IMPLEMENTATION OF AUTOMATED ASSEMBLY

By
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APPROVAL SHEET

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ABSTRACT

Title of Thesis : IMPLEMENTATION OF AUTOMATED ASSEMBLY

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Research has shown that about 60 - 80% wealth producing activities is related to manufacturing in major industrial countries.

Increased competition in industry has resulted in a greater emphasis on using automation to improve productivity and quality and also to reduce cost.

Most of the manufacturing works such as machining, painting, storage, retrieval, inspection and transportation have changed to automation successfully, except assembly. Manual assembly is predominant over automatic assembly techniques due to inherent assembly problem and the fact that the assembly machines lack the innate intelligence of human operator and lack sufficient flexibility to changeover when product designs and market demands change.

With the advent of flexible manufacturing systems, which involve very large capital costs and complex interactions. For the reduction the risk of the investment and analyze the system, simulation is a valuable tool in planning the systems and in analyzing their behavior, and get the best use of them.

This thesis applies animation techniques to simulate an automatic assembly system.

In chapter 1 to 9, we cover some of the fundamental concepts and principles of automatic assembly and simulation. Some manufacturers put the subject of part orientation first on their list of priorities; but design for assembly (DFA) techniques have proven extremely valuable in developing better assembly techniques and ultimately, better products. We discuss DFA in chapter 1, part feeding and orientation in chapter 2. Chapter 3, 4 and 5 are concerned with assembly process, machines and control system, respectively. Annual sales for industrial robots have been growing at the rate of about 25 percent per year in major industrial countries, we review the robot application in chapter 6. The cost of material handling is a significant portion of the total cost of production, material storage uses valuable space and consumes investment, we cover these two topics in chapter 7 and 8. Chapter 9 is concerned with simulation.

In chapter 10, 11,12 and 13, we implement a software package IGRIP to build a model of an automatic assembly system and analyze the result.

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CHAPTER 1 PART DESIGN

As industry strives to meet the competition, tremendous pressure is now placed on the product design engineer to deliver innovative products which can be manufactured in a most efficient manner. In addition, the design/development cycle has been compressed in many industries because of the accelerated rate at which new products are introduced. This accelerated pace puts great emphasis on "doing things right the first time" since product life tends to be short and production decisions tend to be based on delivery schedules.

A better philosophy is to design new products for automated assembly. This approach will often lead to basic improvements in overall product design because of the discipline associated with automated assembly. Furthermore, it allows maximum flexibility in the actual assembly process, since design for automated assembly will lead to products which can be assembled manually or by robot.

Many researchers have developed working rules to guide designers with respect to component and product design that facilitates automated assembly. This section describes and illustrates these guidelines:

1. MINIMIZE TOTAL NUMBER OF PARTS

Minimize number of parts encourages the designer to clearly think about the function of the product and how that function may be achieved with the minimum number of parts and fasteners. There are rules to eliminate parts:

i. No need for relative motion.

ii. No need for subsequent adjustment between parts.

iii. No need for service or repairability.

iv. No need for materials to be different.

Part reduction should not exceed the point of diminishing return where further part elimination adds cost and complexity because the remaining parts are to heavy, or to complicated to make and assemble, or are to unmanageable in other ways.

The best way to eliminate parts is to identify a design concept which requires few parts. Integral design, or the combining of two or more parts into one, is another approach. Integral design reduces the amount of interfacing information required, and decreases weight and complexity. One piece structures have no fasteners, no joints, and fewer points of stress concentration.

Extrusions and precision castings are good ways to eliminate subassemblies. Although switching to a different manufacturing process may lead to a more costly part, experience with part integration has shown that a more costly part often turns out to more economical when assembly costs are considered.

2. DEVELOP A MODULAR DESIGN

A module is a self-contained component with standardized interfaces to other product modules and to the production equipment and tooling used in the product manufacture. Individual modules can be varied to provide functional and styling diversity. Similar diversity can be provided by using different combinations of standard modules. All of this has no effect on the production line as long as the module/process equipment and tooling interfaces and standardized. Modular design also reduces final assembly information content because there are less parts to assemble and each module can be fully checked prior to final assembly.

Experience has shown that products consisting of 4 to 8 modules with 4 to 12 parts per module are most automation friendly. A good design strategy is to keep the product generic the modules should be designed to add up to the final product thereby eliminating the need for a housing or other integrating structure.

3. USE STANDARD COMPONENTS

A stock item is always less expensive than a custom-made item. Standard components require little or no lead time and are more reliable because characteristics and weaknesses are well known. They can be ordered in any quantity at any time. They are usually easier to repair and replacements are easier to find. Use of standardized components puts the burden on the supplier and makes the supplier do more.

4. DESIGN PARTS TO BE MULTI-FUNCTIONAL

Combine function wherever possible. For example, design a part to act both as a spring and a structural member, or to act both as an electrical conductor and structural member. An electronic chassis can be made to act as an electrical ground, a heat sink, and a structural member. Less obvious combinations of function might involve adding guiding, aligning, and/or self-fixturing features to a part to aid in assembly as shown as Fig. 1.

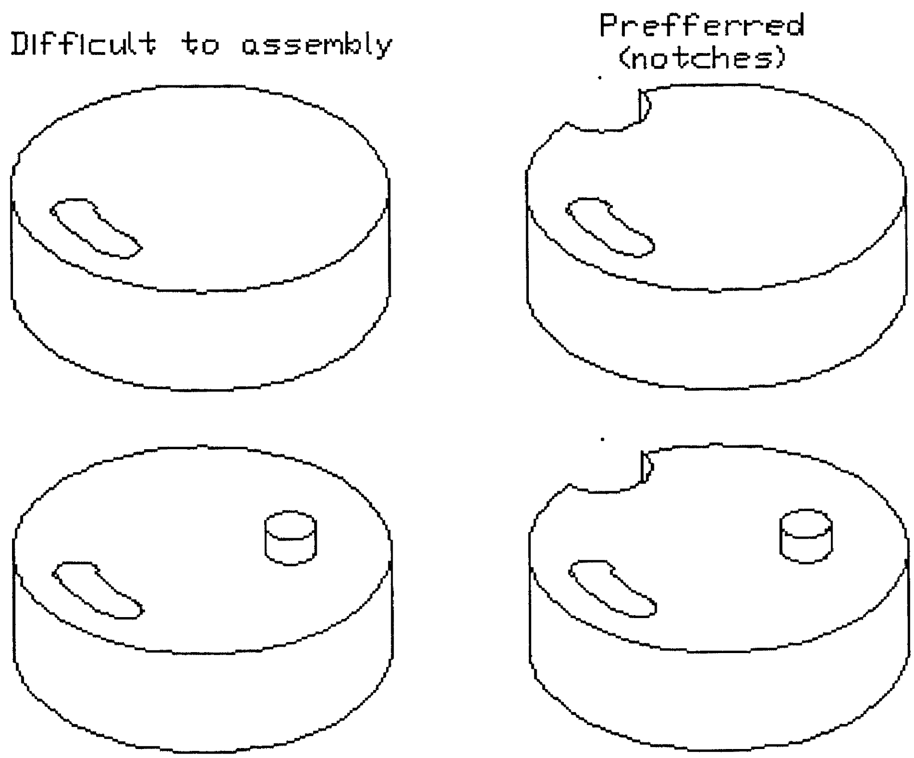


Fig. 1: Self-aligning part

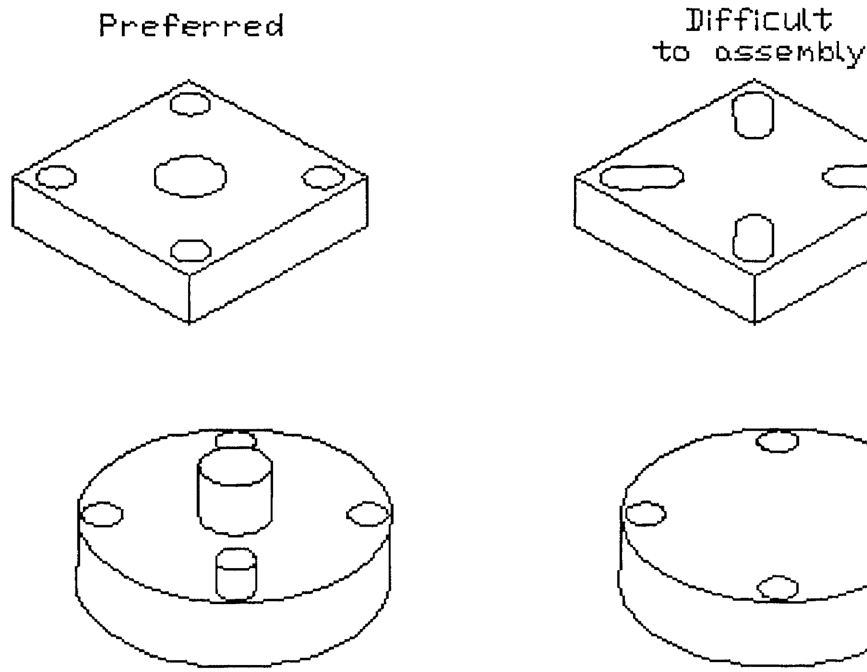


Fig. 2: Self-fixturing part

5. DESIGN PARTS FOR MULTI-USE

Many parts can be designed for multi-use. For example, the same mounting plate can be designed to mount a variety of components. Key to multi-use part design is identification of part candidates. One approach involves sorting all parts (or a statistical samples) manufactured or purchased by the company into two groups:

i. Parts which are unique to a particular product or model.

ii. Parts which are generally needed in all products and/or model.

