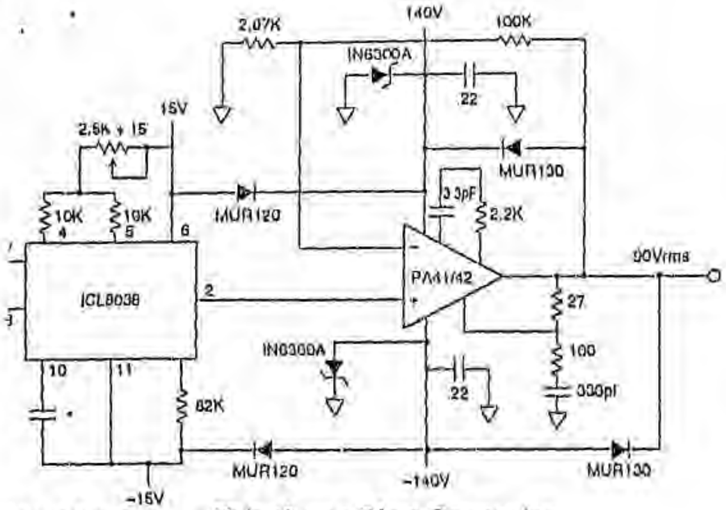


SONAR



MOTOR





* 1.5 µF @ 16Hz
1.2 µF @ 20Hz

Telephone Ring Generator

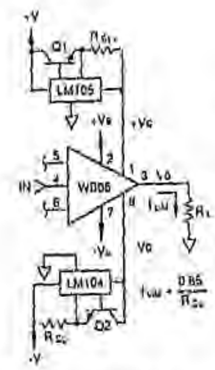


Figure 1: ...put voltage regulation and current limit

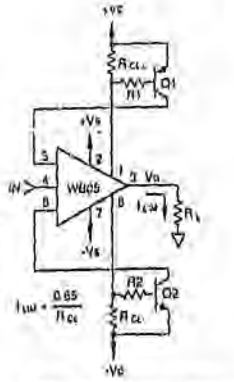


Figure 2: Current limit using sleep pins

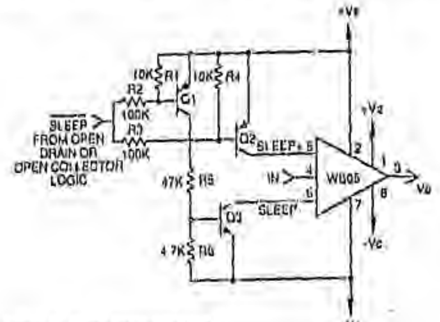
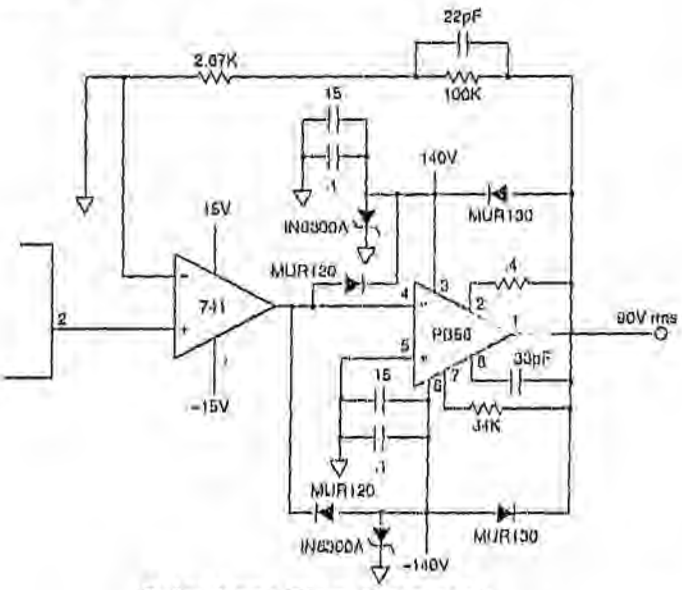
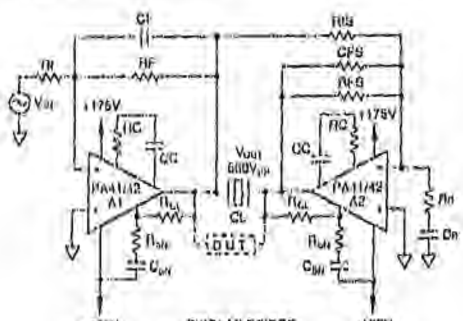


