DESIGN AND DEVELOPMENT OF A MICROCOMPUTER CONTROLLED AUTOMATIC STORAGE AND RETRIEVAL MODEL

by

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Major Professor

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1. Introduction

1.1 Preamble

Industry will undergo a profound change in 1980's as automation is introduced at a rapid pace. In recent years, there have been many innovations in the fields of material handling and industrial automation.

The term automation is not new. Automated devices for both industrial and non industrial applications have been in existence for a long time. Examples of such devices include cam operated toggles, tracer machines and player pianos.

If automation has been in existence for considerable period of time, then why is there so much ado about automation at the present time. The answer lies in the fact, that the term automation as used today refers mostly to programmable automation generally under computer control and not to fixed automation devices of the past. Further, it not only refers to the control of mechanical devices but also the information component of the operations.

Programmable automation was applied gradually to industry due to three main reasons. Firstly, economic justification was difficult due to relatively low labor costs. Secondly, the computer technology was not user friendly, and thirdly, the pressure of foreign competition was virtually non existent.

Recently, a change in the industrial environment can be sensed. Labor costs have risen and computer costs have reduced drastically thereby making it easier to economically justify automation. Todays computer systems are highly sophisticated and at the same time increasingly user friendly. Besides, the pressure of competition can be felt from all corners of the world. Due to all these reasons, many industries big and small are introducing automation with increasing fervor within all levels of their operations.

The concept of an automated factory is to integrate the basic functions of manufacturing into a simple operating system, and in doing so, to apply the highest level of automation economically feasible for each one of the functions (1).

Computer integrated manufacturing is another name for this approach. Computer-aided design and computer-aided manufacturing (CAD/CAM) are part of the total concept of an automated factory. So too are flexible manufacturing systems, automated material handling and robotics.

Currently there are only few "fully" automated factories in existence. However, there are many manufacturing industries throughout the world that are moving towards the automated factory.

There are several ways to automate the factory. The several ways here refer to the several integrated systems that result in the choice of different automated mechanical equipments and different software based control systems. Whatever the types of devices or control systems used for the automated factory, the following are the basic elements of all integrated manufacturing systems.

1) Production and assembly machines.
2) Material handling devices that store and transfer material.
3) Computer-aided design and computer-aided manufacturing systems.
4) Information systems that gather, process and transmit data.
5) Control systems that control material and equipment resources and communicate with man-machine type systems.
6) Production planning systems for scheduling, release and control of work orders.
7) Accounting systems for financial control.

Automated material handling is one of the key elements in the automated factory. Many experts feel that it is the most vital characteristic of the automated factory because it is the common interface to all functions and processes. It is also a fruitful area for productivity improvement since materials or goods are either handled or stored during most of the time that they spend in the plant. Without automated material handling systems, the automated factory is simply not possible.

Automated material handling systems include both those that store material and those that transport material. Examples of storage type devices are Automated Storage/Retrieval (AS/R) systems and Carousels; and examples of transport type devices are

Automated Guided Vehicles (AGVS) and Tow-line Conveyors.

AGVS are vehicles used for transportation of material generally along a guided path under computer control. AGVS are used for delivery of material in most of the flexible manufacturing systems. They can load and unload automatically.

Automated storage and retrieval systems are computer controlled material handling devices used to store and retrieve material on a pallet or in a bin tray with minimal human interference. AS/R systems are a key element in the automated factory. They integrate islands of automation with a material handling system to insure the scheduled flow of materials through the factory (2). The automated factory depends upon the controlled movement of material through the factory.

Carousels are continuously revolving material handling devices used for storage of small components. Carousels can also be used as AS/R devices to handle work-in process inventory.

This thesis deals mainly with the design and development of a model AS/R system.

1.2 Research need and objectives

In recent times, most of the engineering students are aware of the theoretical aspects of fixed as well as programmable automation. Although most of the students have come across fixed automated equipment in some form or the other, only a minority have interacted with programmable automated equipments.

The necessity to familiarize all the engineers of tomorrow with programmable automated equipment is not refuted by anyone. But translating this necessity in an academic environment is by no means a simple task. These automated devices cannot be easily introduced in the schools because of their high cost and sometimes large size. However, programmable automation can be introduced in the universities by using microcomputer controlled physical models. These models are relatively cheap and are easier to handle within the university environment.

The models capture many of the working principles of the actual life size equipment. In many cases, they incorporate similar features excepting that they are of much smaller dimensions. These models can work as a very effective teaching tool for engineering as well as non-engineering students. With these models, students will not have to wait for a job in the "real world" to know about programmable automation and associated equipment.

With a strong commitment to educate its students in programmable automation, the Department of Industrial Engineering at Kansas State University has recently embarked upon an ambitious program to build a physical model of an automated factory in its laboratory. This is intended to be used for both teaching as well as research purposes. This model factory of the future will have table top machines, an automatic identification and sorting system to identify and sort material, robots to load and unload machines and, an AS/R system to store raw material and finished goods.

The current research efforts are a part of the overall goal of the Department of Industrial Engineering at Kansas State University. Specifically, the efforts will be directed to the AS/R portion of the model automated factory. Simply stated, the objectives of the research are;

1) To design and fabricate a physical model of an AS/R system to ultimately integrate with other equipment to form a model automated factory.
2) To demonstrate the principles of loading and retrieving in AS/R systems using microcomputer control of AC and DC motors.
3) To provide the model with generalized software such that it can be upward compatible and be integrated with the other components of the model automated factory.

1.3 Review of relevant literature

In the past several years, there have been developments of programmable automated models in educational institutions. Although several schools have started gathering resources to develop models under computer control, there is hardly any published material documenting the research and development efforts on microcomputer controlled models. In 1976, a model AS/R system was developed at Arizona State University. It was controlled by a primitive "mini" computer built in the mid 60's (3). After some time a modified AS/R system was developed at

Oklahoma State University. It was controlled by a microcomputer (4). The models emphasized more on motor control than the concept of racks and palletization. Moreover they were designed to function as stand alone systems rather than to be an integral part of a model automated factory. In contrast to previous efforts on physical models of AS/R systems that are documented in the literature, this effort ensures the upward compatibility of the system. Further this system is an actual representation of a commercial system.

2. AUTOMATIC STORAGE AND RETRIEVAL SYSTEMS

2.1 Yesterday today and tomorrow

The first high rise storage and retrieval systems appeared in industry about twenty years ago. This technology did not take the world by storm at that time. The systems were expensive, land and labor were very cheap and economic justification was very hard to come. As a result, acceptance of AS/R systems came slowly.

As computer hardware costs dropped drastically, the cost of AS/R systems also reduced. The lower cost of AS/R systems combined with the rising cost of labor spurred the acceptance of such systems.

Further, developments in other production control systems such as Material Requirement Planning required accurate and sometimes real time inventory control which was not possible with a manually controlled stock room. With the onslaught of powerful microcomputers and microprocessors, real time inventory control via AS/R systems was possible. Thus investment in material requirement planning (MRP) type systems was soon followed by investment in AS/R type systems.

AS/R systems were generally used to store raw material or finished goods in warehouses. They have since graduated from the warehouse to the manufacturing plant. They are being used to control inplant inventories, and to supply raw materials and work-in-process parts to work stations and assembly lines.

AS/R systems have become a major factor in unit-load storage because they can store goods higher than any truck, require no on-board operator, and work in aisles only a few inches wider than the load they carry.

Computer control is a necessity for the AS/R systems of today that handle several sophisticated functions such as automatic identification, storage and retrieval, real time inventory control and communication with other production control systems.

With a computer, direct human interaction is required only at the input end of the system where each incoming load is identified for the computer usually through a CRT/ keyboard terminal. However, even these operations are automated with incoming loads identified by individual machine readable bar-codes.

Once the computer knows the identity of a load, it can handle all S/R machine control and data processing functions: assign storage addresses, update inventory records, direct the load to proper stations and control the cycling of the S/R machine. Relevant up-todate information about the inventory in the system can be provided by the computer through CRT's or printers.

Important changes are taking place in the design of control systems for AS/R systems. Stand alone centrally controlled systems, popular a few years ago, are being rapidly replaced by dedicated or hierarchical control systems. In hierarchical control systems the tasks are broken down and releqated to appropriate computers within the hierarchy. In a typical hierarchical control, a large frame computer called the host computer controls several minicompnters. In turn, each of the minicomputers control several microcomputers and microprocessors. One of the minicomputers is dedicated to the AS/R system. The minicomputer maintains inventory records, makes store/retrieve decisions and controls the operation of the AS/R equipment. The minicomputer can also communicate with the host computer to obtain scheduling information and to report daily operations. The host computer handles day to day operations, and the minicomputer handles hour to hour operations.

The next level of operations is controlled by microcomputers. Functions served at this level deal with subsystem control, including semi-automatic modes of operations. This level within the computer hierarchy controls minute to minute operations.

The lowest level of control is second by second operation. Microcomputers and programmable controllers are used at this level.

What will be the role of AS/R systems in the average factory of 2000 A.D.? How will the typical AS/R system differ from the AS/R systems of today? These are a few of the questions which are in the minds of most manufacturing engineers.

In one respect, AS/R technology today is still what it was at its introduction about 25 years ago - a better way to store the maximum number of loads into a given system. With the introduction of inexpensive computer power, the better storage technology has blossomed into a powerful tool to help manage inventories. Over the years the existing processes, activities and procedures that might be impacted by AS/R systems were re-examined.

Not too long ago, the AS/R concept was synonymous with big high rise systems that handled big loads. But, because of widespread changes in both manufacturing and inventory strategies, that limited perspective no longer defines the AS/R system. The new trend will be for smaller AS/R systems.