Each group is then divided into categories of similar parts.

Multi-use parts are then created by standardizing similar parts. In standardizing, the designer should sequentially seek to

i. Minimize the number of part categories.

ii. Minimize the number of variations within each category.

iii. Minimize the number of design features within each variation.

Once developed, the family of standard parts should be used wherever possible in existing products and used exclusively in new product designs. Also, manufacturing processes and tooling based on a composite part containing all design features found in a particular part family should be developed. Individual parts can then be obtained by skipping some steps and features in the manufacturing process.

6. DESIGN PARTS FOR EASE OF FABRICATION

This guideline requires that individual parts be designed using the least costly material that just satisfies functional requirements and such that both material waste and cycle time are minimized. This in turn requires that the most suitable fabrication process available be used to make each part and that the part be properly designed for the chosen process.

This guideline is based upon the recognition that higher material and/or unit process cost can be accepted if it leads to lower overall production cost, i.e., adding information content to a particular part is acceptable as long as total information content of the product/process is reduced.

7. AVOID SEPARATE FASTENERS

Separate fasteners involve large amounts of information. Even in manual assembly, the cost of driving a screw can be six to ten times the cost of the screw. One of the easiest things to do is eliminate fasteners in assembly by using snap-fits. If fasteners must be used, cost as well as quality risks can be significantly reduced by minimizing the number, size, and variations used and by using standard fasteners whenever possible. Screws that are too short or too long, separate washers, tapped holes, and round and flat heads (not good for vacuum pickup) should be avoided.

8. MINIMIZE ASSEMBLY DIRECTIONS

All parts should be assembled from one direction. Extras directions mean wasted time and motion as well as more transfer stations, inspection stations, and fixture nests. This in turn leads to increased cost, increased wear and tear on equipment due to added weight and inertia load, and increased reliability and quality risks. The best possible assembly is when all parts are added in a top down fashion to create a z-axis stack. Multi-motion insertion should be avoided as shown as Fig. 3.

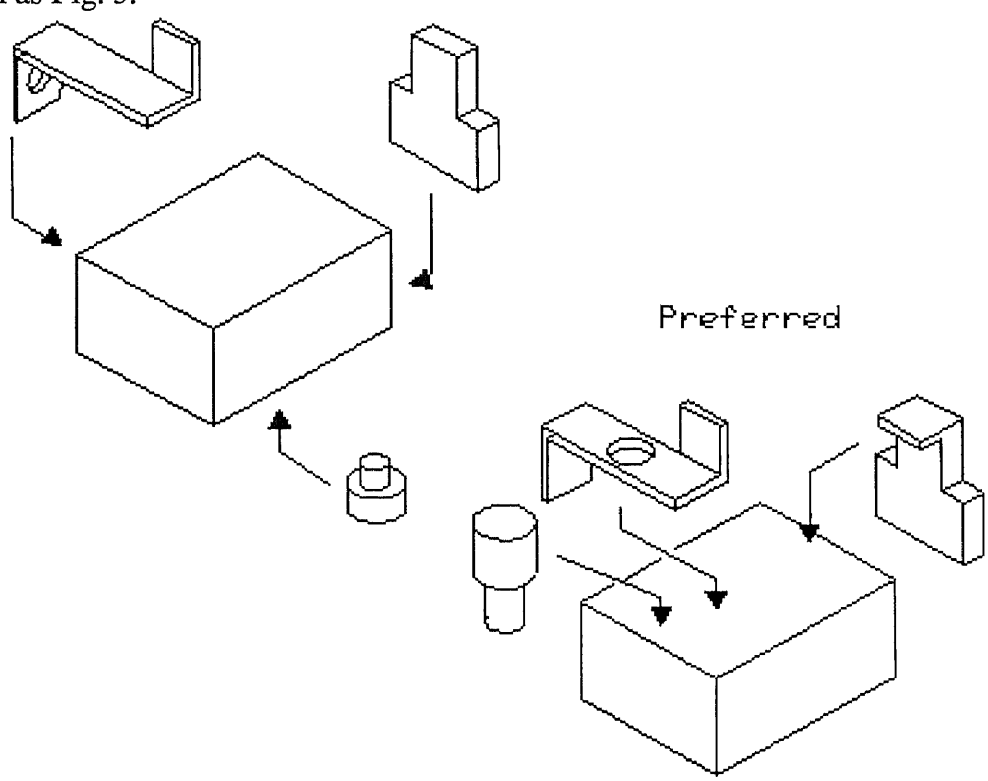


Fig. 3: Minimize directions

9. MAXIMIZE COMPLIANCE

Because parts are not always identical and perfectly made, misalignment and tolerance stack-up can produce excessive assembly force leading to sporadic automation failures and/or product unreliability. Major factors affecting rigid part mating include part geometry, stiffness of assembly tool, stiffness of jigs and fixtures holding the parts, and friction between parts. To guard against this, compliance must be built into both the product and production process.

Methods for providing compliance include highly accurate parts, use of "worn-in" production equipment, remote center compliance, selective compliance in assembly tool, tactile sensing, variety of systems, designed-in compliance features, and external effects. Although a variety of combinations of these approaches are commonly used, experience has shown that the simplest solution consists of a combination of acceptable quality parts, designed-in compliance features, accurate (rigid) base components, and selective compliance in the assembly tool.

10. MINIMIZE HANDLING

Position is the sum of location (x, y, z) and orientation (Á, Ã, ã). Position costs money. Therefore, parts should be designed to make position easy to achieve as shown as Fig. 4; and the production process should maintain position once it is achieved.

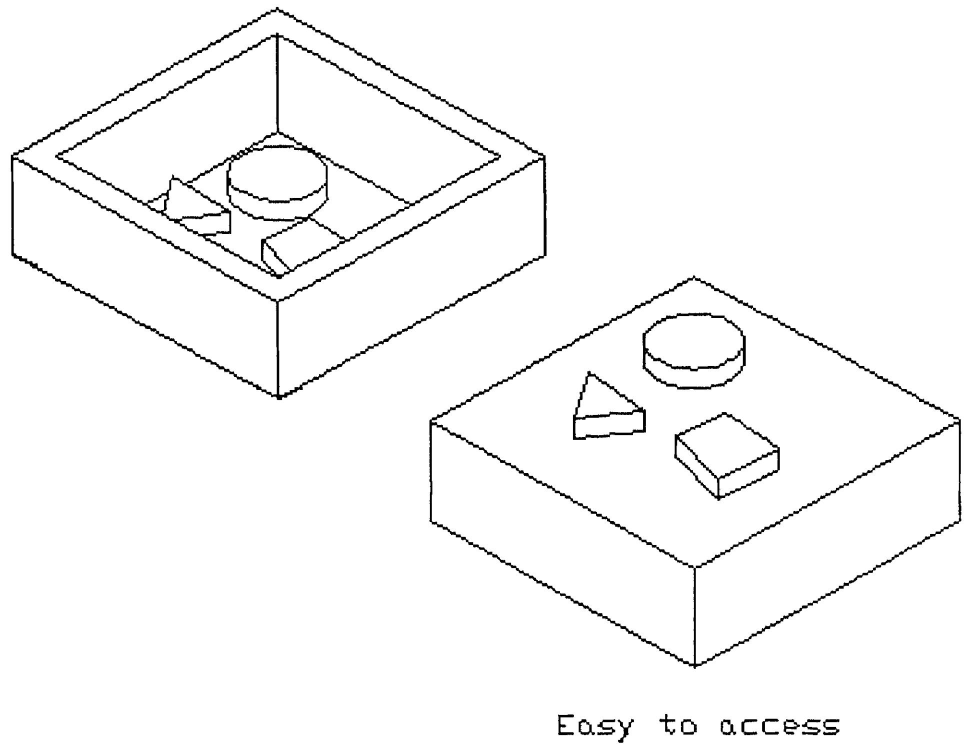


Fig. 4: Providing unobstructed access

The number of orientations required during production equates with increased equipment expense, greater quality risk, slower feed rates, and slower cycle times. To assist in orientation, parts should be made as symmetrical as possible as shown as Fig. 5. If polarity is important, then an existing asymmetry should be accentuated, or a very obvious asymmetry should be designed in, or a clear identifying mark provided.