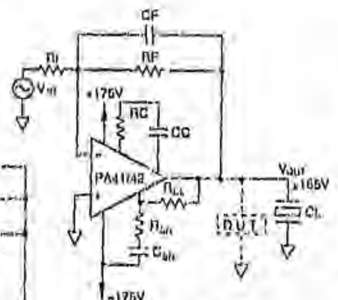
Figure 3: Sleep mode interface



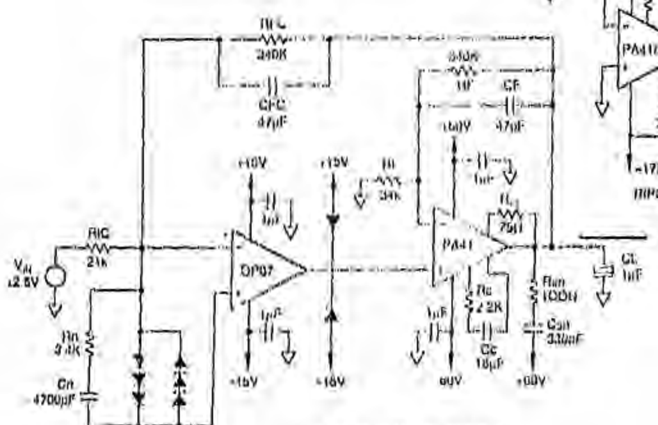
Telephone Ring Generator



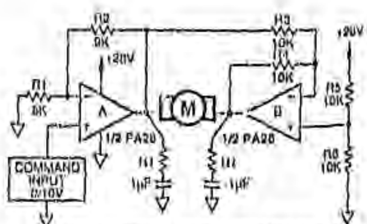
BIPOLAR BRIDGE



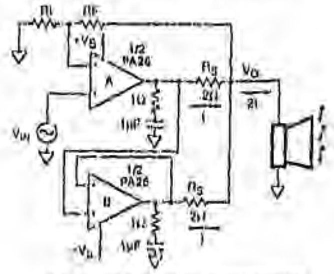
BIPOLAR OUTPUT



ALL DIODES = 1N4148-1



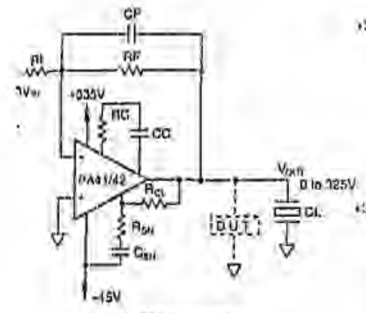
BIDIRECTIONAL SMALL MOTOR DRIVE



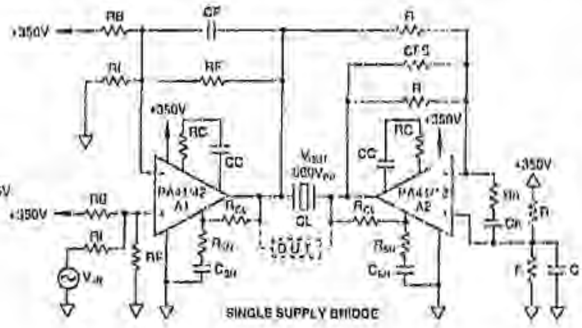
5A AUDIO PARALLEL CONNECTION

APEX Power Op Amps

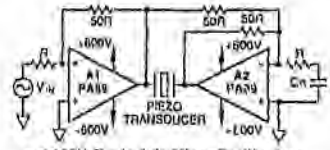
Circuit Diagrams and Applications Information



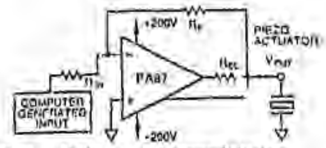
ASYMMETRICAL OUTPUT



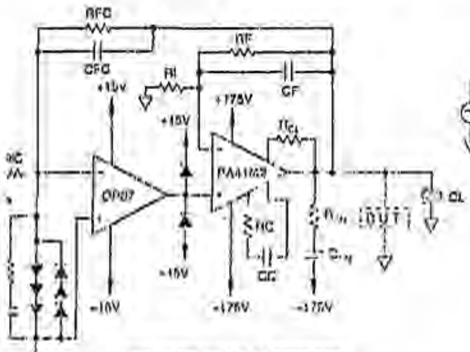
SINGLE SUPPLY BRIDGE



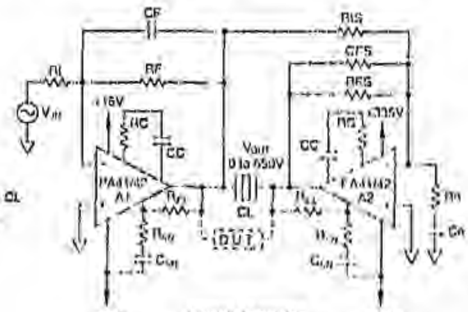
±1100V Single Axis Micro-Positioning



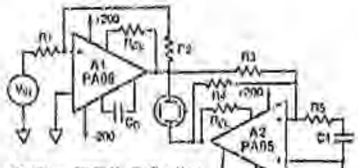
Deformable/Segmented Mirror Actuator



HIGH ACCURACY PA41 COMPOSITE

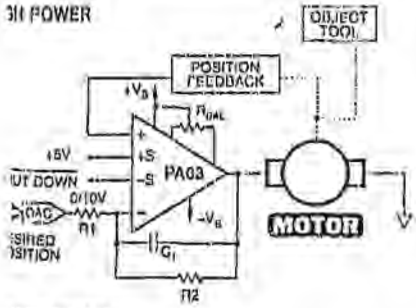


UNIPOLAR BRIDGE

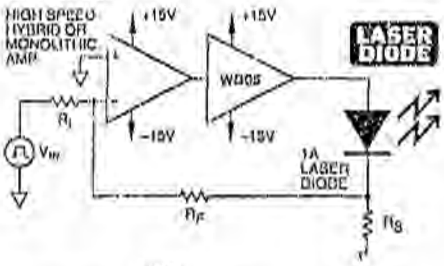


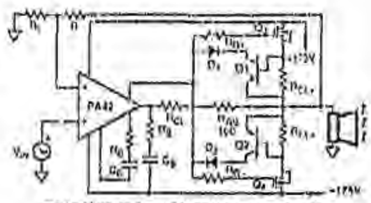
800Vp-p 500kHz Deflection For Beam Deposition System

HIGH POWER



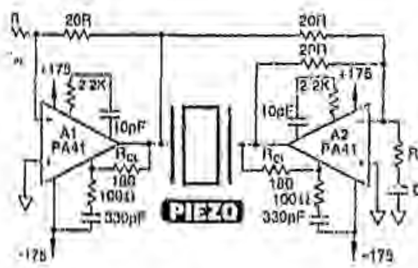
HIGH SPEED



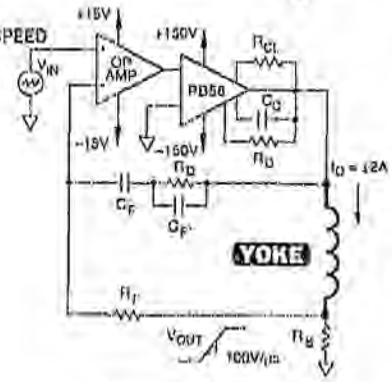


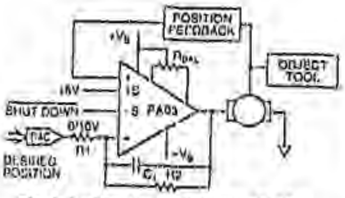
PA42 With External MOSFETS Creates A Super Power Audio Amp Subwoofer Driver