With the growing emphasis on the automated factory, the principle of storing items at the point of use favors the use of smaller and scattered AS/R systems. This approach fits in well with the trend towards flexible manufacturing operations; the storage racks can be the core of the production line made up of workstations around its periphery. In this way any load stored in the system is easily accessible by any work station.

A small system definitely has some advantages, e.g. it can be very easily added to the existing plant. They can be designed for the specialized load characteristics that distinguish the various processing activities in a plant. With small AS/R systems, the automated factory can be built or developed in a step-by-step modular manner instead of in one large multimillion dollar step (5). Because of these reasons, more of the small sized AS/R systems with their locations near the processing stations will be seen in the future (6).

AS/R systems will play a significant role in flexible manufacturing systems in years to come. For example automated storage and retrieval systems consisting of one or two aisles and serviced by wire guided vehicles which carry material to and from robotic load and unload stations will be seen. The robots will place the material from the AS/R systems on precision high speed transport systems such as a car on tracks, which will rapidly position the material for processing (7).

The future will also see more use of electronics and computer integrated systems as part and parcel of AS/R systems. Production control systems will interact more effectively with AS/R systems than at the present time (8).

2.2 Characteristics of AS/R systems

In traditional manually controlled warehouses, the man would have to go to the storage location to get material. However in AS/R systems the material is automatically brought to him from the storage location, thereby underscoring the addage "Material to man and not man to material".

As the name suggests, AS/R systems can store and retrieve material automatically. Since the system stores and retrieves automatically, it needs to keep track of both the location of a particular load as well as the contents of a location.

The system also maintains accurate inventory records of the material that goes in and out of the system.

Finally, most of the elements of AS/R systems are typically under computer control. Without this feature none of the above mentioned capabilities are possible.

2.3 Features of AS/R systems

Although there are many variations in the different AS/R systems manufactured by the various manufacturers, the following are the common major features that are either present in every AS/R system or affect every AS/R system.

1) S/R machine or stacker crane
2) Conveyors
3) Computers
4) Software
5) Identification methodology
6) Length of the bay
7) Width of the bay
8) Height of the bay
9) Number of tiers

S/R Machine:- The heart of an automated storage/retrieval system is the S/R machine, also sometimes called a stacker crane. Typically, the S/R machine travels at speeds up to 150 ft./min on a floor-mounted rail. The rails are placed on a narrow aisle 5 to 6 feet wide. When the S/R machine stores and retrieves loads from both sides of the aisle it is called double masted, and when it is restricted to one side of the aisle it is said to be single masted. Each S/R machine is often dedicated to a single aisle of the AS/R system. Sometimes the S/R machine can serve several aisles. In such cases, transfer cars are used to move the crane from one aisle to another. The S/R cranes can operate upto lengths of 100 feet. The items stored through these machines can be large units such as car bodies or steel coils, or unitized loads in containers or pallets.

Conveyors:- Conveyors are used to carry material from the end of the aisle to the input stations as well as the output stations. The width of the conveyor is normally greater than the width of the pallet. The conveyors are controlled by microcomputers or programmable controllers.

Computers:- The computers are the main element of the AS/R system. The size and type of the computer used depends upon the size and functions of the AS/R system. An AS/R system can be controlled by different sizes of "computers" varying from programmable controllers to microcomputers to main frame computers.

Software:- All the functions of the AS/R system are based upon particular software designed for the automatic control and functioning of the system. The full benefit of an AS/R system cannot be realized without appropriate software.

Identification methodology:- In AS/R systems, the load is identified at a identification station prior to storage within the system. The identification is done by weight, size or bar codes on the pallets or load. Based upon the characteristics of the identified load and empty storage locations within the system, the pallet or load is directed to a particular location.

Length of the bay:- It is the length from the dead end of the bay to the main aisle rail. It is usually same for all the bays. The bays are parallel to each other. The distance between the bays (i.e. inter bay distance) depends upon the depth of the racks. Bays are generally enclosed by the racks.

Width of the bay:- This is always constant for all bays in one AS/R system. The width normally depends upon the width of the S/R machine. Because of the accuracy of the AS/R machine, the width of the bay is normally only a few inches more than the width of the S/R machine.

Height of the bay:- This depends upon the structure of the AS/R system. In rack supported structures the height is constant for all the bays but in the conventional buildings it can be kept variable. In rack supported structures, the height of the bay cannot be increased; but in conventional buildings, it can be increased.

Number of tiers:- since the racks are used to house the pallets, the number of tiers depend upon the height of the pallets and the height of the building. They are also dependent on the capacity of stacker crane. Generally, the heavier or the larger pallets are stored in the lower tiers.

2.4 Classifications and types of AS/R systems

AS/R systems can be classified based upon the type of load they store and the rack configurations.

Based on the type of load stored, AS/R systems can be sub classified as 1) Unit load systems or 2) Mini load systems.

Unit load systems:- In these systems a pallet contains generally one type of item and could have either single or multiple members of the same item. The items stored are generally large scale components. The unit load includes pallet loads, coil containers or large sub-assemblies. Unit load systems generally have high rise storage rack systems, and high density or deep lane configurations. The rack heights of unit load systems are generally between 40-100 feet. There are some installations which are as high as 130 feet. The high rise racks are served by S/R machines that travel in narrow aisles. The aisles are normally 5 to 6 feet wide. The high density or deep lane storage involves stacking loads one behind the other in rows, so that typically only the load in the first row can be retrieved.

Mini load systems:- Mini load systems consist of a tray or bin containing several compartments; they normally have one type of item in one compartment, and each compartment can have several members of the same item. Mini load systems are used for storing small parts or work-in-process goods. Sometimes mini load systems are also used for storing finished goods. The bins are assigned in high density configurations on both sides of an aisle. The entire system is totally enclosed, providing security and close control over inventories. Typical stacking heights are 15 to 20 feet. The bin capacities range from 200 to 750 pounds. Mini load systems also use a S/R machine. Each mini load system may serve one or more work stations.

Based on rack/building configuration, AS/R systems can be sub classified as 1) Rack supported structures or 2) Conventional buildings with free standing racks.

Rack supported structures:- Most of the high rise AS/R systems have rack supported structures. In rack supported type AS/R systems, the storage rack supports the building. Both the building and the racks use common steel structure. Internal support structures common to conventional buildings are eliminated. There is just the floor and the rack structure, to which, the building skin is attached. The skin is normally made from prefabricated wall panels.

Free standing racks:- Free standing rack systems are normally housed in conventional buildings. The building stands without the rack support. Free standing racks are supported by the floor and not attached to any part of the building structure. So both the building and the rack system need separate set of steel structures.

Comparison of rack supported structures and conventional buildings:- One of the basic decisions to be made in planning an AS/R system is whether to use free standing buildings or to go for rack supported structures. Both the systems have their own advantages and disadvantages.

Free standing racks are supported by the floor and are not attached to the building structure. The advantage of this kind of structure is that the racks can be removed to use the floor for other purposes. In rack supported structures, the building cannot be converted for production purposes because there is no support for the building without the racks. Free standing racks can be very easily incorporated in the shop floor area. The cost is very high in free standing AS/R systems because of the extra steel used. This high cost offsets some of the advantages that free standing racks have over rack supported structures.

As explained earlier, in rack supported buildings the storage racks themselves are the support structures. There is just the floor and the rack structure, to which the building exterior is attached. Because of the common steel structure for both the building and the rack, the construction cost is low.

Rack supported structures offer several advantages which includes less cost. They can be completed in less time than the free standing buildings. The problem of moving racks into the building is eliminated because the racks are erected first and then the skin of the building. The storage/retrieval machine can be placed in the building before the building skin is applied.

such systems are not without their disadvantages. For example, the building cannot be used for production purposes nor can such systems be constructed in existing buildings.

One of the big advantages the rack supported structures have is the tax benefit. Because this specialized structure has no other practical use, it is treated as operating machinery. The five years Accelerated Cost Recovery System (ACRS) allows the industrial equipment to be written off in five years with 10% tax credit. The ability to depreciate the cost of the building and claim investment tax credit on it offers a financial incentive for management to lean towards rack supported structures as opposed to AS/R systems in free standing buildings.

2.5 Advantages of AS/R systems

Automated storage and retrieval systems are highly specialized material handling systems that require very high capital investments. The savings and benefits resulting from installation of such systems must therefore be sufficient to justify the enormous expenditures. The following are some of the tangible and intangible benefits of an AS/R system.

1) It greatly facilitates order picking. A desired load can be withdrawn from storage, transferred by conveyors to a picking station, part of it picked and the remaining load returned to storage (9).
2) AS/R systems are capable of first-in first-out (FIFO) form of inventory control.

3) Reduced storage requirement due to random storage.

4) Reduction in space due to better utilization of aisle space and better use of overhead space.

5) Reduced spoilage and pilferage as a result of less manual handling, and restricted human access to the material.

6) Reduced inventory levels due to accurate inventory record keeping.

7) Increase in productivity up to 20% . This can be measured in terms of the cost of each unit of material stored or retrieved in the AS/R system against the cost of each unit of material stored or retrieved in the manually controlled stock room.

2.6 Disadvantages of AS/R systems

The following are some of the disadvantages of AS/R systems.

1) High installation cost.

2) More need of skilled labor than in manually controlled stock rooms.

3) In case of a breakdown, backup is not convenient.

4) The material stored is not externally visible to the eyes. This creates a psychological impact on management. They feel less sure of the inventory levels.