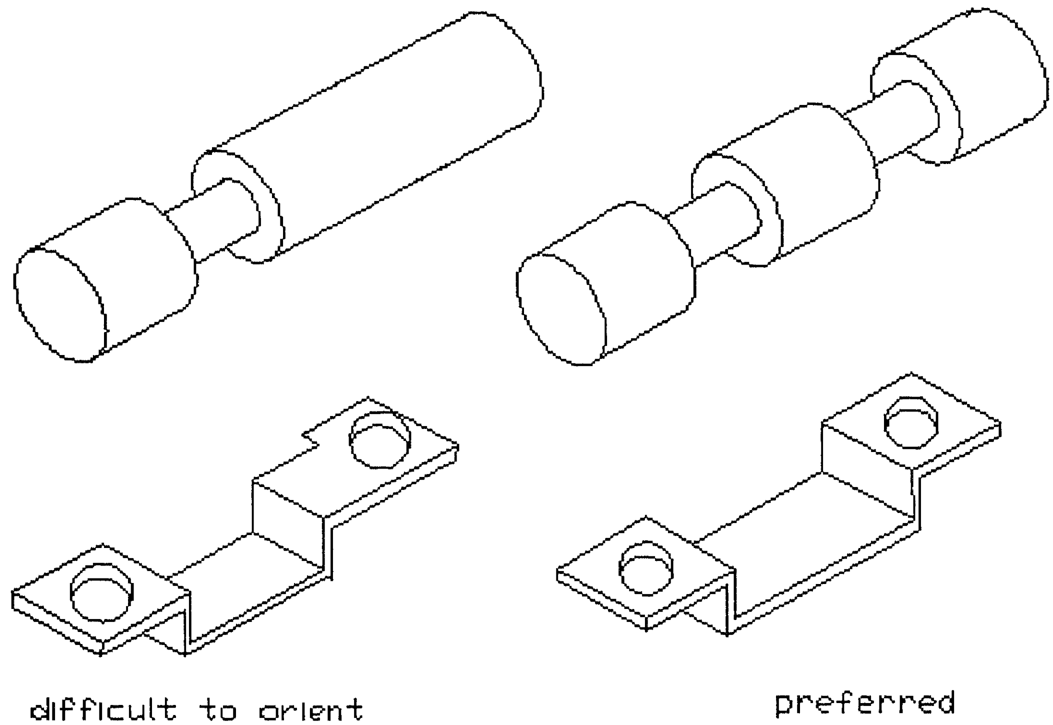


Fig. 5a: Symmetry helps with part orientation

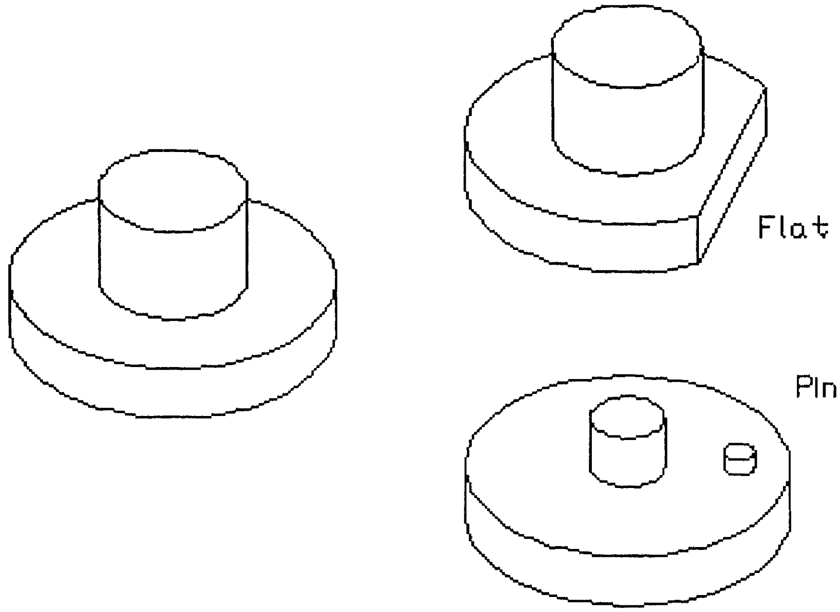


Fig. 5b: External features provide orientation of hidden feature

Orientation can also be assisted by designing in features which help guide and locate parts in the proper position. Parts should also be designed to avoid tangling, nesting as shown as Fig. 6, and shingling in vibratory part feeders.

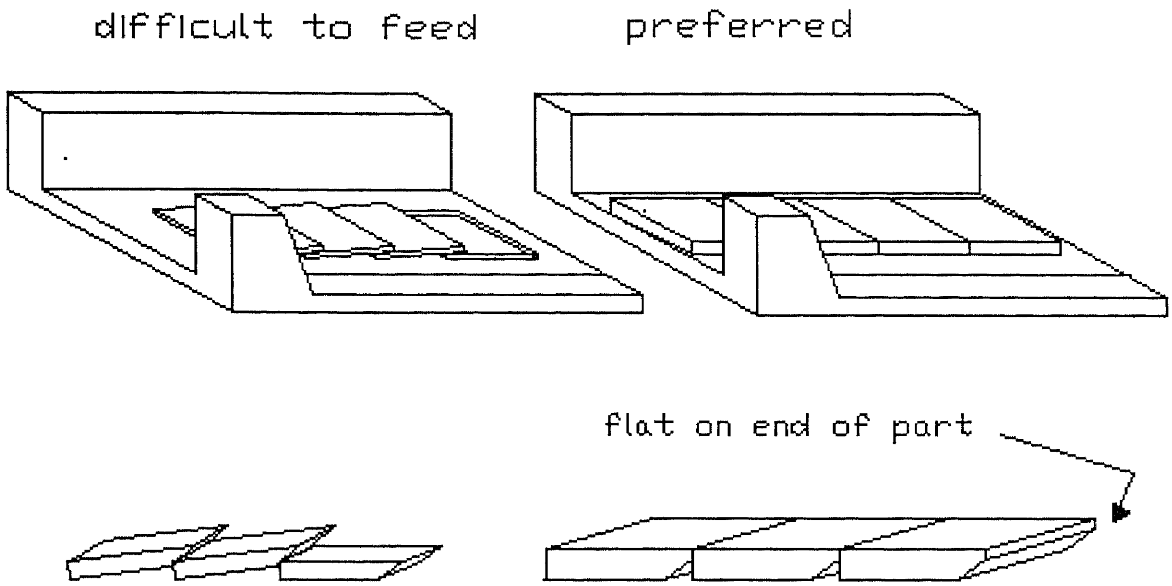


Fig. 6a: Avoid parts which shingle

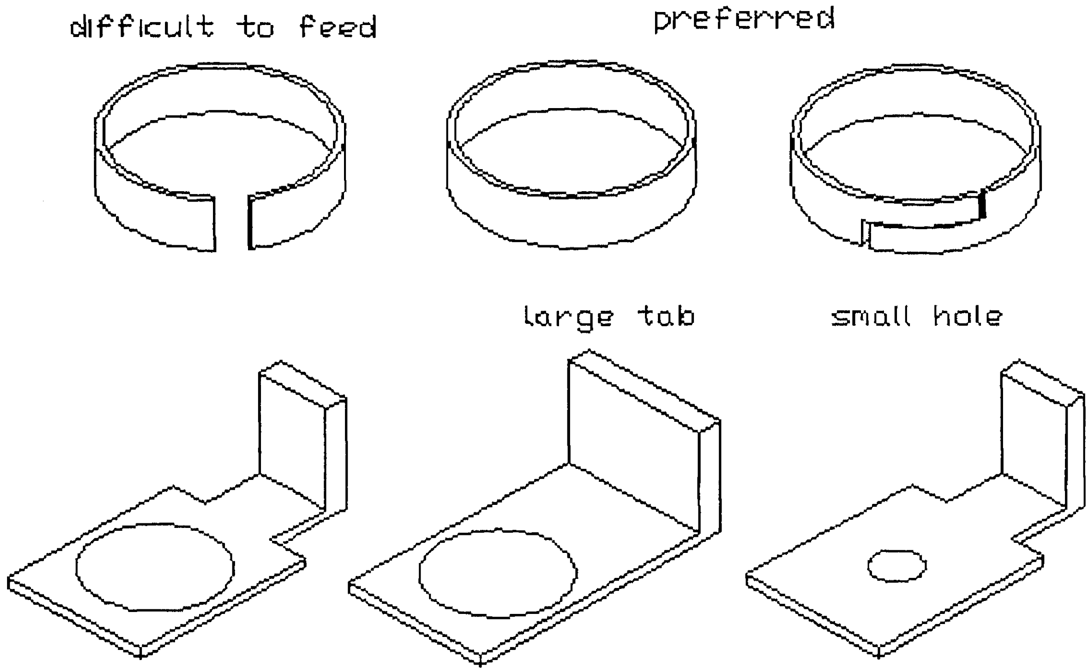


Fig. 6b: Avoid parts which tangle or daisy chain

To facilitate robotic part handling, provide a large, flat, smooth top surface for vacuum pickup, or provide and inner hole for spearing, or provide a cylindrical surface or other feature of sufficient length for gripper pickup as shown as Fig. 7.