HIGH VOLTAGE

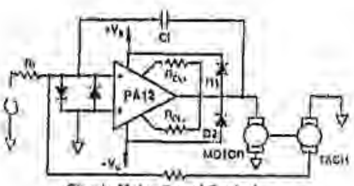


HIGH SPEED

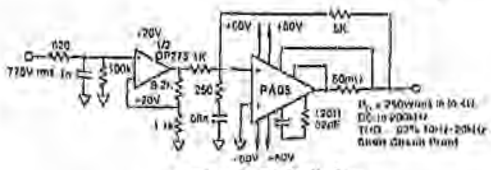




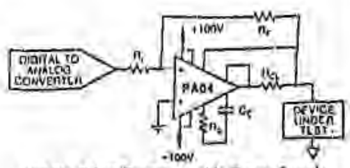
Simple Position Control Using the PA03



Simple Motor Speed Control



Premium Quality Audio Amp



ATE Pin Driver Programmable Power Supply

APEX® HIGH POWER/DESC SMD AVAILABILITY PRODUCT SELECTOR GUIDE

HIGH POWER

Model	Internal Power Watts Max	Output Current (Cont.) Amps., Min	±Supply Range Volts Min/Max	Saturation @I_oMax (V_s-V_o) Volts, Max	Slew Rate V/µs Typ	V_{os} Initial mV Max	V_{os} vs Temp µV/°C Max	Bias Current nA Max	I_q mA Max	Gain BW Product MHz Typ	Current Limit (Amps)	Thermal Shutdown	Temp Range °C Min/Max	Packaging Type
PA30	1000	50	15/100	7.5/9.5(1)	45	10	50	.05	40	1	Ext Adj	Yes	−25/85	SL15
PA03	500	30	15/75	7	8	2	30	.05	300	1	Thermal	Yes	−25/85	MO-127
PA03A	*	*	*	*	*	.5	10	.01	*	*	*	*	*	*
PA04	200	20	15/100	5.3/8.8(1)	50	10	50	.05	90	2	Ext Adj	No	−25/85	MO-127
PA04A	*	*	*	*	*	5	30	.02	*	*	*	*	*	
PA05	250	30	15/50	5.8/9.5(1)	100	10	50	.05	120	3	Ext Adj	Yes	−25/85	MO-127
PA05A	*	*	*	*	*	5	30	.02	*	*	*	*	*	*
PA12	125	10	10/45	6	4	6	65	30	50	4	Ext Adj	No	−25/85	TO-3
PA12A	*	15	10/50	7	*	3	40	20	*	*	*	*	−55/125	*
PA12M/883	*	*	10/45	6	*	6	65	30	*	*	*	*	*	*
PA12H	*	1	*	4		6		30	100		*	*	−25/200	*
PA61(2)	97	10	10/45	7	2.8	6	65	30	10	1	Ext Adj	No	−25/85	TO-3
PA61A(2)	*	*	*	6	*	3	40	20	*	*	*	*	*	*
PA61M/883(2)	*	*	*	7	*	6	65	30	*	*	*	*	−55/125	*
PA51(2)	97	10	10/36	8	2.6	10	65	40	10	1	Ext Adj	No	−25/85	TO-3
PA51A(2)	*	*	10/40	*	*	5	40	20	*	*	*	*	*	*
PA51M/883(2)	*	*	10/36	*	*	10	65	40	*	*	*	*	*	*
PA07	67	5	12/50	5	5	2	30	.05	30	1.3	Ext Adj	Yes	−25/85	TO-3
PA07A	*	*	*	*	*	.5	10	.01	*	*	*	*	*	*
PA07M/883	*	*	*	*	*	2	30	.05	*	*	*	*	−55/125	*
PA10	67	5	10/45	8	5	6	65	30	30	6	Ext Adj	No	−25/85	TO-3
PA10A	*	*	10/50	8	*	3	40	20	*	*	*	*	−55/125	*
PA10M/883	*	*	10/45	8	*	6	65	30	*	*	*	*	*	*
PA73(2)	67	5	10/30	8	2.6	10	65	40	5	1	Ext Adj	No	−25/85	TO-3
PA73M/883(2)	*	*	*	*	*	*	*	*	*	*	*	*	−55/125	*
PA01	67	5	10/28	10	2.6	12	65	50	50	1	Ext Adj	No	−25/85	TO-3
PA02	48	5	7/19	4	20	10	50	.2	37	4.5	Ext Adj	No	−25/85	TO-3
PA02A	*	*	*	*	*	3	25	.1	*	*	*	*	−55/125	*
PA02D	48	5	7/19	4	20	10	50	.2	110	4.5	Ext adj	No	−25/85	TO-3
PA02M/883	*	*	*	*	*	3	50	.2	37	*	*	*	−55/125	*
PA21	36	2.6	2.5/20	3.0	1.2	10	15 typ	1000	90	5	(3)	Yes	−25/85	TO-3
PA21A	*	3.0	*	3.5	*	4	10 typ	250	*	*	(4)	*	*	*
PA21M	*	2.5	*	3.0	*	10	15typ	1000	*	*	(3)	*	−55/125	*
PA25	36	2.5	2.5/25	3.0	1.2	10	15 typ	1000	90	.8	(3)	Yes	−25/85	TO-3
PA25A	*	3.0	*	3.5	*	4	10typ	25	*	*	(4)	*	*	*
PA26	36	2.5	2.5/25	3.0	1.2	10	15 typ	1000	90	.8	(3)	Yes	−25/85	TO-3
PB50	35	2	30/100	11	100	1750	7000	—	18	2.5	Ext Adj	No	−25/85	TO-3
PB58	60	1.5	15/150	11	100	1500	7000	—	12	2.5	Ext Adj	No	−25/85	TO-3
PB58A	*	2.0	*	*	*	1000	*	—	*	*	*	*	*	*