2.7 Design factors for AS/R systems

Since AS/R systems are built with considerable cost, it is extremely important to design AS/R systems that can yield maximum benefits. The following are a few of the several factors to be considered in the design of AS/R systems.

Inventory levels:- The storage space available for an AS/R system is designed on the basis of the maximum , average, and minimnm inventory levels. Thus, these parameters have to be known or estimated before the system can be designed.

Number of aisles and height:- The height and number of aisles in an AS/R system depend upon the space required to hold the forecasted inventory. It also depends on the number of cranes in the system and the maximum operating height of the crane.

Throughput rate:- AS/R systems should be designed for the flow of material and not for permanent stock piling. The throughput rate is the rate at which material should be either stored or retrieved by the AS/R system. This throughput rate has an impact on the crane speeds, conveyor speeds and type of methods used to locate an empty rack.

Crane speeds:- The crane speed is also critical for an AS/R system. The crane speed is dependent on the desired throughput rate , the maximum weight of the load, and the maximum height and distance to which the load is to be carried.

Type of control hierarchy:- AS/R systems can have different types of control hierarchy depending upon their applications. AS/R systems are normally controlled by a minicomputer which performs job scheduling, maintains inventory records and controls the S/R machines. These days with the introduction of microcomputers, the microcomputer controls the S/R machines and the task of maintaining inventory records and scheduling is done by the minicomputer. In the case of AS/R systems functioning in integrated manufacturing environments, the minicomputer also communicates with the main frame computer.

Sophistication of software:- The sophistication in the control system of AS/R systems is based upon the type of software used. The more sophisticated the software is, the more will be the flexibility in control system. However, the cost also increases with increased sophistication in the software.

3. THE MODEL

3.1 Physical description of the model

The model warehouse is constructed from plexiglass of 1/8 inch thickness. There is one aisle which services two storage bays, each with 20 storage locations. The items are pallets of size 4.8"x4.0"x5.0". The storage racks are also made from plexiglass. The dimensions of each rack opening are 6"x6"x4". The overall dimension of each storage bay is 30"x4"x30".

This kind of system was chosen for a variety of reasons. Firstly, it is similar to high rise type AS/R systems and secondly, fabrication is relatively straight forward.

The aisle is served by an S/R machine . The S/R machine has a lead screw mechanism for the fore-and-aft motion (Y-axis), another lead screw mechanism for the vertical motion (Z-axis), and a rack and pinion arrangement for in and out motion (X-axis).

All the movements of the S/R machine are initiated by two AC motors and a DC stepper motor. The motion of the S/R machine along the Y-axis is provided by a powerful AC motor . This is mainly because the y-axis drive bears the weight of the drive components along the x and z axes. The AC motor is directly coupled to a lead screw with the help of an aluminium sleeve. The lead screw along the Y-axis is half inch in diameter, 3 feet in length and has 13 threads per inch. The lead screw passes through a pair of roller bearings at either ends. The guide rails used along this axis are mild steel pipes 1/4 inch in diameter and 3 feet in length.

The vertical motion (Z-axis) to the lead screw is also provided by an AC motor. Since the Z-axis drive components bear the weight of the X-axis components, an AC motor was selected to provide motion along the Z-axis. The motor is directly coupled to a lead screw with the help of an aluminium sleeve. The lead screw is half inch in diameter and 3 feet in length and has 13 threads per inch. The lead screw passes through a pair of roller bearings at either end. The guide rails used along this axis are similar to the one used in Z-axis. The Z-axis assembly is mounted on an aluminium block. The dimensions of the block are as shown in Figure 1.

The in and out motion (X-axis) is provided by a medium duty DC stepper motor. The DC motor provides the motion to the pinion shaft in a rack and pinion arrangement. The X-axis assembly is made from plexiglass. The dimensions of the X-axis slide mechanism are as shown in Figures 2 and 3. The X-axis assembly along with the motor is mounted on an aluminium block of size 4.25"X1"X2". Figure 4 details the final machined view of the block.

Figure 5 details the dimensions of the AC motor mounting plates. The complete assembly of the model AS/R is shown in Figures 6, 7 and 8.

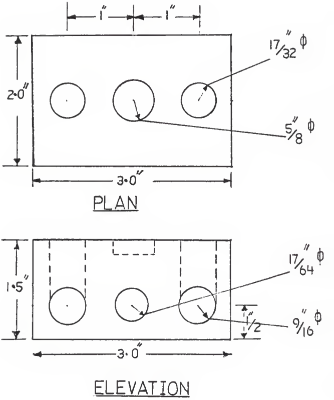


FIGURE 1 :- Z-AXIS MOUNT

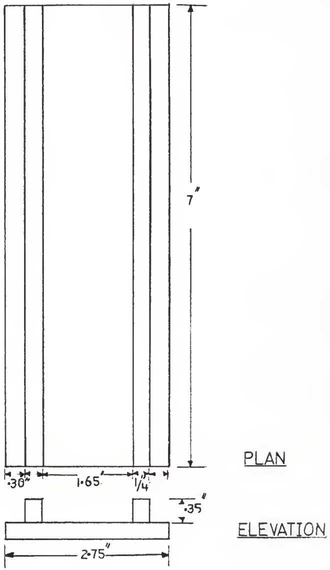


FIGURE 2:- X-AXIS SLIDE

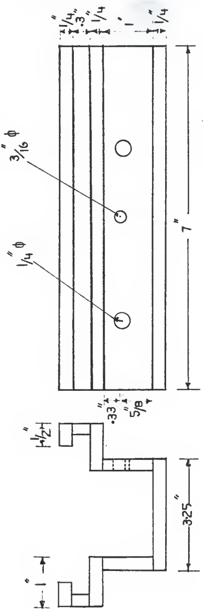


FIGURE 3 :- X-AXIS SLIDE

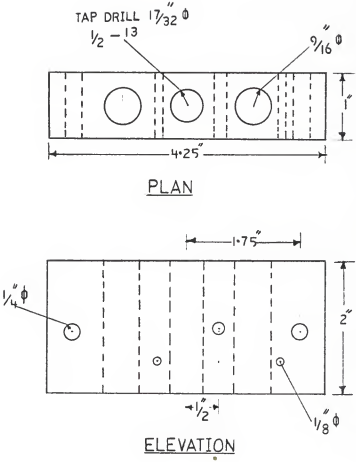


FIGURE 4 :- X-AXIS MOUNT

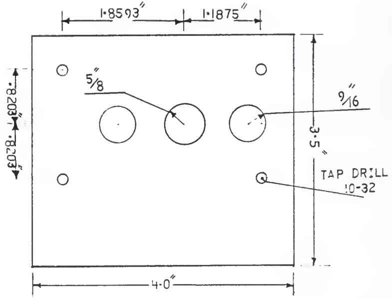


FIGURE 5 :- MOTOR MOUNTING PLATE

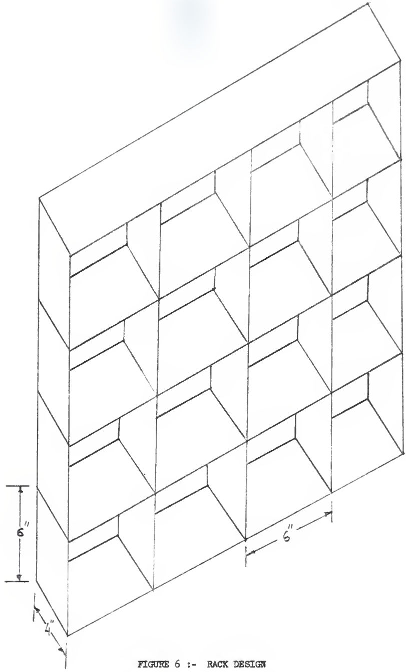


FIGURE 6 :- RACK DESIGN

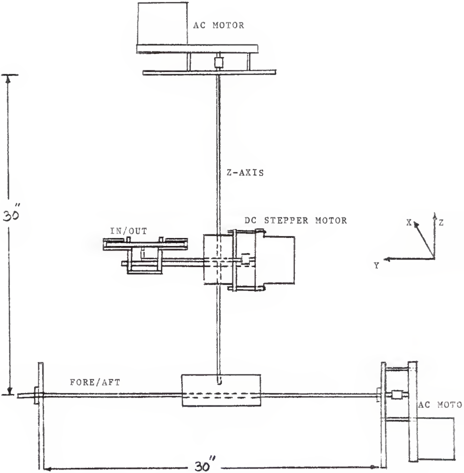


FIGURE 7 :- AS/R MODEL

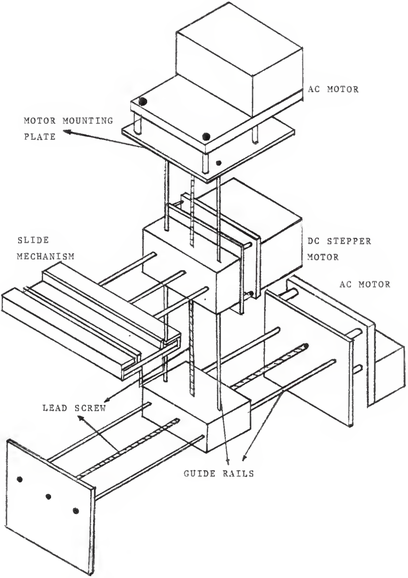


FIGURE 8 :- AS/R MODEL

3.2 Computer control

All the functions of the model are based upon the communication between the S/R machine and the microcomputer. The microcomputer directs the S/R machine to perform the specified tasks of storage and retrieval. Circuits to control the motors are designed to interface the AS/R system with the microcomputer.