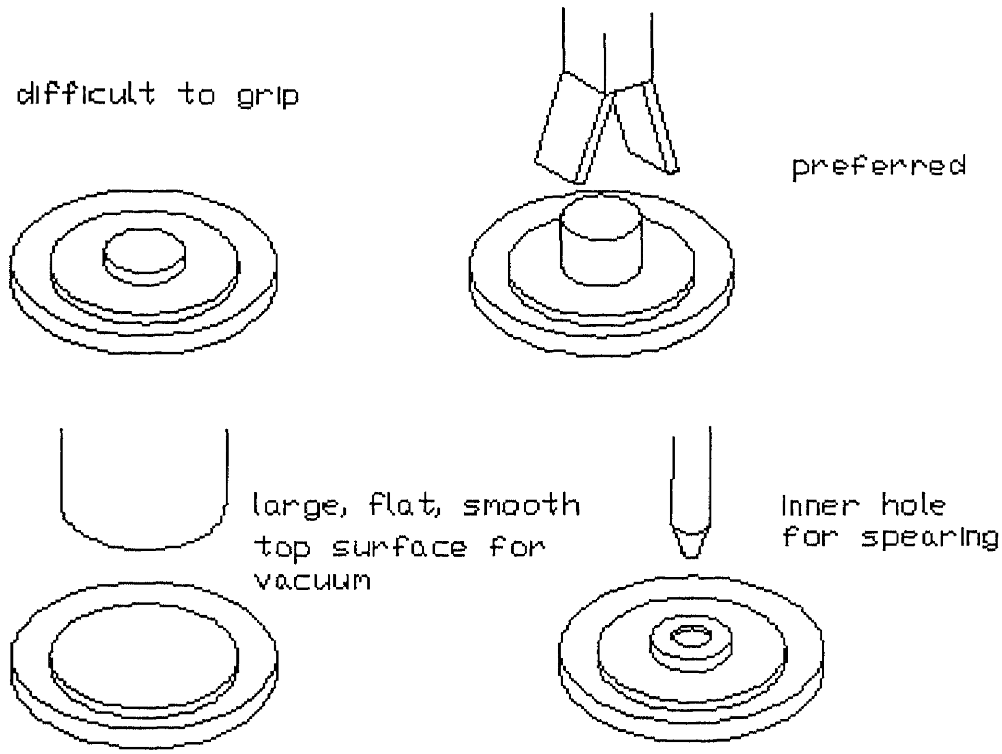


Fig. 7: Part design for handling

Application of the design for automation guideline is not always easy or straightforward. They show the way, but do not replace the talent, innovation, and experience of the product development team. They must also be applied in manner which maintains and, if possible, enhances product performance and marketing goals. In applying the design guidelines, they should be thought of as "optimal suggestions", which , if successfully followed, will result in a more optimal, automation friendly design. If a product performance or marketing requirement prevents full compliance with a particular guideline then the next best alternative consistent with the design for automation principles should be selected. Use of the guidelines in this way helps to both assure a product design optimized for automated production and to delineate problem areas requiring special attention.

CHAPTER 2 PART FEEDING DEVICES

At a work station components are manipulated and fitted to other components to form assemblies. The output of parts from the device is always restricted by the machine being fed. The machine will generally use parts at a strictly uniform rate and this may be referred to as the machine rate. In the design and testing of parts feeding devices it is often convenient to observe the feed rate when the device is not connected to a machine, i.e., when no restriction is applied to the output of the device. The feed rate under these circumstances will be referred to as the unrestricted feed rate. Clearly, in practice the mean unrestricted feed rate must not fall below the machine rate.

Certain other general requirements of feeding devices may be summarized as follows:

The unrestricted feed rate should not vary widely since this will simply mean that when the device is connected to a machine, the parts will be continuously re-circulated within the device for much of the time. This will cause excessive wear and may eventually damage the parts. This undesirable characteristic often occurs in feeding devices where the feed rate is sensitive to changes in the quantity of parts present in the device and will be referred to as the load sensitivity of the device.

With feeding devices suitable for automatic machines it is necessary that all the parts be presented to the machine in the same attitude, i.e., they must be fed correctly oriented. Some feeders are able to feed and orient many types of part whilst others are only able to handle a very limited range of part shapes.

Undoubtedly the reliability of a feeding device is one of its most important characteristics. Feeding devices should be designed so that the possibility of parts jamming in the feeder, or in its orienting devices, is minimized or eliminated.

It is sometimes suggested that feeding devices can also act as inspection devices. It is possible to design certain feeding devices so that misshapen parts, swarf, etc. will not be fed to machine but will be rejected by the device fitted to the feeder. This can be an important feature because defective parts or foreign matter, if fed to the machine, will probably cause a breakdown and may stop the whole production line.

Components can be presented to a work station in five basic ways:

i. They may be placed in a bin or pile that the (manual) operator can take from as necessary.

ii. They may be presented one at a time from a bulk holder to a picked point.

iii. They may be supplied on a reeled tape or strip for automatic or manual removal.

iv. They may be manufactured as desired at the work station.

v. They may be presented singly from a gravity magazine, feeder, or tray.

The elements of the parts feeding system are illustrated schematically in Fig. 1. A more detailed description of the various elements of the feeding system is described in the following sections.

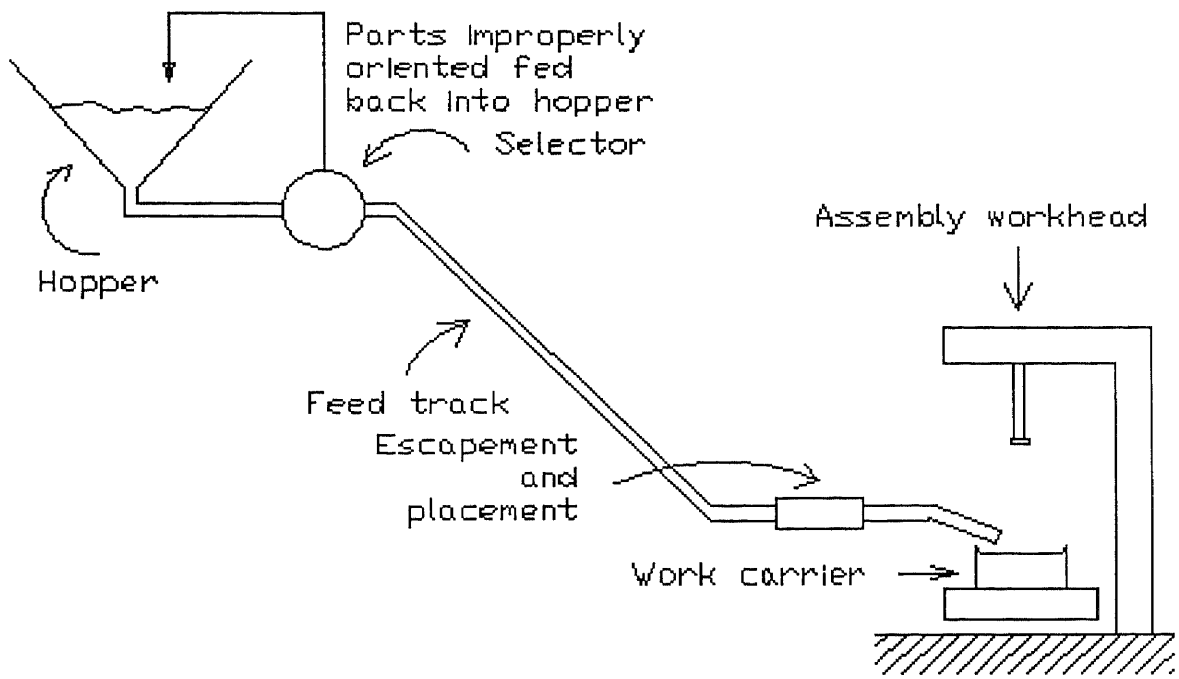


Fig. 1: Elements of the parts feeding system at an assembly workstation

1. HOOPER

This is the container into which the components are loaded at the workstation. A separate hopper is used for each components type. The components are usually loaded into the hopper in bulk. This means that the parts are randomly oriented initially in the hopper.