†Specifications apply for T_c = 25°C, unless otherwise stated *Specification is same as above

(1) 1st number with Boost Voltage = V_s + 5V; 2nd number without Boost Voltage. (2) Class "C" output—optimized for low cost—not recommended above 1KHz

DESC SMD AVAILABILITY

Apex Model Number	SMD Part #
High Power	
PA02M/883	5962-9067901HXC
PA07M/883	5962-9063801HXC
PA10M/883	5962-9082801HXC
PA12M/883	5962-9065901HXC
PA51M/883	5962-8762002YC

Apex Model Number	SMD Part #
High Voltage	
PA08M/883	5962-9072301HXC
PA83M/883	5962-9162101HXC
PA84M/883	5962-9073601HXC
High Speed	
PA09M/883	5962-9170001HXC

APEX®

HIGH VOLTAGE/HIGH SPEED PRODUCT SELECTOR GUIDE

HIGH VOLTAGE

Model	±Supply Range Volts Min/Max	Output Current (Cont.) mA, Min	Saturation @I_OMax (V_S-V_O) Volts, Max	Internal Power Watts Max	Slew Rate V/μs Typ	V_{OS} Initial mV Max	V_{OS} vs Temp μV/°C Max	Bias Current nA Max	I_q mA Max	Gain BW Product MHz Typ	Current Limit (Amps)	Thermal Shutdown	Temp Range °C Min/Max	Packaging Type
PA89	50/600	75	30	40	16	2	30	.05	6	10	Ext Adj	No	-25/85	MO-127
PA89A	•	•	•	•	•	.5	10	.01	•	•	•	•	•	•
PA85	15/225	200	10	35	1000	2	30	.05	25	100	Ext Adj	No	-25/85	TO-3
PA85A	•	•	•	•	•	.5	10	.01	•	•	•	•	•	•
PA85M	•	•	•	•	400	4	30	.05	•	•	•	•	-55/125	•
PA88	15/225	100	10	15	30	2	30	.05	2	2	Ext Adj	No	-25/85	TO-3
PA88A	•	•	•	•	•	.5	10	.01	•	•	•	•	•	•
PA88M	•	•	•	•	16	4	30	.05	•	•	•	•	•	•
PA41	50/175	60	12	12	40	60	130	.05	2	1.6	Ext Adj	No	-25/85	TO-3
PA41A	50/175	60	10	12	40	30	65	.05	1.8	1.6	Ext Adj	No	-25/85	•
PA41M	50/175	60	12	12	5	60	130	.05	2	1.6	Ext Adj	No	-55/125	•
PA42	50/175	60	12	9	40	60	130	.05	2	1.6	Ext Adj	No	-25/85	TO-3
PA42A	50/175	60	10	9	40	30	65	.05	1.8	1.6	Ext Adj	No	-25/85	•
PA42M	50/175	60	12	9	5	60	130	.05	2	1.6	Ext Adj	No	-55/125	•
PA08V	15/175	150	15	17.5	30	2	30	.05	8.5	5	Ext Adj	Yes	-25/85	TO-3
PA08	15/150	•	•	•	•	•	•	•	•	•	•	•	•	•
PA08A	•	•	•	•	•	.5	10	.01	•	•	•	•	•	•
PA08M/883	•	•	•	•	•	2	30	.05	•	•	•	•	-55/125	•
PB58	15/150	1500	11	80	100	1750	7000	—	12	2.5	Ext Adj	No	-25/85	TO-3
PB58A	•	2000	•	•	•	1000	•	—	•	•	•	•	•	•
PA03	15/150	75	10	17.5	30	3	25	.05	8.5	5	(.1)	Yes	-25/85	TO-3
PA03A	•	•	•	•	•	1	10	.01	•	•	•	•	•	•
PA03M/883	•	•	•	•	•	3	25	.05	•	•	•	•	-55/125	•
PA04	15/150	40	7	17.5	200	3	25	.05	7.5	76	(.05)	Yes	-25/85	TO-3
PA04A	•	•	•	•	•	1	10	.01	•	•	•	•	•	•
PA04M/883	•	•	•	•	•	3	25	.05	•	•	•	•	-55/125	•
PA04S	•	•	•	•	•	•	•	•	•	•	•	•	-25/85	•
PA82J	70/150	15	5	11.5	20	3	25	.05	8.5	5	(.025)	Yes	0/70	TO-3
PB50	30/100	2000	11	35	100	1750	7000	—	16	2.5	Ext Adj	No	-25/85	TO-3
PA81J	32/75	30	5	11.5	20	3	25	.05	8.5	5	(.05)	Yes	0/70	TO-3

†Specifications apply for T_C = 25°C, unless otherwise stated. *Specification is same as above.