The microcomputer that controls the mechanical components of the model is a MMD-1 microcomputer manufactured by E&L Instruments. The MMD-1 has a 8080A central processor. The random access memory of the MMD-1 has a capacity of 1024 bytes. Data are entered in machine language through the keyboard and the digital output is provided at special interface sockets or three latched output ports.

3.3 Power requirement on each axis

It is extremely important to calculate the power requirement on each axis mainly because each axis is carrying substantial amount of weight. The torque required for each axis has been calculated separately and are detailed below.

Power requirement for the Y-axis

1) T = Tl+Tf (10)

Where, T = total torque load (N.m)

Tl = torque required to accelerate the load (N.m)

Tf = frictional torque (N.m)

2) Tl = Jt.a (10)

where, Jt = total moment of inertia ($Kg.m^2$)

a = acceleration ($rad./sec^2$)

3) $Jt = Jr+Js+Jrl$ (10)

where, Jr = rotor moment of inertia of the motor ($Kg.m^2$)

Js = inertia of steel lead screw load ($Kg.m^2$)

Jrl = reflected inertia of the load ($Kg.m^2$)

4) $Js = D^4.L.ps.\pi/32$ (10)

Where, D = diameter of the lead screw (m)

L = lead of the screw (m)

ps = Density of steel ($Kg./m^3$) = 7870 $Kg./m^3$

5) $Jrl = M1X(L/2.\pi)^2$ (10)

Where, M1 = mass of load (Kg.)

M1 = Mw1+Mw2+Mw3+Mwy+Mwz+Mwm+Mwp

where, Mw1 = mass of AC motor = 1.3 Kg.

Mw2 = mass of DC motor = 0.45 Kg.

Mw3 = mass of x-axis plexiglass assembly = 0.65 Kg.

Mwy = mass of base block = 0.53 Kg.

Mwz = mass of z-axis block = 0.25 Kg.

Mwm = Mass of motor support plate = 0.35 Kg.

Mwp = mass of MS pipes = 1.3 Kg.

M1 = 4.83 Kg.

The inertia of the reflected load is

$Jrl = 4.83\ (.00195/2.\pi)^2$

$= 0.46 \times 10^{-6}\ Kg.m^2$

The rotor moment of inertia of motor from the specifications is

$9.3 \times 10^{-6}\ Kg.m^2$

The inertia of lead screw is given by

$$Js = (.0127)^4 \times 0.00195 \times 770$$
$$= 0.39 \times 10^{-9}\ Kg.m^2$$

The total moment of inertia is given by

$$Jt = (.467 \times 10^{-6} + 9.3 \times 10^{-6} + 0.39 \times 10^{-9})$$
$$= 9.767 \times 10^{-6}\ Kg.m^2$$

The angular velocity at 10 RPM is equal to 1.04 Rad/sec.

The frictional torque measured with the help of a torque wrench was found to be 28 oz-in.

$$Tf = 28\ oz\text{-}in = 197.68\ mN.m$$

The total torque on the Y-axis is given by

$$T = (9.767 \times 1.04) \times 10^{-6} + 197.68$$
$$= 198\ mN.m$$

Power requirement for the Z-axis:-

The torque required for the Z-axis AC motor is found with the help of the force diagram shown in Figure 9. The torque required to accelerate the the load has been neglected because of slow speed of the motor.

F = force exerted due to the weight of the load (mN.)

Q = force required to raise the load on an incline plane (mN.)

P1 = frictional force due to the steel lead screw and the aluminium nut (mN.)

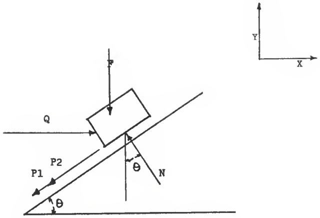


FIGURE 9 :- Z-AXIS FORCE DIAGRAM

P2 = frictional force caused by the aluminium slide moving against steel guide rails (mN.)

$\tan\theta = L/2R$

$= .00195/.0127$

$\theta = 8.867$.

P1 = NU

P2 = NU

Where, U = coefficient of friction between steel and aluminium is 0.6

The total load on Z-axis = 1100 gms.

F = M X Accel. due to gravity

= 1100 X 9.8

= 10780 mN

Summing the forces in the Y-direction

Fy = N cos -F-0.6N sin -0.6N sin = 0

or, 0.8N = 10780

or, N = 13475 mN

Summing the forces in the X-direction

Fx = Q-N(sin +0.6cos +0.6cos) = 0

or, Q = 13475(.154+1.185)

= 18043.68 mN.

Since the force Q acts at a distance R (radius of lead screw), the estimated torque to raise the Z-axis load is given by

T = QR

= 18043 X 0.00635

= 115 mN.m

Power requirement for the X-axis:-

1) The equivalent moment of inertia

$Jeqv. = MR^2 \ gm.cm^2$ (10)

where, M = mass of load = 150 gms

R = radius of pinion = 0.79 cm.

$Jeqv. = 94 \ gm.cm^2$

Rotor moment of inertia

$Jr = 4.63 \ gm.cm^2$

3) Moment of inertia between pinion and rack

$Jp = MR^2/2$ (10)

$47 \ gm.cm^2$

4) The total moment of inertia

$Jt = 94+4.63+47$

$= 145.63 \ gm.cm^2$

$= 14.5 \times 10^{-6} \ Kg. \ m^2$

The frictional torque as measured with the help of a torque wrench is

Tf = 28 mN.m

The total torque required on x-axis can be found by

T = Jt.a+Tf

The angular acceleration can be found from the stepping rate. The maximum stepping rate of the motor under consideration is 480 steps/sec. selecting the mid point for the calculation of the angular acceleration

$a = 240 \times 240/2\pi \times 2\pi/96$

$= 600 \text{ rad./sec}^2$

The total torque required on the X-axis is given by

$T = (600 \times 14.5 \times 10^{-6}) + 28$

28.1 mN.m

3.4 Motor Characteristics

Table 1 gives the characteristics of the AC motors that transmit motion along Y and Z axes and characteristics of the DC stepper motor that transmits motion along X-axis.

Table 1 Motor Characteristics

Type	HP	RPM	Torque in-lbs Run	Torque in-lbs Start	Weight
AC	1/100	10	45	30	3 lbs. (11)
AC	1/100	10	45	30	3 lbs. (11)
	Steps/sec.		Pull Torque		
DC	240		54 oz-in		1 lbs. (10)

4. HARDWARE DESIGN

This section deals mainly with the circuits designed to interface the MMD-1 microcomputer with the DC and AC motors. The overall configuration of the microcomputer controlled system is shown in Figure 10. As can be seen from the figure, data and program are entered into the MMD-1 from the +5 V input side. The microcomputer sends the output in digital form to the output ports or to special interface sockets. This output is provided to the DC and AC motors through the interface circuits.

In the AC circuit, the input to the relay is in +5 V. This triggers the photo transistor of the relay which in turn permits 110 V AC to flow. In the case of the DC motor, +5 V is provided at the base of a transistor, which behaves as a switch in the DC circuit.

The outputs from these circuits serve as the inputs to the various motors.

4.1 AC motor drive circuit

The AC motor drive circuit serves as the interface circuit between the microcomputer, and the Y-axis and Z-axis drive motors. The circuit consists of three solid state relays, four IC chips for each axis and one SN 75154 IC 4-line to 16-line decoder chip (12).

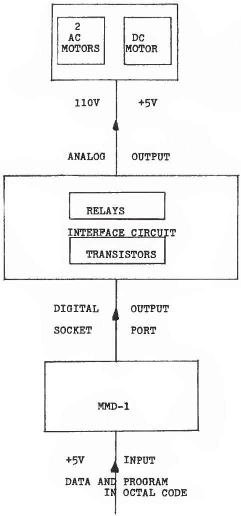


FIGURE 10 :- OVERALL CONFIGURATION

The AC motor has three power input leads; gray lead to the winding for counter clockwise rotation of the motor, a yellow lead to the winding for clockwise rotation and a black lead common to both directions. The motor runs in clockwise direction when 110 V is applied between the yellow and the black leads. It runs in counter clockwise direction if the current is applied between the gray and the black leads.

The solid state relays in the circuit act as a switch. With the help of these relays, the motors can not only be switched on/off but the direction of the rotation can also be changed. The solid state relays consist of light emitting diodes (LED) and a photo transistor. The +5V and the 110V circuits are separated by an opto isolator. When the current flows through the +5V circuit (i.e. LED), the light produced by the LED triggers the photo transistor which in turn permits 110V AC to flow through the motor windings.

In order to control an AC motor, three solid state relays are needed. One relay performs the on/off function for the common winding, the second relay performs the on/off function for the clockwise winding and the third relay performs the on/off function for the counter clockwise winding. In all cases the input side (+5V) of the relay must be complete to have the output side (110V) to function. In Figure 11, Relay 1 is used to turn the Y-axis motor on/off, and relays 2 and 3 allow the Y-axis motor to rotate in clockwise and counter clockwise directions. Similarly relay 4 is used to turn the Z-axis motor on/off, and relays 5 and 6 are used to turn the Z-axis motor in clockwise and counter clockwise directions.