A. RECIPROCATING TUBE HOPPER

A reciprocating tube hopper is illustrated in Fig. 2 and consists of a conical hopper with a hole in the center through which a delivery tube passes. Relative vertical motion between the hopper and the tube is achieved by reciprocating either the tube or the hopper. During the period when the top of the tube is below the level of parts, some parts will fall into the delivery tube. It is usual to machine the top of the tube at an angle so that a part resting across the opening will fall clear and not block the opening as the tube is pushed upward through the mass of parts. Care must be taken in choosing the angle of the conical hopper because if the angle is too small there is a possibility of parts jamming between the tube and the hopper.

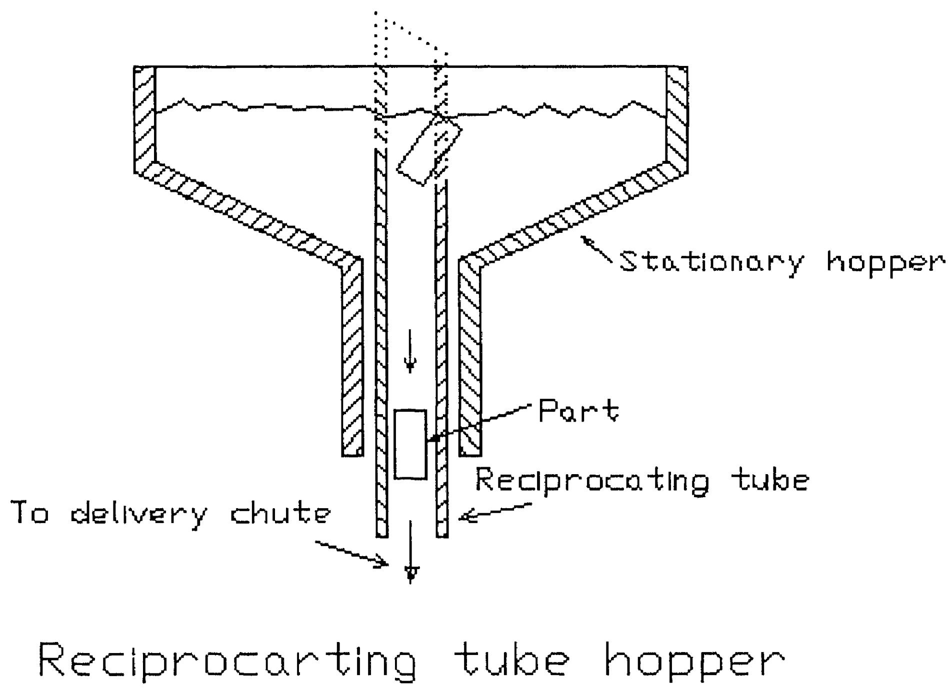


Fig. 2: Reciprocating tube hopper

B. CENTRIFUGAL HOPPER

The centrifugal hopper shown in Fig. 3, is particularly suitable for feeding plain cylindrical parts. In this device, the parts are placed in a shallow cylindrical hopper whose base rotates at constant speed. A delivery chute is arranged tangentially to the stationary wall of the hopper and parts adjacent to this wall which have become correctly oriented, due to the general circulation, pass into the delivery chute. No orienting devices are provided in the hopper and parts must be taken off in the attitude which they naturally adopt in the hopper as indicated in the figure.

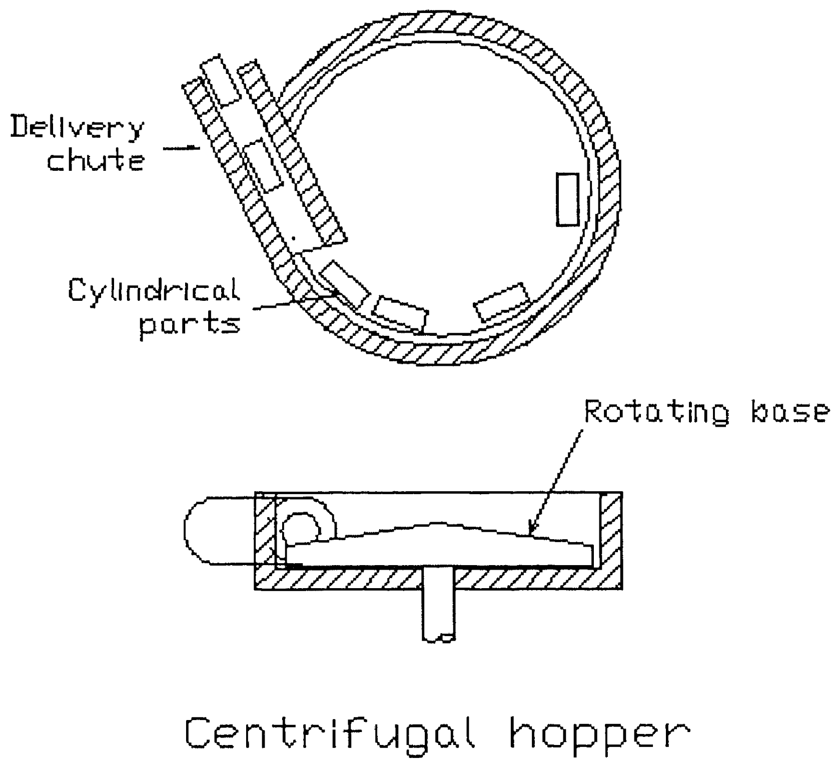


Fig. 3: Centrifugal hopper

C. REVOLVING HOOK HOPPER

The revolving hook hopper shown in Fig. 4 consists of a hopper in the shape of an inverted truncated cone which is open at the top for parts to be loaded, and closed at the base. The base has a hole in the center which forms the beginning of the delivery chute. Revolving about the center of the base and offset so as to clear the hole is a curved wiper blade which extends to the outer edge of the leading edge of the hook, towards the hole at the center of the hopper and hence to the delivery chute.

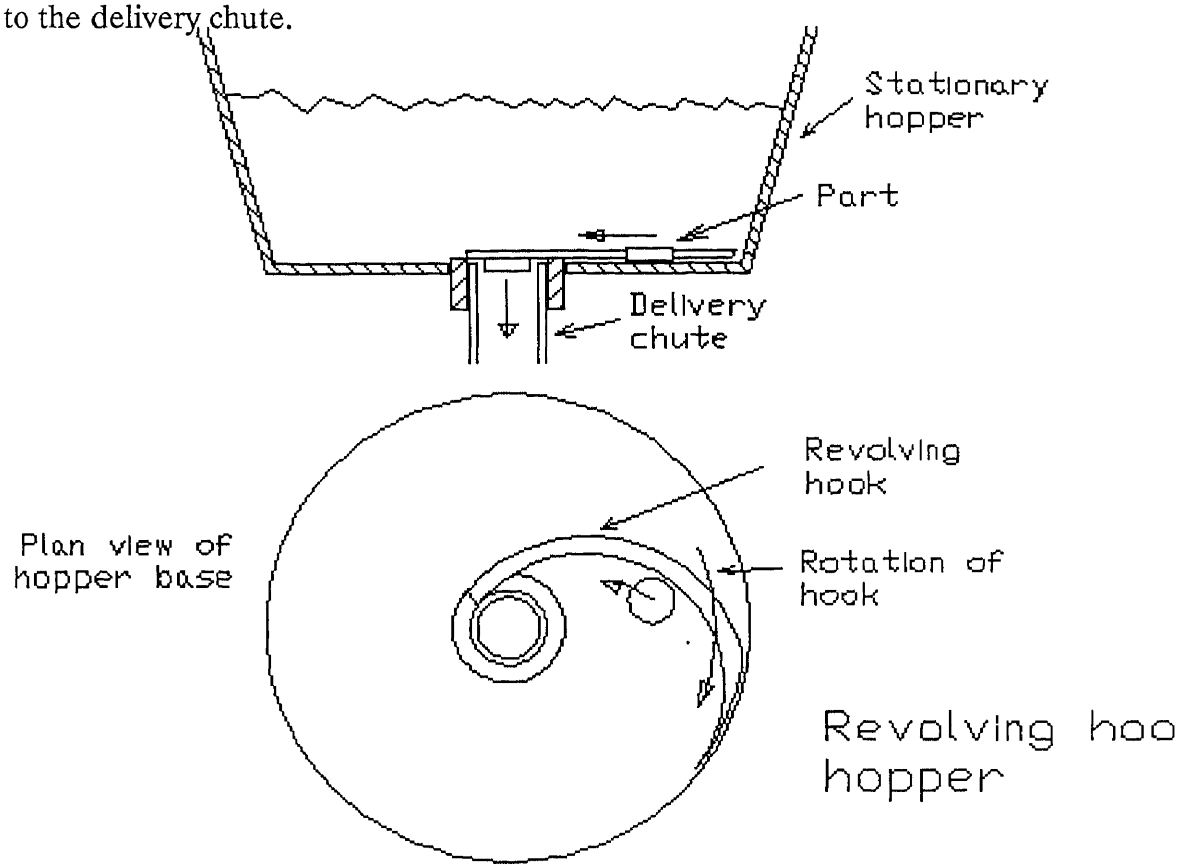


Fig. 4: Revolving hook hopper

D. STATIONARY HOOK HOPPER

This parts feeder as shown as Fig. 5 operates in exactly the same principle as the revolving hook hopper, the only difference being that, in this case, the hook is stationary and the base of the hopper rotates slowly. The parts are guided along the edge of the hook towards the periphery of the hopper, where they are eventually deflected into the delivery chute by a deflector mounted on the hopper wall. One advantage of this type of feeder is its gentle feeding action and this makes it suitable for feeding delicate parts at low speed.