HIGH SPEED

Model	Slew Rate V/μs Typ	Output Current (Cont.) Amps., Min	±Supply Range Volts Min/Max	Saturation @I_OMax (V_S-V_O) Volts, Max	Internal Power Watts Max	V_{OS} Initial mV Max	V_{OS} vs Temp μV/°C Max	Bias Current nA Max	I_q mA Max	Gain BW Product MHz Typ	Current Limit (Amps)	Thermal Shutdown	Temp Range °C Min/Max	Packaging Type
WA01	5000	.4	12/16	[illegible]	10.5	10	50	20000	30	—	(.6)	No	-25/85	TO-3
WA01A	•	•	•	•	•	5	25	10000	•	•	•	•	•	•
WB05	10000	1	5/15	6.5	15	100	500	30000	30	250	(1.5)	No	-25/85	TO-3
PA85	1000	.2	15/225	10	35	2	30	.05	25	100	Ext Adj	No	-25/85	TO-3
PA85A	•	•	•	•	•	.5	10	.01	•	•	•	•	•	•
PA85M	•	•	•	•	•	2	30	.05	•	•	•	•	-55/125	•
PA19	900	[illegible]	15/40	5	78	3	30	.2	120	100	Ext Adj	Yes	-25/85	TO-3
PA19A	•	•	•	•	•	.5	10	.05	•	•	•	•	•	•
PA09	400	2	12/40	6	78	3	30	.1	85	150	(4.5)	Yes	-25/85	TO-3
PA09A	•	•	•	•	•	.5	10	.02	•	•	•	•	•	•
PA09M/883	•	•	•	•	•	3	30	.1	•	•	•	•	-55/125	•

†Specifications apply for T_C = 25°C, unless otherwise stated. *Specification is same as above.

PA26 Dual Monolithic Power Op Amp

Key Features

- Wide supply voltage range 6 - 40V.
- Dual amplifier.
- Low cost.
- Common mode range includes negative rail.
- Unity gain stable.
- Output of 3A x 2 (dual 3 amp)
- VCM = ground to Vss -2.
- V Sat = 2 V at 2.5A.
- Plastic SIP or TO-3 packages.
- Single supply circuits are easy to implement.
- Current sensing pins.
- Good input offset & drift.

Typical Applications

- 12V automotive.
- 28V for military vehicles and aircraft.
- Robotics.
- Consumer, aud radio, t.v. and toys.
- Computer peripherals.
- Power supplies.
- Brush type DC motor drives uni- or bi- directional.
- Solenoid/actuator drive.
- Valve control.
- Temperature and lamp controllers.
- Microstepping applications.
- Voltage regulators.
- Transducers (including low voltage Piezo).
- Multi phase motor drives.

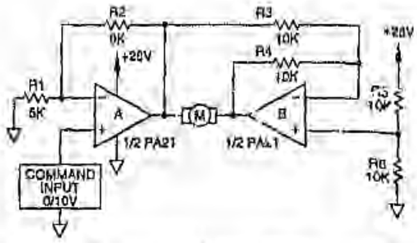


FIGURE 1: BIDIRECTIONAL SPEED CONTROL FROM A SINGLE SUPPLY

PA41/PA42 High Voltage Power Op Amp

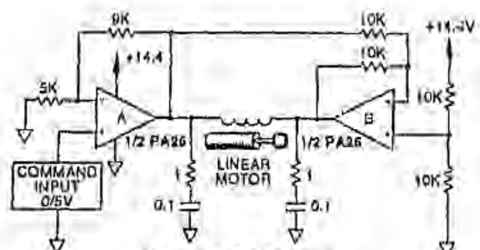
Key Features

- High Voltage operation Vss=350
- High output current - 60mA.
- 40V/us slew rate.
- Low quiescent current - 2mA.
- Monolithic MOS technology.
- MOSFET design, no secondary breakdown.
- Programmable current limit
- Low cost.
- Unity gain stability.
- 10-pin SIP package.
- 40V/us slew rate.
- 26 kHz power bandwidth.
- Common mode and differential input protection.

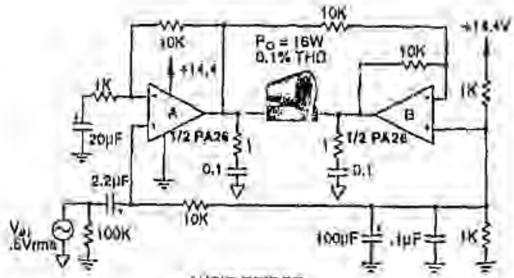
Typical Applications

- Automatic test equipment for pin drivers.
- Vacuum tube interface.
- High voltage line driver.
- Electrolysis control.
- Electrostatic deflection
- Piezo transducer control.
- Waveform generator output stages.
- Piezo electric device amplifiers.
- Beam/CRT system deflection.
- Electrostatic lens control.

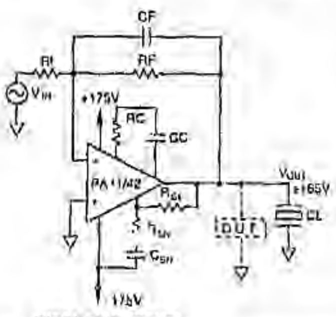
Typical Circuits



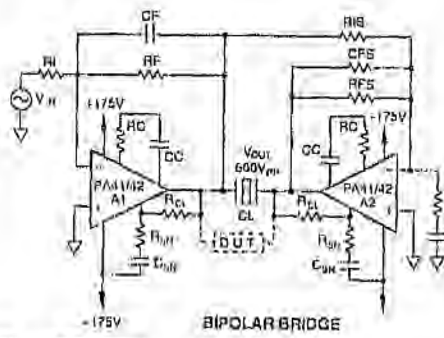
AUTOMOTIVE ACTUATOR



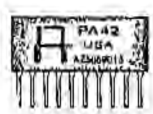
AUDIO BRIDGE



BIPOLAR OUTPUT



BIPOLAR BRIDGE



EAGLE TECHNOLOGY

P O Box 4376
Cape Town 8000

Fax: (021) 24-4637
Phone: (021) 23-4943

Power OP Amps

These power operational amplifiers will be of great use to designers and to engineers involved in power control, amplifiers, oscillators or switching.