Beginning from the left in Figure 12, the first chip encountered is a SN 74154 IC 4-line to 16-line decoder. The input to this chip is from the address bus of the MMD-1. Pins 17 and 18 of this chip are set at logic 0 to enable the chip. The logic table for this chip is shown in Table 2. Next to the SN 74154 IC is the SN 7432 IC which serves as an OR gate. The logic table for this chip is as shown in Table 3. The output from the decoder and the OUT signal from the MMD-1 act as the input to four OR gates of the SN 7432 IC. An SN 7474 IC is connected to the output of the SN 7432 IC. This SN 7474 IC can latch the input signal to the solid state relays. The logic table for the SN 7474 IC is shown in Table 4. This device is actually a dual data latch which incorporates a clear and a preset pin to each latch. The pins provide the clear and preset functions of the latch. Pins 2 and 12 of this chip are connected to ground to have logic 0 at the data pin. A signal to the preset pin of the SN 7474 IC can be used to turn the +5V side of the relay on and a signal to the clear pin can be used to turn it off. The output from the chip is connected to a SN 75492 IC buffer inverter. This chip not only inverts the output of the SN 7474 IC but also boosts its power high enough to drive the relays. One output of this inverter goes to the relay for the common winding and the other goes to the relay of one of the windings and the SN 7406 IC inverter. The SN 7406 IC inverts the signal coming from the SN 75492 IC. The output of the SN 7406 IC is connected to a relay which in turn is connected to one of the winding. Table 5 shows the list of the octal codes output from the microcomputer that serve as inputs to the decoder.

TABLE 2 Logic table for 74154 decoder (13)

INPUTS	OUTPUTS															
D C B A	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0 0 0 0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0 0 0 1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0 0 1 0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
0 0 1 1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
0 1 0 0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
0 1 0 1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
0 1 1 0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
0 1 1 1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
1 0 0 0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
1 0 0 1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
1 0 1 0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
1 0 1 1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
1 1 0 0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
1 1 0 1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
1 1 1 0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
1 1 1 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0

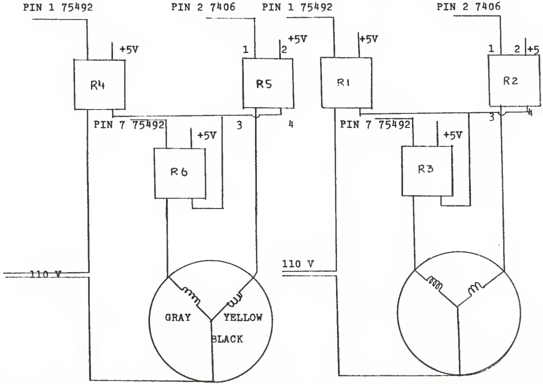
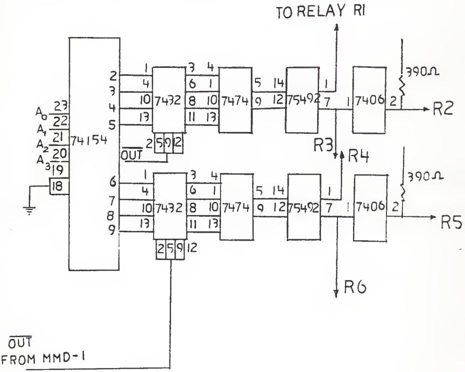


FIGURE 11 :- AC MOTOR RELAYS CIRCUIT

DRIVE CIRCUIT Y & Z AXIS AC MOTOR



PIN HOOK UP

TYPE	GROUND	+5V	MISC PIN CONNECTIONS
74154	12	24	18, 19 - GROUND
7432	7	14	2, 5, 9 & 12 - $\overline{OUT}$ MMD-1
7474	7	14	2, 12 - GROUND
75492	4	11	1 to 2, 3 to 14, 7 to 9 to 13, 8 to 10 to 12
7406	7	14	2 to +5V thru 390Ω RESISTOR

FIGURE 12 :- AC MOTOR DRIVE CIRCUIT

TABLE 3 Logic table for OR gate (13)

INPUTS		OUTPUT
A	B	C
0	0	0
1	0	1
0	1	1
1	1	1

TABLE 4 Logic table for 7474 latch (13)

INPUTS				OUTPUTS	
Preset	Clear	Clock	D	Q	$\overline{Q}$
0	1	X	X	1	0
1	0	X	X	0	1
0	0	X	X	*	*
1	1	|	1	1	0
1	1	|	0	0	1
1	1	0	X	Qo	Qo

TABLE 5 Microcomputer codes as input to decoder (14)

Octal codes	Decimal codes	Purpose
001	1	Turn Y-axis motor ON
002	2	Turn Y-axis motor OFF
003	3	Turn Y-axis motor CW
004	4	Turn Y-axis motor CCW
005	5	Turn Z-axis motor ON
006	6	Turn Z-axis motor OFF
007	7	Turn Z-axis motor CW
010	8	Turn Z-axis motor CCW

4.2 DC motor drive circuit

The DC motor drive circuit is the interface circuit between the microcomputer and the X-axis motor. This circuit consists of an Exclusive-OR gate, four transistors and four 1Kohm resistors. The stepper motor is a DC permanent magnet motor. The permanent magnet of the DC stepper motor has its center attached to a rotor and is centered within four windings. When the current is allowed to flow through the windings, the permanent magnet is attracted or repelled depending upon its polarity. This in turn produces a torque at the rotor. Figure 13 demonstrates the rotation of the motor based on the settings in each of the four windings. When logic 1 is at winding A, and logic 0 at the other windings, the north pole will be attracted to winding A (Figure 13a). Similarly with logic 1 at windings A and C, and logic 0 at windings B and D, the magnet will rotate in counter clockwise direction to a position halfway between windings A and C (Figure 13b). Tables 6 and 7 show the sequence of octal codes for clockwise and counter clockwise rotation of the DC motor.

The sequence of octal codes for clockwise and counter clockwise rotation can be output through the ports of the MMD-1. From the port, the signal passes through the input pins of the exclusive-OR gates of SN 7486 IC as shown in Figure 14 (12). The second pin of each of the exclusive-OR gates is connected to +5V (logic 1). The logic table for the exclusive-OR gate is given in Table 8. An input of logic 0 from the port of the MMD-1 to the input of the exclusive-OR gate will result in an output of logic 1. This output from the exclusive-OR gate is the input to the base of a npn transistor. The base is pulled up to 5V through a pullup resistor of 1 Kohm. The transistor in this circuit acts as a switch. When logic 1 is applied to the base of the transistor, the transistor does not allow the current to flow from the center tap and through the windings to the ground. When the logic 0 is input to the base of the transistor there is a potential difference across the resistor and the current flows. This allows the motor to rotate 3.75 in one step. With a proper sequence of signals from the port of the MMD-1, the motor can be made to rotate continuously.

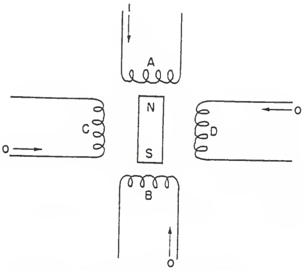


FIGURE 13 a :- OPERATION OF DC MOTOR

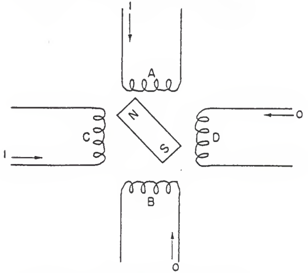
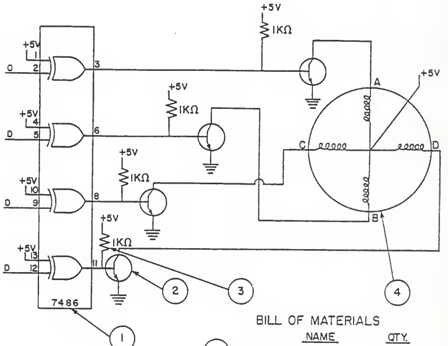


FIGURE 13 b :- OPERATION OF DC MOTOR

DRIVE CIRCUIT X AXIS
DC STEPPER MOTOR



BILL OF MATERIALS

	NAME	QTY.
1	SN 7486 IC	1
2	NPN TRANSISTOR TIP 29	4
3	RESISTOR 1KΩ	4
4	PHILLIPS DC LOGIC MOTOR	1

PIN CONNECTIONS

1, 4, 10, 13, 14	+5V
3, 6, 8, 11	TIP29
X AXIS 2, 5, 9, 12	MMO-1 PORT 0 D13, D14, D15, D16
Y AXIS 2, 5, 9, 12	MMD-1 PORT 2 D21, D22, D23, D24
7	GROUND

FIGURE 14 :- DC MOTOR DRIVE CIRCUIT

TABLE 6 Clockwise code for DC stepper motor

Octal code				Decimal code
A	B	C	D	
1	0	0	0	010
1	0	0	1	011
0	0	0	1	001
0	1	0	1	005
0	1	0	0	004
0	1	1	0	006
0	0	1	0	002
1	0	1	0	012
1	0	0	0	100

TABLE 7 Counter clockwise code for DC stepper motor

Octal code				Decimal code
A	B	C	D	
1	0	0	0	010
1	0	1	0	012
0	0	1	0	002
0	1	1	0	006
0	1	0	0	004
0	1	0	1	005
0	0	0	1	001
1	0	0	1	011
1	0	0	0	100

TABLE 8 Logic table for Exclusive-OR gate (13)

INPUT		OUTPUT
A	B	C
0	0	0
1	0	1
0	1	1
1	1	0

5. SOFTWARE DESIGN

5.1 Overall physical view

The software for the MMD-1 to control the S/R machine is divided in three sections as shown in Figure 15.

The first section contains programs for the movement of the motors in both clockwise and counter clockwise directions, simultaneous movement of Y and Z axes motors in both clockwise and counter clockwise direction, and the functions to pick and place the pallet in the rack.