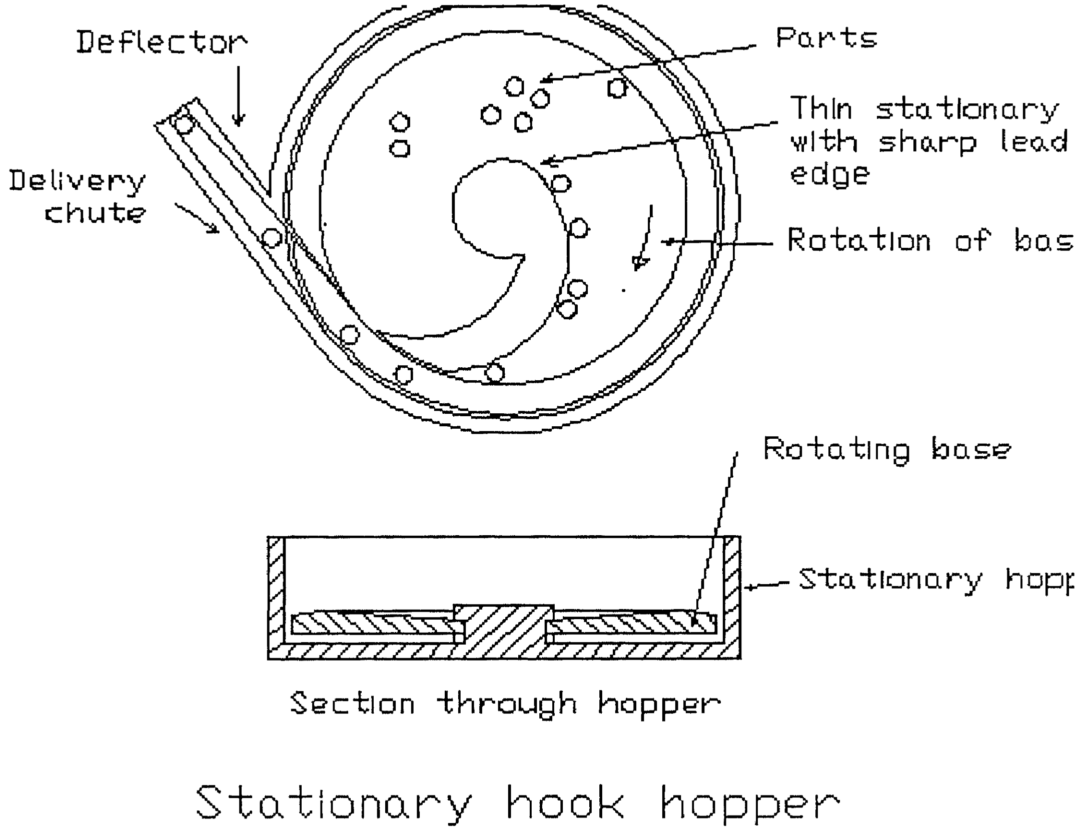


Fig. 5: Stationary hook hopper

E. PADDLE WHEEL HOPPER

In the paddle wheel hopper as shown as Fig. 6, the tips of the blades of a vertical multiblades paddle run in a groove in the bottom of the hopper. The groove has dimensions such that the parts in the hopper may be accepted by the groove in one particular attitude only. Rotation of the paddle agitates the parts in the hopper and causes parts arriving at the delivery point in the wrong attitude to be pushed back into the mass of parts.

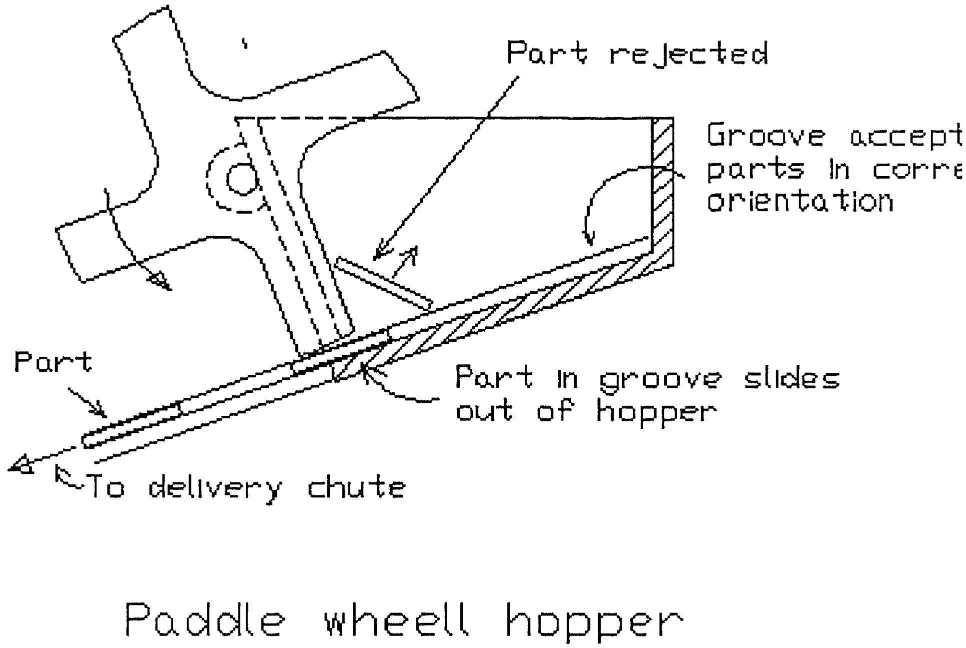


Fig. 6: Paddle wheel hopper

F. TUMBLING BARREL HOPPER

In the tumbling barrel hopper as shown as Fig. 7, the cylindrical container, which has internal radial fins, rotates about an inclined vibratory feed track. Parts placed in bulk in the hopper are carried upward by the fins until at some point they slide off the fin and cascade onto the vibratory feed track. The feed track is shaped to suit the required attitude of the part being fed and only retains and feeds those parts falling in this attitude.