The 65 different devices available from Eagle range from the new monolithic SIP or TO3 packaged PA42 which is rated 350V at 60ma, and which is ideal for bridge amplifiers and piezo drives to the SIP or TO3 packaged PA21/25/26. These three devices are dual OP amps extensively used for motor drivers, power amps and sole id drivers. Very high voltage (1200V), very high power (2000 WATTS RMS), and very high speed (900VOLTS/μs) and are high performance devices in the product range.

Applications

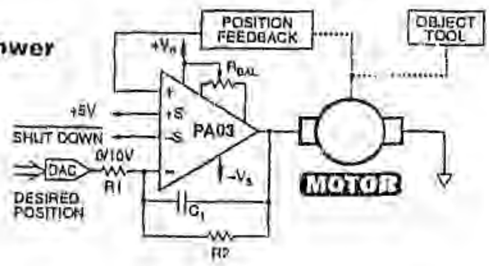
- Sonar
- Programmable power supplies
- Voltage ~ current conversion
- Power boosters
- Power amplifiers audio etc.
- Piezo drive circuits
- Automatic test equipment
- High voltage line drivers
- Waveform generators
- Welding
- Motor drivers – half and full bridge
- Multi phase motor drives
- Magnetic deflection/focus
- Electro-luminescent displays
- Lasers
- Biomedical
- Voltage regulators
- Lamp controllers
- Solenoid/actuator drivers
- Valve control
- Vacuum tube interface

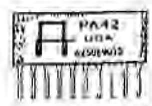
Key Features

- Many industrial and communication applications shown on the applications list.
- Low cost high voltage monolithic amplifiers now available in SIP10 (PA42) or TO-3 package (PA41).
- Prime source for devices – other second sources available.
- 65 Models to choose from.
- Very high Voltage Models – up to ± 600V (1200V rail to rail) (PA89).
- Very high speed models – 200 VOLT/μs at 6 amps (PA19).
- Very high power models up to 2000 WATTS RMS (PA30).
- High speed buffers – 15,000 VOLTS/μs at 0.5 amps (Model WB05).
- Very quick delivery.
- Competitive prices.
- MIL SPEC devices available – DESC SMD.
- Surface mount.
- Product handbook gives full technical specifications available.
- Excellent applications and product support.
- Many low cost devices in the range.
- High efficiency and low distortion.

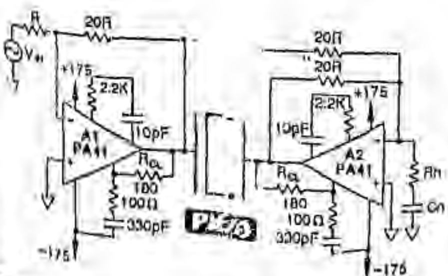
Typical Applications

High Power

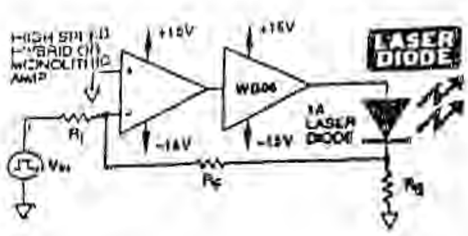




High Voltage



High Speed



THERMAL DATA

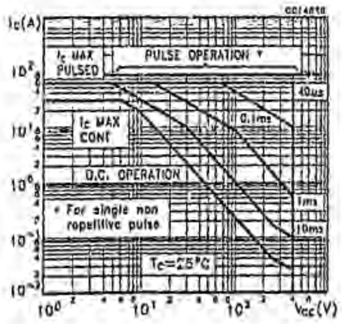
$R_{thj-case}$	Thermal Resistance Junction-case (quarte bridge)	Max	0.66	°C/W
$R_{thj-case}$	Thermal Resistance Junction-case (diode)	Max	1.1	°C/W
R_{thc-h}	Thermal Resistance Case-heatsink With Conductive Grease Applied	Max	0.05	°C/W

ELECTRICAL CHARACTERISTICS (T_{case} = 25 °C unless otherwise specified)

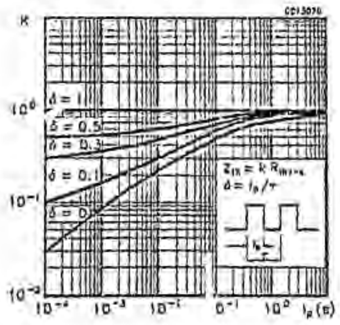
Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{CES}	Collector Cut-off Current (V_{BE} = 0)	V_{CE} = 500 V V_{CE} = 400 V T_j = 125 °C		 3	2 10	mA mA
I_{CEV}	Collector Cut-off Current (V_{BE} = -2 V)	V_{CE} = 500 V V_{CE} = 400 V T_j = 125 °C			2 10	mA mA
I_{EBO}	Emitter Cut-off Current (I_C = 0)	V_{EB} = 2 V			90	mA
$V_{CE(sat)}$*	Collector-Emitter Saturation Voltage	I_C = 30 A I_B = 2 A I_C = 40 A I_B = 4 A		1.5 1.9	3 2.5	V
$V_{BE(sat)}$*	Base-Emitter Saturation Voltage	I_C = 40 A I_B = 4 A		2.6	3.3	V
h_{FE}*	DC Current Gain	I_C = 30 A V_{CE} = 5 V I_C = 40 A V_{CE} = 3 V	40 16	50		
 t_s t_f	INDUCTIVE LOAD Storage Time Fall Time	V_{CC} = 50 V I_C = 30 A I_{B1} = 2 A $V_{BE(off)}$ = -5 V T_j ≤ 125 °C (see test circuits)		 1.3 0.2	 4 0.7	 µs µs
V_F	Diode Forward Voltage	I_F = 30 A		1.3	2	V
t_{rr}	Diode Reverse Recovery Time	I_F = 30 A dI/dt = 100 A/µs		0.2	0.5	µs