The second section of the software contains delay subroutines for the X-axis motor, Y and Z axes motors, and for pick and place functions of the Z-axis.

The third section of the software controls the storage and retrieval operations of the S/R machine. With the help of this section, access to all the locations of the AS/R system can be achieved.

5.2 Functional view

The functional view of the program is in Figure 16. A particular set of data is entered into the microcomputer through the input keys at fixed locations (Between 037 HI and 000 LO).

Section 1

HI	LO	Description
030	000	CCW subroutine for Y-axis motor
030	015	CCW subroutine for Z-axis motor
030	030	CW subroutine for X-axis motor
030	130	CW subroutine for Z-axis motor
030	144	CW subroutine for Y-axis motor
030	163	CCW subroutine for X-axis motor
030	275	Lift subroutine for Z-axis motor
030	310	Leave subroutine for Z-axis motor
030	330	CCW subroutine for Y and Z axes motors
030	350	CW subroutine for Y and Z axes motors

Section 2

HI	LO	Description
032	100	AC motor delay subroutione
032	150	DC motor delay subroutine
032	200	Lift/Leave delay subroutine

Section 3

HI	LO	Description
035	000	Main Program
037	000	Data entry location

FIGURE 15 :- PHYSICAL ORGANIZATION OF SOFTWARE

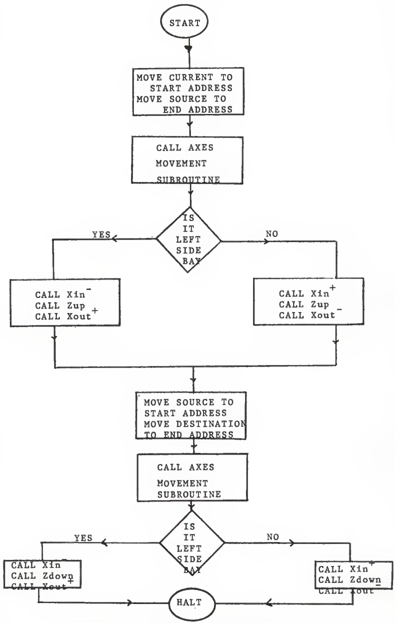


FIGURE 16 :- FUNCTIONAL FLOW CHART

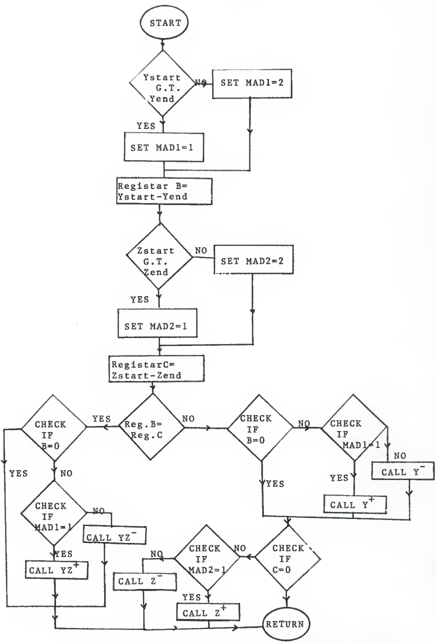


FIGURE 17 :- FLOW CHART FOR AXES MOVEMENT SUBROUTINE

The data entered includes the following :

a) Current location

i) rack location defined by row and column. If it is at home position it is (0,0)

b) Source information

i) bay number for the source load

ii) rack location defined by row and column number in the bay. If it is home position the bay number is 1 and location number is (0,0).

c) Destination information

i) bay number for the destination load

ii) rack location defined by row and column number in the bay. If it is home position the bay number is 1 and location number is (0,0).

The bays are defined as the left hand and the right hand side bay. If the loading or unloading is from left hand side bay, 001 is entered and if the loading or unloading is from the right hand side, 002 is entered. The row index for the rack location varies from 000 to 003 for the 4 tiers and the column index for the rack location varies from 001 to 005 for 5 racks in each row.

A sample input is provided in appendix B. This sample data can be used to store a pallet from the home position to the rack location (1,1) of the right hand bay. Similarly appendix C details the input section to retrieve a load from rack location (1,1) of the left hand bay. Appendix D details the input data to retrieve a load from rack location (2,1) of the right hand side bay and store it in rack location (2,2) of the left hand side bay.

As can be seen from Figure 16, the first step in the logical operation is to move the current location to an address in the memory called the start address. Also, the source location is moved to an address in the memory called the end address. The next step is to call the axes movement subroutines (Figure 17) which move the Y and Z axes motors to the source location based on the values in the start and the end address. Figure 15 shows the detailed functional logic of the axes movement subroutine.

Once the crane has reached the source location from the current location, the next step is to load the pallet from the user specified bay. Now the crane has to be moved to the destination location. The next step then is to move the source location to the start address and the destination location to the end address in the memory. As before, the axes movement subroutine is called. Execution of this subroutine will move the loaded crane from the source location to the destination location. Following this, the routines to unload the pallet are called after which the program halts.

5.3 Delay programs

The displacement along the axes is indirectly controlled by the software via two different methods depending on whether an AC motor or a DC motor is used to drive the axes.

In case an AC motor is used, the time the motor needs to be operational to effect a predetermined displacement is first calculated. This time duration is based on the speed of the motor and the number of revolutions required to produce the predetermined displacement. Thus the software needs to send an "on" signal for this calculated time duration. This is effectively accomplished by executing a set of statements called the delay program. This delay program is so structured that the time the computer requires to execute this delay program is equal to the previously calculated duration of time for the motor to be operational.

In case of the DC motor as opposed to time, the number of rotational steps the DC motor needs to make to effect a predetermined displacement is calculated. The software sends an "on" signal to the DC motor and counts the number of rotational steps taken by the motor. When the number of rotational steps taken by the motor is equivalent to the number of rotational steps required to produce the displacement, an "off" signal is sent to the DC motor. In this research delay programs are also used while controlling DC motors in order to reduce the rate at which the rotational steps are taken by the DC motor.

The time delay for the Y and Z axes motors is calculated on the basis of the distance between two successive locations (center to center) and the height of each rack. The height of each rack is same as the distance between two locations. The center to center distance between any two locations is the same for all locations. The following shows the calculation to determine the time the Y or Z axes motor needs to be operational such that the S/R machine moves from one location to a successive location.

The distance between two successive racks = 6 inches.

Number of threads per inch on the lead screw =13

Speed of the AC motor = 10 RPM

Thus, the time delay = 13 X 6/10

= 7.8 minutes.

In the case of the X-axis motor, the number of steps the motor has to take are based on the number of teeth on the rack and pinion and the angle of rotation. The following shows the calculation to determine the number of steps that the DC motor has to rotate to move the crane arm in or out of the rack.

Rotational step covered by one step of the motor = 3.75°.

Number of teeth on pinion = 20

Number of teeth on rack = 6/inch

The distance the rack has to be moved = 25/6 inches

Thus, the number of steps required = 25/6 X 2/20 X 360/3.75

=120 steps

6. SUMMARY

6.1 Conclusions

As stated previously, the following are the main objectives of this thesis.

1) To design and fabricate a physical model of an AS/R system to ultimately integrate with other equipment to form a model automated factory.
2) To demonstrate the principles of loading and retrieving in AS/R systems using microcomputer control of the DC and AC motors.
3) To provide the model with generalized software such that it can be upward compatible and be integrated with the other components of the model automated factory.

All these objectives have been met. The model was successfully built and demonstrated under computer control. The model also demonstrates the principle of storage and retrieval in AS/R systems using microcomputer control of DC and AC motors.

The software has been generalized to maintain flexibility and upward compatibility. The software is highly flexible, in the sense that any type of operation, namely, store, retrieve, retrieve/store can be performed from any location to any other location. The software has been designed such that the user input is kept minimal. The software is written in modular fashion such that it is upward compatible. In an integrated environment, the data on current, source and destination location is not provided by the user in octal code, rather it is down loaded to the MMD-1 in octal code from a central computer.

6.2 Future directions

Future development of this model can take place in two directions.

1) Mechanical and cosmetic changes to improve efficiency and appearance of the system.
2) Integration of the AS/R model with other equipment in the model factory.

With respect to the first direction, the whole model can be housed in a permanent fixture to provide rigidity and stability. Also the speed of operation can be improved with high speed motors.

To integrate the AS/R model into the factory model is a time consuming task. This task involves two components. Firstly, the hardware and software necessary for the controlling computer to talk to the MMD-1 has to be designed and implemented. Secondly, a control system to coordinate the functions and the timing of the functions within the AS/R model with other equipment has to be designed and developed. This may require the AS/R model to have tight tolerences, the accomplishment of which is a task by itself.

However difficult the tasks may be, they have to be accomplished if the department of Industrial Engineering at Kansas State University is to realize its goal of building a laboratory model of an automated factory. The author from his experience would like to warn future researchers in model building not to underestimate the man hours required in such efforts.

6.3 Cost analysis

The model AS/R was mostly built from the limited resources available within the laboratory. The Approximate cost of the various components used to build the model system is given below.