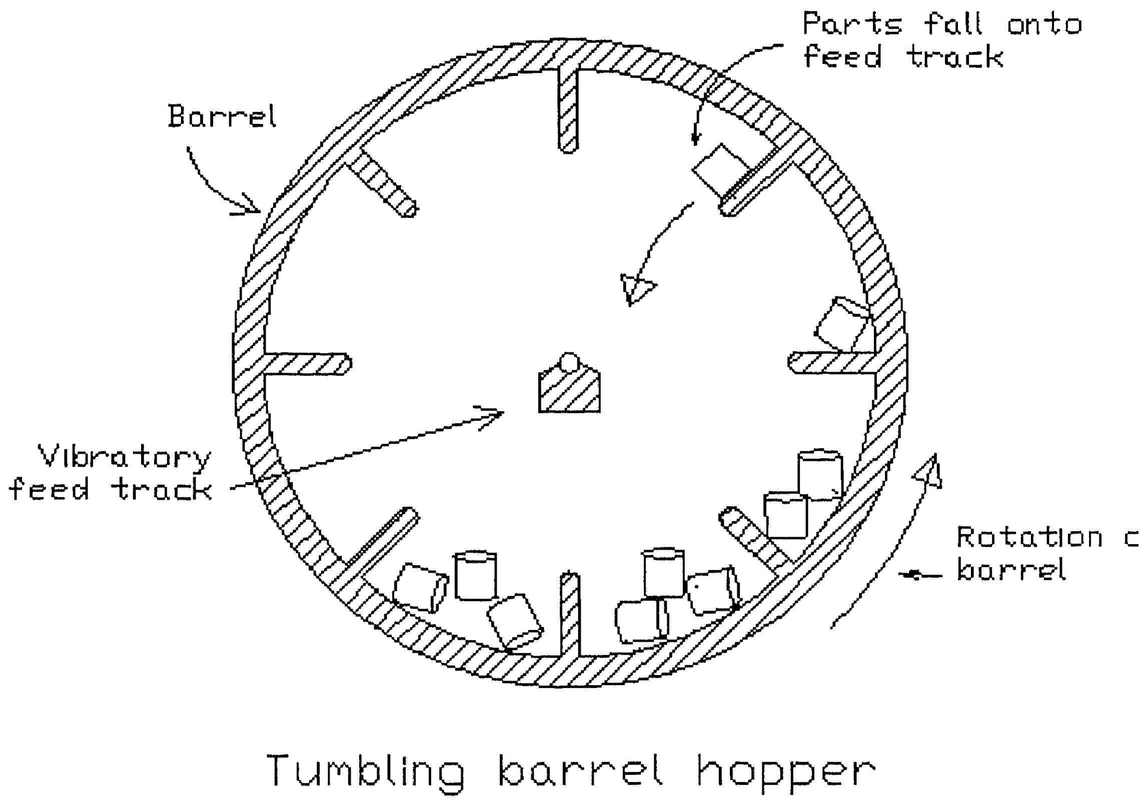


Fig. 7: Tumbling barrel hopper

G. ROTARY CENTERBOARD HOPPER

In the rotary centerboard hopper as shown as Fig. 8, it consists of a bladed wheel which rotates inside a suitably shaped hopper. The edges of the blades are profiled to collect parts in the desired attitude and lift them clear of the bulk of parts. Further rotation of the wheel causes the oriented parts to slide off the blade which will then be aligned with the delivery chute. It is usual to drive the wheel intermittently by either a Geneva mechanism or a ratchet and pawl mechanism. The design of the indexing mechanism should take into account the dwell time required for a full blade to discharge all its parts when aligned with the delivery chute.

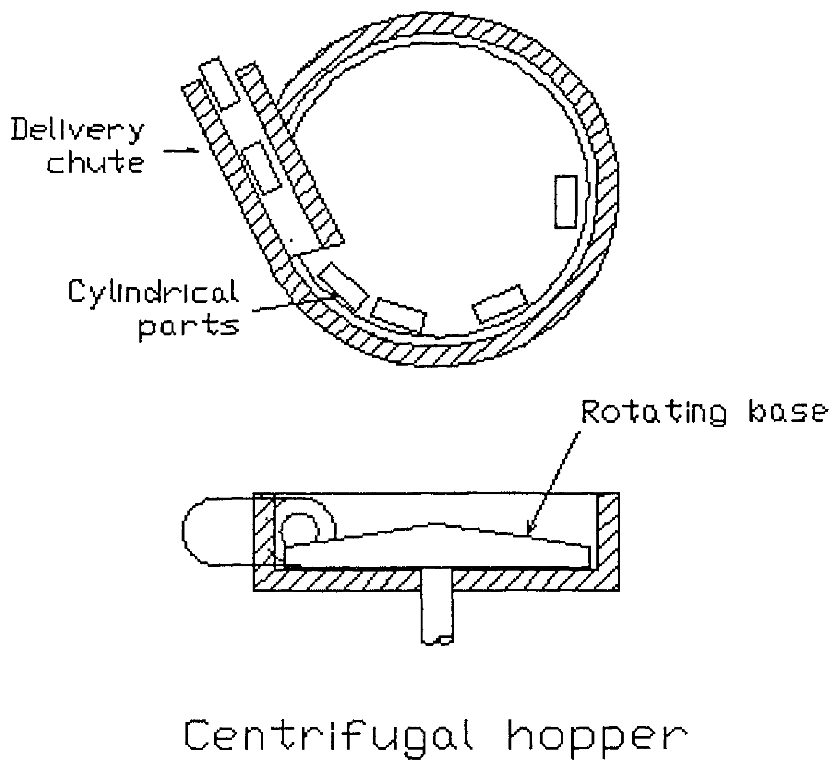


Fig. 8: Rotary centerboard hopper

H. ELEVATING HOPPER FEEDER

This feeder as shown as Fig. 9 has a large hopper with inclined sides. Often an agitating device is fitted to the base to encourage the parts to slide to the lowest point in the hopper. An endless conveyor belt fitted with a series of selector ledges, is arranged to elevate parts from the lowest point in the hopper. The ledges are shaped so that they will only accept parts in the desired attitude. The parts slide off the ledges into the delivery chute which is situated at a convenient point above the hopper.

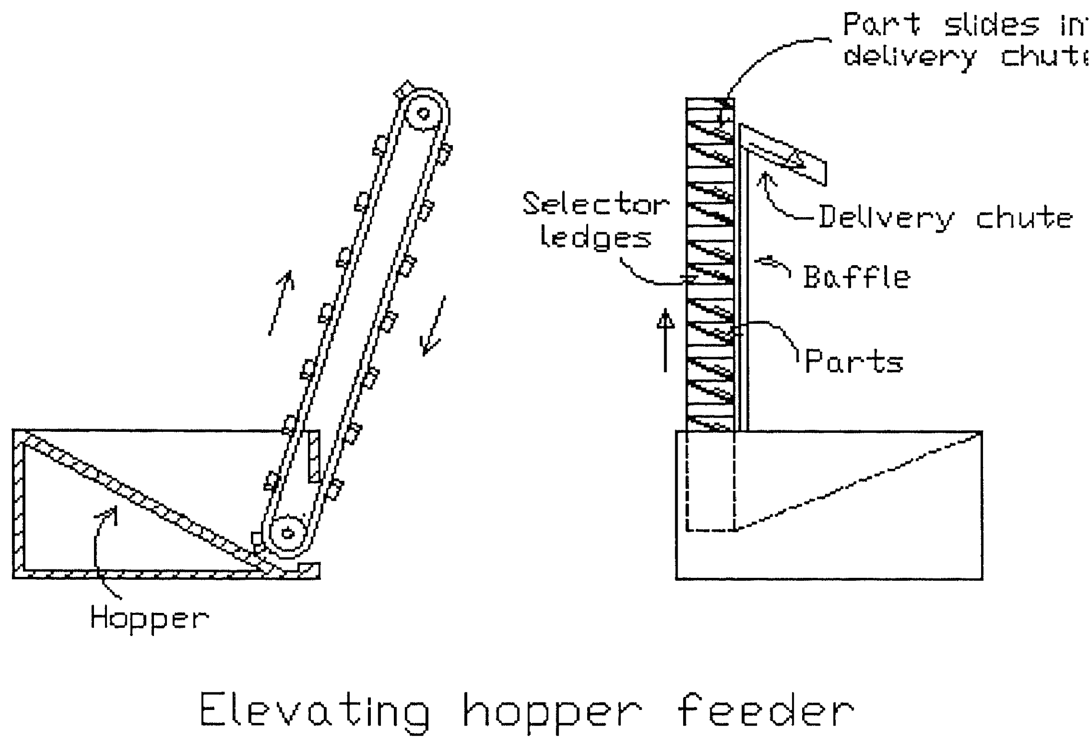


Fig. 9: Elevating hopper feeder

2. PARTS FEEDER

This is a mechanism that removes the components from the hopper one at a time for delivery to the assembly workhead. The hopper and parts feeder are often combined into one operating mechanism. The vibratory bowl feeder is a very common example of the hopper-feeder combination.

One of the recent developments in the technology of parts feeding is the programmable parts feeder. The programmable parts feeder is capable of feeding components of varying geometries with only a few minutes required to make the adjustments (change the program) for the differences. This type of feeder would possible the flexibility to be used in batch production assembly systems. Most parts feeders are designed as fixed automated systems for high-production assembly.

A. VIBRATORY BOWL FEEDER

The Vibratory feeder is probably the most widely used mechanism for feeding and orienting parts. A vibratory bowl feeder is illustrated in Fig. 10. It consists of a bowl and bowl mounting cross arm coupled to an electromagnetic drive by means of leaf springs. Intermittent charges supplied by electromagnetic coil cause mechanical vibration to occur at generally 3600 or 7200 vibrations per minute with amplitudes ranging from 0.025 to 0.075". The vibration cycle imparts a forward and upward flight of the part, causing it to land further along the bowl track. While in motion, parts encounter such orientation devices as wipers, air jets, special clips, and rejectors to ensure the necessary discharge position at the required rate.

The growing demand for equipment capable of orienting parts at increasingly higher rates of feed sparked the invention of the rotary parts feeder. Feed rates vary according to part size, configuration, and required orientation. Average feed rates from rotary feeders range from 200 to 1400 parts per minute; however, feed rates as high as 4000 parts per minute have been achieved.

The majority of rotary feeders contain a rotating outer bowl and an inclined rotating inner disk. Centrifugal force of the disk and bowl, as well as friction of the disk on the parts, cause them to be projected to the bowl flange, where they are oriented into a single line of feed. Correctly oriented parts are permitted to discharge from the feeder. Maloriented parts are recirculated into the bowl for reorientation.