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

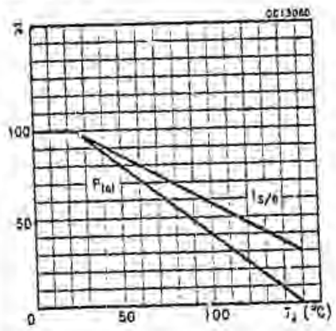
Safe Operating Areas



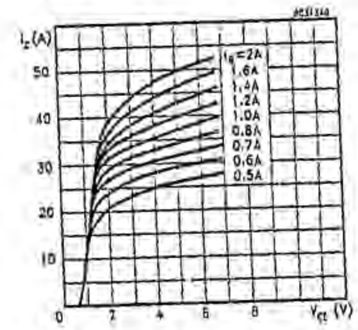
Thermal Impedance



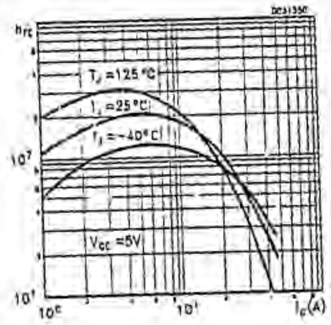
Derating Curve



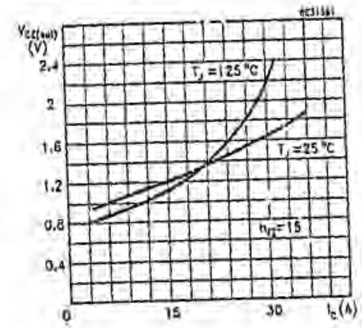
Output Characteristics



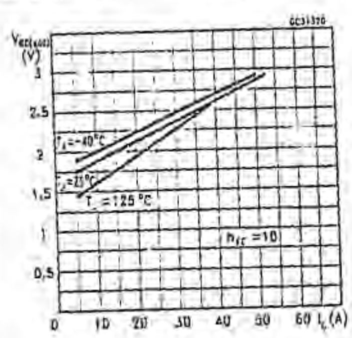
DC Current Gain



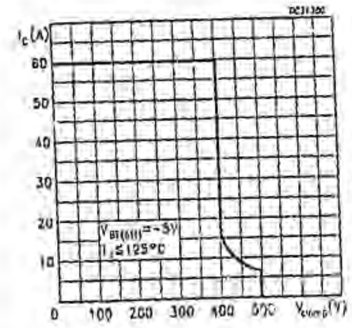
Collector-Emitter Saturation Voltage



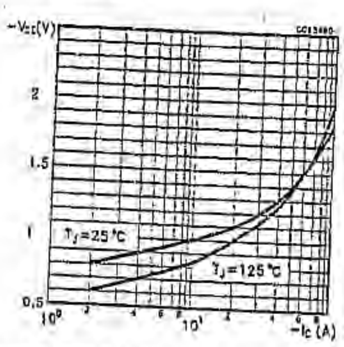
Base-Emitter Saturation Voltage



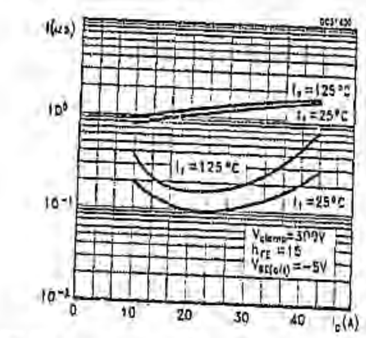
Reverse Biased SOA



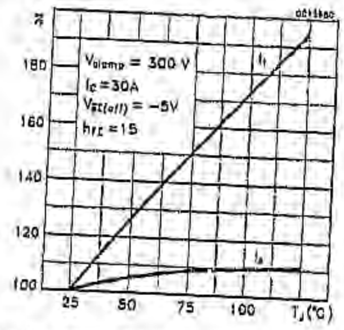
Typical V_F Versus I_F



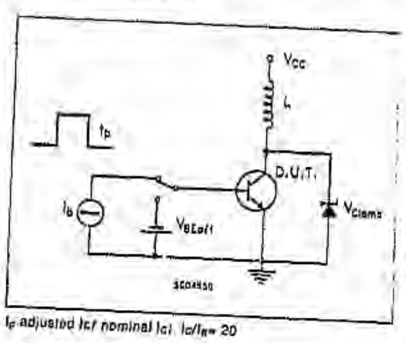
Switching Times Inductive Load



Switching Times Inductive Load Versus Temperature

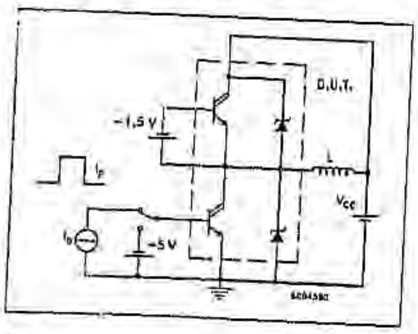


RBSOA Test Circuit



I_B adjusted Ic/ nominal Ic. Ic/I_B= 20

Switching Times Test Circuit



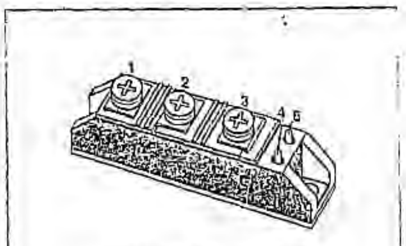
SGS-THOMSON MICROELECTRONICS

SGS30DB045D

HALF BRIDGE NPN DARLINGTON POWER MODULE

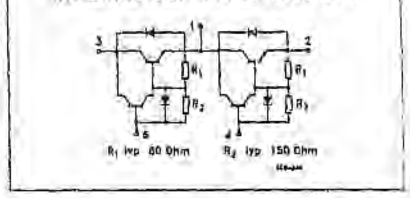
- POWER MODULE WITH INTERNAL ISOLATION (2500V RMS)
- LOW R_{th} JUNCTION TO CASE
- FREEWHELING DIODE
- ADAPTED FOR HIGH POWER SWITCHING APPLICATIONS