ITEM	COST	
Material cost		
2 AC Motors	$ 60.00	
1 DC Motor	$ 30.00	
Plexiglass Sheet	$ 40.00	
4 MS pipes	$ 4.00	
1 MS Flat (1'X3"X1/4")	$ 2.00	
1 Aluminium block	$ 4.00	
IC Chips	$ 15.00	
6 Relays	$ 60.00	
3 Breadboards	$ 30.00	
Total material cost		$ 245.00
Labor cost		
150 Hrs. Fabrication cost	$1500.00	
35 Hrs. Hardware design	$ 875.00	
100 Hrs. Software design	$2500.00	
Total labor cost		$4875.00
Incidental cost		$ 50.00
Total cost		$5170.00

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8. Appendix A

Section 1

Location		Octal code	Description
* Program for y-axis motor in CCW direction			
030	000	000	No operation
	001	323	OUT
	002	004	(Y-axis motor CCW)
	003	000	NOP
	004	323	OUT
	005	001	(Y-axis motor ON)
	006	315	CALL (Delay subroutine)
	007	000	LO
	010	032	HI
	011	323	OUT
	012	002	(Y-axis motor off)
	013	000	NOP
	014	311	RETURN
* Program for Z-axis motor in CCW direction			
	015	323	OUT
	016	010	(Z-axis motor CCW)
	017	323	OUT
	020	005	(Z-axis motor ON)
	021	315	CALL (Delay subroutine 1)
	022	000	LO
	023	032	HI
	024	323	OUT

```
    025          006          (Z-axis motor off)
    026          000          NOP
    027          311          RETURN
* Program for X-axis motor in CW direction
    030          016          Move immediate byte to regstr C
    031         <017>         Timing byte
    032          000          NOP
    033          076          Move immediate byte to accum.
    034          010          Device code
    035          323          OUT
    036          000          Output to port 0
    037          315          CALL (Delay subroutine 2)
    040          050          LO
    041          032          HI
    042          076          Move immediate byte to accum.
    043          011          Device code
    044          323          OUT
    045          000          Output to port 0
    046          315          CALL (Delay subroutine 2)
    047          050          LO
    050          032          HI
    051          076          MVI A
    052          001          Device code
    053          323          OUT
    054          000          Output to port 0
    055          315          CALL (Delay subroutine 2)
    056          050          LO
```

057	032	HI
060	076	MVI A
061	005	Device code
062	323	OUT
063	000	Output to port 0
064	315	CALL (Delay subroutine 2)
065	050	LO
066	032	HI
067	076	MVI A
070	004	Device code
071	323	OUT
072	000	Output to port 0
073	315	CALL (Delay subroutine 2)
074	050	LO
075	032	HI
076	076	MVI A
077	006	Device code
100	323	OUT
101	000	Output to port 0
102	315	CALL (Delay subroutine 2)
103	050	LO
104	032	HI
105	076	MVI A
106	002	Device code
107	323	OUT
110	000	Output to port 0
111	315	CALL (Delay subroutine 2)

112	050	LO
113	032	HI
114	076	MVI A
115	012	Device code
116	323	OUT
117	000	Output to port 0
120	315	CALL (Delay subroutine 2)
121	050	LO
122	032	HI
123	015	Decrement content of C by 1
124	302	Jump if content of C not 0
125	030	HI
126	033	LO
127	311	Return

* Program for Z-axis motor in CW direction

130	000	NOP
131	323	OUT
132	007	(Z-axis motor CW)
133	323	OUT
134	005	(Z-axis motor ON)
135	315	CALL
136	000	LO
137	032	HI
140	323	OUT
141	006	(Z-axis motor off)
142	000	NOP
143	311	RETURN

* Program for Y-axis motor in CW direction

144	000	NOP
145	000	NOP
146	000	NOP
147	000	NOP
150	323	OUT
151	003	(Y-axis motor CW)
152	323	OUT
153	001	(Y-axis motor ON)
154	315	CALL (Delay subroutine 1)
155	000	LO
156	032	HI
157	323	OUT
160	002	(Y-axis motor off)
161	000	NOP
162	311	Return

* Program for X-axis motor in CCW direction

163	016	MVI C
164	017	Data byte
165	076	MVI A
166	010	Data byte
167	323	OUT
170	000	Output to port 0
171	315	CALL (Delay subroutine 2)
172	050	LO
173	032	HI
174	076	MVI A

175	012	Data byte
176	323	OUT
177	000	Output ot port 0
200	315	CALL (Delay subroutine 2)
201	050	LO
202	032	HI
203	076	MVI A
204	002	Data byte
205	323	OUT
206	000	Output ot port 0
207	315	CALL (Delay subroutine 2)
210	050	LO
211	032	HI
212	076	MVI A
213	006	Data byte
214	323	OUT
215	000	Output ot port 0
216	315	CALL (Delay subroutine 2)
217	050	LO
220	032	HI
221	076	MVI A
222	004	Data byte
223	323	OUT
224	000	Output ot port 0
225	315	CALL (Delay subroutine 2)
226	050	LO
227	032	HI

230	076	MVI A
231	005	Data byte
232	323	OUT
233	000	Output ot port 0
234	315	CALL (Delay subroutine 2)
235	050	LO
236	032	HI
237	076	MVI A
240	001	Data byte
241	323	OUT
242	000	Output ot port 0
243	315	CALL (Delay subroutine 2)
244	050	LO
245	032	HI
246	076	MVI A
247	011	Data byte
250	323	OUT
251	000	Output ot port 0
252	315	CALL (Delay subroutine 2)
253	050	LO
254	032	HI
255	015	DCR C
256	302	JNZ
257	030	HI
260	165	LO
261	000	NOP
262	000	NOP

263	000	NOP
264	000	NOP
265	000	NOP
266	311	RETURN
267	000	NOP
270	000	NOP
271	000	NOP
272	000	NOP
273	000	NOP
274	000	NOP

* Program for Z-axis motor to lift pallet

275	323	OUT
276	010	(Z-axis motor CCW)
277	323	OUT
300	005	(Z-axis motor ON)
301	315	(Delay subroutine 3)
302	100	LO
303	032	HI
304	323	OUT
305	006	(Z-axis motor OFF)
306	000	NOP
307	311	RETURN

* Program for Z-axis motor to leave the pallet

310	000	NOP
311	323	OUT
312	007	(Z-axis motor CW)
313	323	OUT

314	005	(Z-axis motor ON)
315	315	CALL (Delay subroutine 3)
316	100	LO
317	032	HI
320	323	OUT
321	006	(Z-axis motor OFF)
322	000	NOP
323	311	RETURN
324	000	NOP
325	000	NOP
326	000	NOP
327	000	NOP

* Program for Z-axis & Y-axis motor in CCW direction

330	323	OUT
331	004	(Y-axis motor CCW)
332	323	OUT
333	001	(Y-axis motor ON)
334	323	OUT
335	010	(Z-axis motor CCW)
336	323	OUT
337	005	(Z-axis motor ON)
340	315	CALL (Delay subroutine 1)
341	000	LO
342	032	HI
343	323	OUT
344	002	(Y-axis motor OFF)
345	323	OUT

346	006	(Z-axis motor OFF)
347	311	RETURN

* Program for Z-axis & Y-axis motor in CW direction

350	000	NOP
351	323	OUT
352	003	(Y-axis motor CW)
353	323	OUT
354	001	(Y-axis motor ON)
355	323	OUT
356	007	(Z-axis motor CW)
357	323	OUT
360	005	(Z-axis motor ON)
361	315	CALL (Delay subroutine 1)
362	000	LO
363	032	HI
364	323	OUT
365	002	(Y-axis motor OFF)
366	323	OUT
367	006	(Z-axis motor OFF)
370	311	RETURN

Section 2

Location		Octal code	Description
* Program AC motor Delay.			
032	100	365	PUSH PSW
	101	305	PUSH B
	102	325	PUSH D
	103	345	PUSH H
	104	000	NOP
	105	076	MVI A
	106	002	Timing byte
	107	026	MVI D
	110	223	Timing byte
	111	006	MVI B
	112	000	Timing byte
	113	016	MVI C
	114	000	Timing byte
	115	015	DCR C
	116	302	JNZ
	117	015	LO
	120	032	HI
	121	005	DCR B
	122	302	JNZ
	123	013	LO
	124	032	HI
	125	025	DCR D
	126	302	JNZ
	127	011	LO

130	032	HI
131	075	DCR A
132	302	JNZ
133	007	LO
134	032	HI
135	341	POP H
136	321	POP D
137	301	POP B
140	361	POP PSW
141	311	RETURN

* Program for DC motor Delay

150	365	PUSH PSW
151	305	PUSH B
152	325	PUSH D
153	345	PUSH H
154	000	NOP
155	016	MVI C
156	001	Timing byte
157	006	MVI B
160	346	Timing byte
161	005	DCR B
162	302	JNZ
163	061	LO
164	032	HI
165	015	DCR C
166	302	JNZ
167	057	LO

170	032	HI
171	341	POP H
172	321	POP D
173	301	POP B
174	361	POP PSW
175	311	RETURN

* Program for leave and lift Delay

200	365	PUSH PSW
201	305	PUSH B
202	325	PUSH D
203	345	PUSH H
204	000	NOP
205	026	MVI D
206	030	Timing byte
207	016	MVI C
210	000	Timing byte
211	006	MVI B
212	000	Timing byte
213	005	DCR B
214	302	JNZ
215	113	LO
216	032	HI
217	015	DCR C
220	302	JNZ
221	111	LO
222	032	HI
223	025	DCR D

224	302	JNZ
225	107	LO
226	032	HI
227	341	POP H
230	321	POP D
231	301	POP B
232	361	POP PSW
233	311	RETURN

Section 3

Location		Octal code	Description
* Axes movement subroutine			
035	000	052	LHDL
	001	002	LO
	002	037	HI
	003	124	MOV D, H
	004	135	MOV E, L
	005	052	LHDL
	006	004	LO
	007	037	HI
	010	174	MOV A, H
	011	272	CMP D
	012	312	JZ
	013	304	LO
	014	035	HI
	015	332	JC
	016	152	LO
	017	035	HI
	020	000	NOP
	021	222	SUB D
	022	127	MOV D, A
	023	175	MOV A, L
	024	273	CMP E
	025	312	JZ
	026	110	LO
	027	035	HI