INDUSTRIAL APPLICATIONS:
- MOTOR CONTROL
- HIGH POWER SMPS AND UPS



TRANSPACK (TO-240)

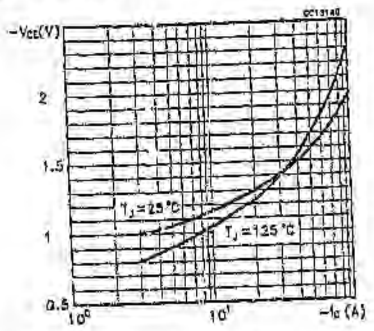
INTERNAL SCHEMATIC DIAGRAM



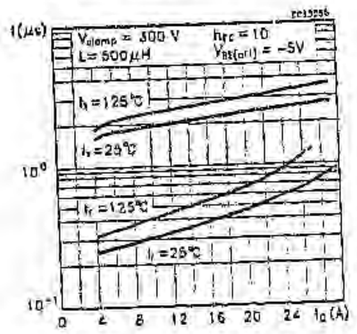
ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{CEO}	Collector-Emitter Voltage (I_B = 0)	450	V
V_{CES}	Collector-Emitter Voltage (V_{BE}= 0)	600	V
V_{CEV}	Collector-Emitter Voltage (V_{BE} = -2V)	600	V
V_{CBO}	Collector-Base Voltage (I_E = 0)	600	V
V_{EBO}	Emitter-Base Voltage (I_C = 0)	7	V
I_C	Collector Current	30	A
$-I_C$	Reverse Collector Current	30	A
I_B	Base Current	6	A
I_{CSM}	Collector Surge Current	300	A
P_{tot}	Total Dissipation at T_c = 25 °C	375	W
T_{stg}	Storage Temperature	-55 to 150	°C
T_j	Max. Operating Junction Temperature	150	°C
V_{ISO}	Insulation Withstand Voltage (AC-RMS)	2500	V

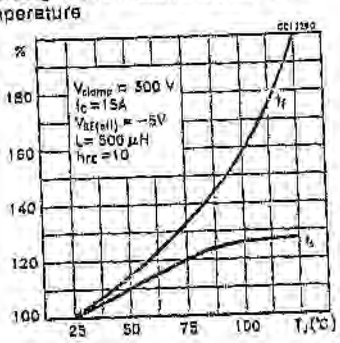
Typical V_F Versus I_F



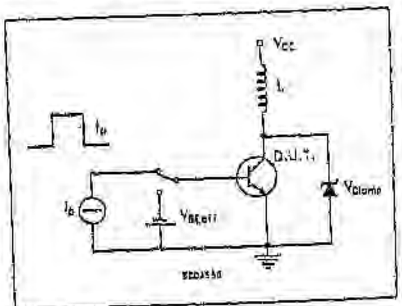
Switching Times Inductive Load



Switching Times Inductiv Load Versus Temperature

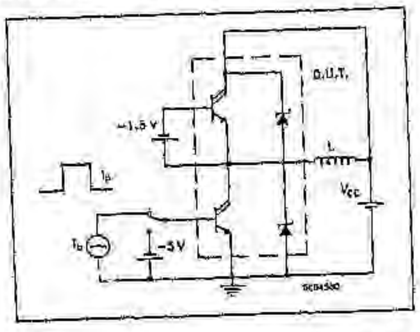


RBSOA Test Circuit



I_B adjusted for nominal I_C; I_C/I_B= 10

Switching Times Test Circuit



SGS-THOMSON MICROELECTRONICS

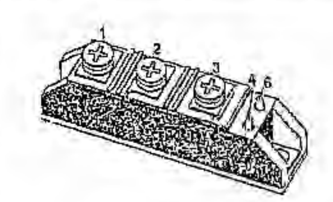
SGS30DB040D

HALF BRIDGE NPN DARLINGTON POWER MODULE

- POWER MODULE WITH INTERNAL ISOLATION (2500V RMS)
- LOW R_{th} JUNCTION TO CASE
- FREEWHELING DIODE
- ADAPTED FOR HIGH POWER SWITCHING APPLICATIONS

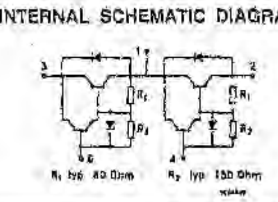
INDUSTRIAL APPLICATIONS:

- MOTOR CONTROL
- HIGH POWER SMPS AND U[illegible]
- HIGH POWER DC/DC A[illegible]D DC/AC CONVENTERS



TRANSPACK (TO-240)

INTERNAL SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{CEO}	Collector-Emitter Voltage (I_B = 0)	400	V
V_{CES}	Collector-Emitter Voltage (V_{BE} = 0)	500	V
V_{CEV}	Collector-Emitter Voltage (V_{BE} = -2V)	500	V
V_{CBO}	Collector-Base Voltage (I_E = 0)	500	V
V_{EBO}	Emitter-Base Voltage (I_C = 0)	7	V
I_C	Collector Current	30	A
$-I_C$	Reverse Onllector Current	30	A
I_B	Base Current	6	A
I_{CSM}	Collector Surge Current	300	A
P_{tot}	Total Dissipation at T_c = 25 °C	375	W
T_{stg}	Storage Temperature	-55 to 150	°C
T_j	Max. Operating Junction Temperature	150	°C
V_{ISO}	Insulation Withstand Voltage (AC-RMS)	2500	V