030	000	NOP
031	332	JC
032	122	LO
033	035	HI
034	000	NOP
035	223	SUB E
036	000	NOP
037	272	CMP D
040	312	JZ
041	072	LO
042	035	Hi
043	000	NOP
044	000	NOP
045	157	MOV L, A
046	315	CALL (Y-axis CCW SUB)
047	000	LO
050	030	HI
051	055	DCR L
052	302	JNZ
053	046	LO
054	035	HI
055	000	NOP
056	000	NOP
057	315	CALL (Z-axis CCW SUB)
060	015	LO
061	030	HI
062	025	DCR D

063	302	JNZ
064	057	LO
065	035	HI
066	000	NOP
067	303	JMP
070	353	LO
071	035	HI
072	000	NOP
073	315	CALL (Y & Z axes CCW SUB)
074	330	LO
075	030	HI
076	000	NOP
077	025	DCR D
100	302	JNZ
101	073	LO
102	035	HI
103	000	NOP
104	303	JMP
105	353	LO
106	035	HI
107	000	NOP
110	315	CALL (Y-axis CCW)
111	000	LO
112	030	HI
113	025	DCR D
114	302	JNZ
115	110	LO

116	035	HI
117	303	JMP
120	353	LO
121	035	HI
122	157	MOV L, A
123	173	MOV A, E
124	225	SUB L
125	157	MOV L, A
126	315	CALL (Y-axis CCW SUB)
127	000	LO
130	030	HI
131	025	DCR D
132	302	JNZ
133	126	LO
134	035	HI
135	000	NOP
136	315	CALL (Z-axis CW SUB)
137	130	LO
140	030	HI
141	055	DCR L
142	302	JNZ
143	134	LO
144	035	HI
145	000	NOP
146	303	JMP
147	353	LO
150	035	HI

151	000	NOP
152	000	NOP
153	147	MOV H, A
154	172	MOV A, D
155	224	SUB H
156	127	MOV D, A
157	000	NOP
160	175	MOV A, L
161	273	CMP E
162	312	JZ
163	267	LO
164	035	HI
165	332	JC
166	217	LO
167	035	HI
170	000	NOP
171	223	SUB E
172	137	MOV E, A
173	315	CALL (Y-axis CW SUB)
174	144	LO
175	030	HI
176	025	DCR D
177	302	JNZ
200	173	LO
201	035	HI
202	000	NOP
203	315	CALL (Z-axix CCW SUB)

204	015	LO
205	030	HI
206	035	DCR E
207	302	JNZ
210	203	LO
211	035	HI
212	000	NOP
213	303	JMP
214	353	LO
215	035	HI
216	000	NOP
217	157	MOV L, A
220	173	MOV A, E
221	225	SUB L
222	272	CMP D
223	312	JZ
224	253	LO
225	035	HI
226	137	MOV E, A
227	315	CALL (Y-axis CW SUB)
230	144	LO
231	030	HI
232	025	DCR D
233	302	JNZ
234	227	LO
235	035	HI
236	000	NOP

237	315	CALL (Z-axis CW SUB)
240	130	LO
241	030	HI
242	035	DCR E
243	302	JNZ
244	237	LO
245	035	HI
246	000	NOP
247	000	NOP
250	303	JMP
251	353	LO
252	035	HI
253	000	NOP
254	315	CALL (Y & Z CW SUB)
255	350	LO
256	030	HI
257	025	DCR D
260	302	JNZ
261	254	LO
262	035	HI
263	000	NOP
264	303	JMP
265	353	LO
266	035	HI
267	000	NOP
270	000	NOP
271	315	CALL (Y-axis CW SUB)

272	144	LO
273	030	HI
274	025	DCR D
275	302	JNZ
276	271	LO
277	035	HI
300	000	NOP
301	303	JMP
302	353	LO
303	035	HI
304	000	NOP
305	175	MOV A, L
306	273	CMP E
307	312	JZ
310	353	LO
311	035	HI
312	332	JC
313	333	LO
314	035	HI
315	000	NOP
316	223	SUB E
317	137	MOV E, A
320	315	CALL (Z-axis CCW SUB)
321	015	LO
322	030	HI
323	035	DCR E
324	302	JNZ

325	320	LO
326	035	HI
327	000	NOP
330	303	JMP
331	353	LO
332	035	HI
333	000	NOP
334	157	MOV L, A
335	173	MOV A, E
336	225	SUB L
337	137	MOV E, A
340	315	CALL (Z-axis CW SUB)
341	130	LO
342	030	HI
343	035	DCR E
344	302	JNZ
345	340	LO
346	035	HI
347	000	NOP
350	303	JMP
351	353	LO
352	035	HI
353	323	OUT
354	002	(Y-axis OFF)
355	323	OUT
356	006	(Z-axis OFF)
360	311	RETURN

* Main Program

```
036  000     323     OUT
     001     002     (Y-axis OFF)
     002     323     OUT
     003     006     (Z-axis OFF)
     004     000     NOP
     005     052     LHDL
     006     002     LO
     007     037     HI
     010     124     MOV D, H
     011     135     MOV E, L
     012     052     LHDL
     013     004     LO
     014     037     HI
     015     315     CALL (axes movement SUB)
     016     000     LO
     017     035     HI
     020     000     NOP
     021     000     NOP
     022     072     LDA
     023     000     LO
     024     037     HI
     025     107     MOV B, A
     026     005     DCR B
     027     302     JNZ
     030     052     LO
     031     036     HI
```

032	000	NOP
033	315	CALL (X-axis CCW SUB)
034	163	LO
035	030	HI
036	000	NOP
037	315	CALL (Z-lift SUB)
040	275	LO
041	030	HI
042	000	NOP
043	315	CALL (X-axis CW SUB)
044	030	LO
045	030	HI
046	000	NOP
047	303	JMP
050	066	LO
051	036	HI
052	000	NOP
053	315	CALL (X-axis CW SUB)
054	030	LO
055	030	HI
056	000	NOP
057	315	CALL (Z-lift SUB)
060	275	LO
061	030	HI
062	000	NOP
063	315	CALL (X-axis CCW SUB)
064	163	LO

065	030	HI
066	000	NOP
067	000	NOP
070	000	NOP
071	000	NOP
072	000	NOP
073	052	LHDL
074	004	LO
075	037	HI
076	124	MOV D, H
077	135	MOV E, L
100	052	LHDL
101	006	LO
102	037	HI
103	315	CALL (axes movement SUB)
104	000	LO
105	035	HI
106	000	NOP
107	000	NOP
110	072	LDA
111	001	LO
112	037	HI
113	107	MOV B, A
114	005	DCR B
115	302	JNZ
116	137	LO
117	036	HI

120	000	NOP
121	315	CALL (X-axis CCW SUB)
122	163	LO
123	030	Hi
124	000	NOP
125	315	CALL (Z-leave SUB)
126	310	LO
127	030	HI
130	000	NOP
131	315	CALL (X-axis CW SUB)
132	030	LO
133	030	HI
134	303	JMP
135	155	LO
136	036	HI
137	000	NOP
140	315	CALL (X-axis CW SUB)
141	030	LO
142	030	HI
143	000	NOP
144	315	CALL (Z-leave SUB)
145	310	LO
146	030	HI
147	000	NOP
150	315	CALL (X-axis CCW SUB)
151	163	LO
152	030	HI

153	000	NOP
154	000	NOP A, D
155	000	NOP
156	000	NOP
157	166	HALT

APPENDIX B

Sample program

HI	LO	Octal	Description
037	000	001	This code is for left hand bay of source location
	001	002	This code is for the left hand bay of the destination location
	002	000	Row number of current location
	003	000	Column number of current location
	004	000	row number of source location
	005	000	Column number of source location
	006	001	Row number of destination location
	007	001	Column number of destination location
035	000	Press GO	This will do the desired operation

APPENDIX C

Sample program

HI	LO	Octal	Description
037	000	001	This code is for left hand bay of source location
	001	001	This code is for the left hand bay of the destination location
	002	000	Row number of current location
	003	000	Column number of current location
	004	001	row number of source location
	005	001	Column number of source location
	006	000	Row number of destination location
	007	000	Column number of destination location
035	000	Press GO	This will do the desired operation

APPENDIX D

Sample program

HI	LO	Octal	Description
037	000	002	This code is for left hand bay of source location
	001	001	This code is for the left hand bay of the destination location
	002	000	Row number of current location
	003	001	Column number of current location
	004	002	row number of source location
	005	001	Column number of source location
	006	002	Row number of destination location
	007	002	Column number of destination location
035	000	Press GO	This will do the desired operation

DESIGN AND DEVELOPMENT OF A MICROCOMPUTER CONTROLLED AUTOMATIC STORAGE AND RETRIEVAL MODEL

by

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B.Sc(Mech. Engg.), Birla Institute of Technology,

Ranchi, India. 1979.

AN ABSTRACT

OF A MASTER'S THESIS

Submitted in partial fulfillment of the

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MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas.

1984

ABSTRACT

The purpose of this research is to design and develop a microcomputer controlled AS/R model. This model will ultimately be integrated with other equipments to form a model automated factory. The model will demonstrate the principles of loading and retreiving in AS/R systems using microcomputer control of AC and DC motors. The software to control the model will be general so as to be flexible and upward compatible.