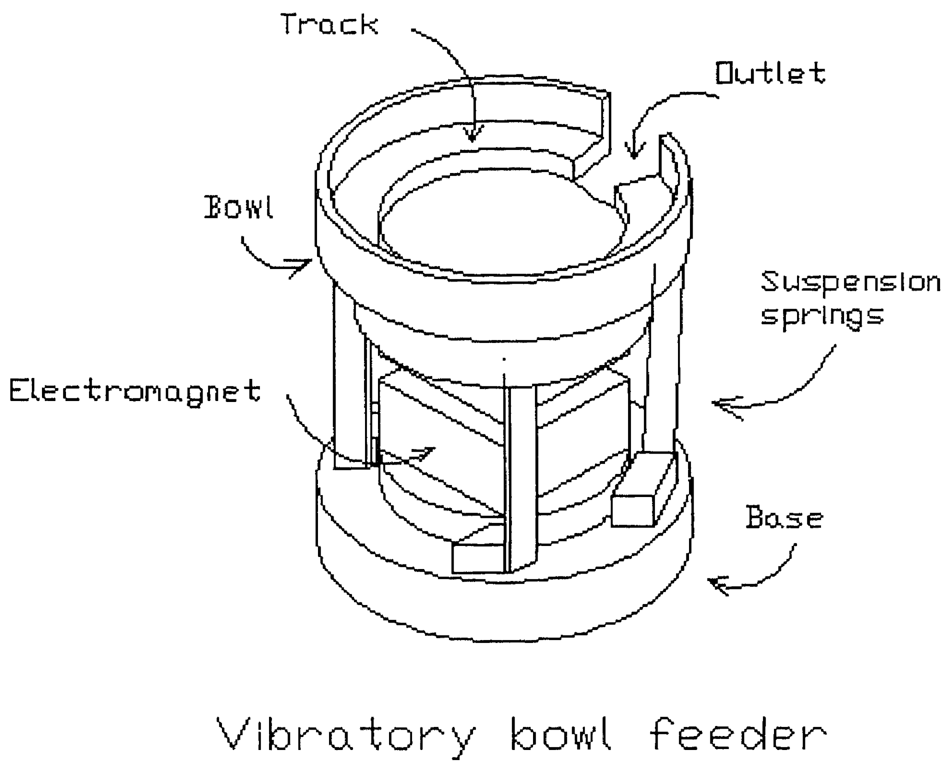


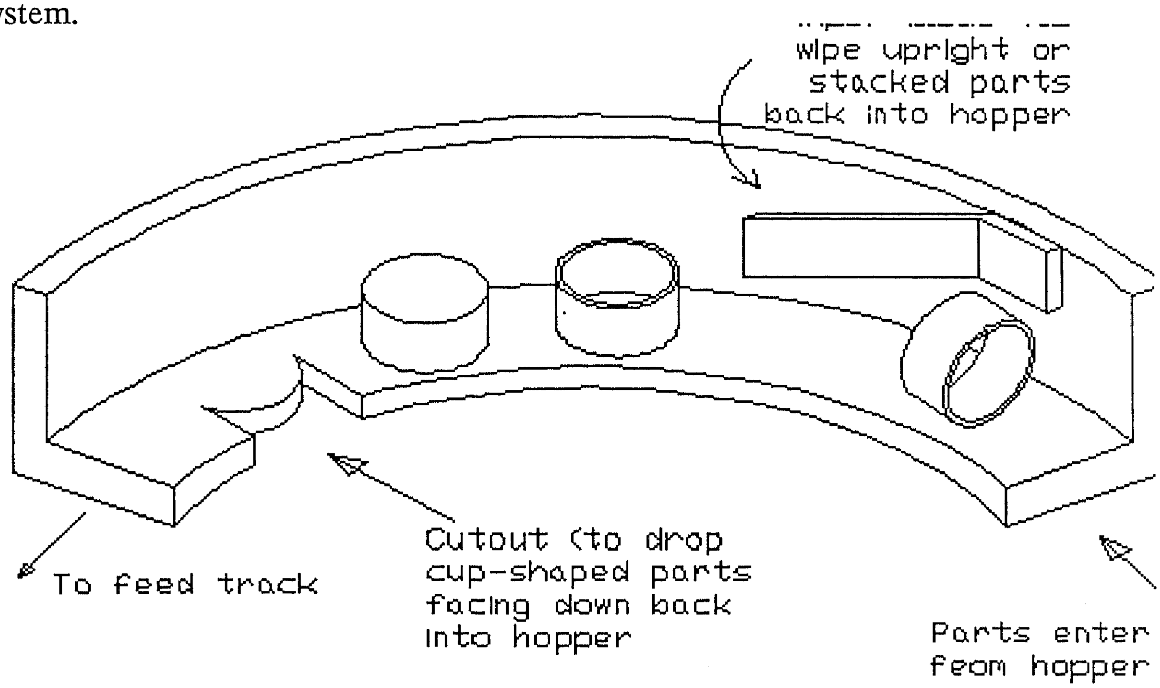
Fig. 10: Vibratory bowl feeder

B. PROGRAMMABLE FEEDER

Programmable feeder consists of a parts feeder, recognition device, vision controller, orienting mechanism, and part conveyor. The parts feeder singles out scrambled parts feeds them past the recognition device, which scans the parts and selects image data. The vision controller determines the part orientation by comparing data from the passing orientation with that of the required orientation previously stored in the memory system. If the images correspond, the system recognizes a part as the acceptable orientation then conveys it to the assembly operation. Parts with undesirable orientations are diverted into the feeder for recirculation and reorientation. Orienting mechanisms are triggered by vision controller to orient or divert various part. They can rotate parts 180 ^{0} to accommodate reverse orientations or rotate about two axes to produce one acceptable orientation from parts arriving in any one of four possible attitudes.

3. SELECTOR AND/OR ORIENTOR

These elements of the feeding system establish the proper orientation of the components for the assembly workhead. A selector is a device that acts as a filter. Permitting only parts that are in the correct orientation to pass through. Components that are not properly oriented are rejected back into the hopper. An orientor is a device that allows properly oriented parts to pass through but provides a reorientation of components that are not properly oriented initially. Several selector and orientor schemes are illustrated in Fig. 11a & b. Selector and orientor devices are often combined and incorporated into one hopper-feeder system.



Selector

Fig. 11a: Selector

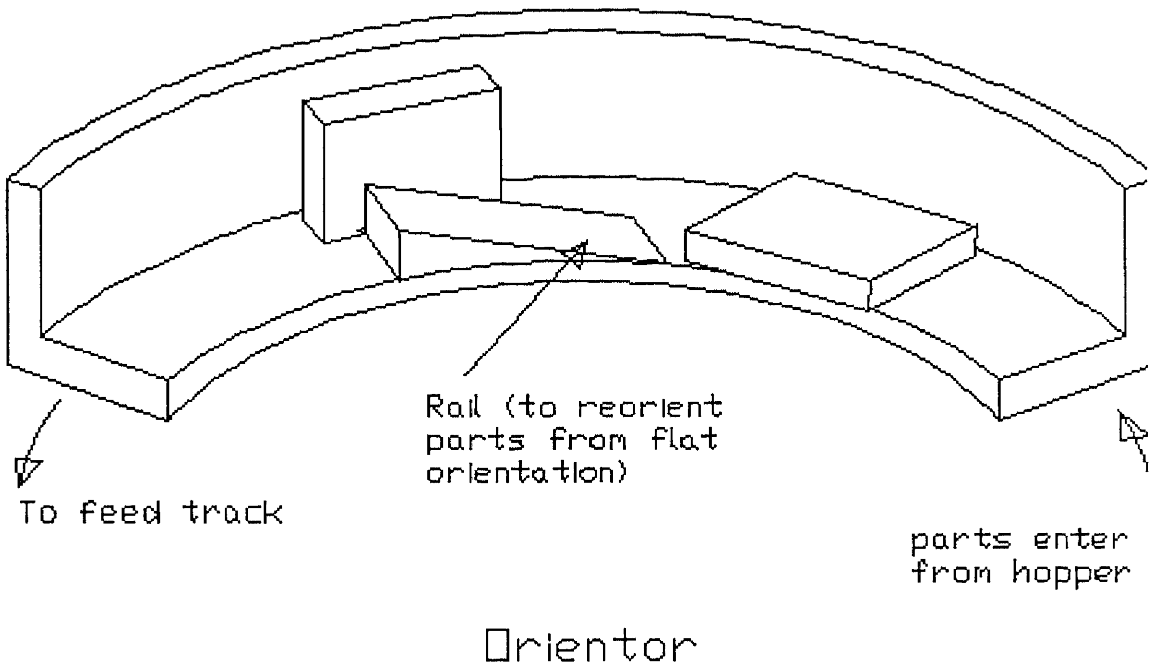


Fig. 11b: Orientor

4. FEED TRACK

The preceding elements of the feeding system are usually located some distance from the assembly workhead. A feed track is used to transfer the components from the hopper and parts feeder to the location of the assembly workhead, maintaining proper orientation of the parts during the transfer. There are two general categories of feed tracks: gravity and powered. The gravity feed track is most common. In this type the hopper and parts feeder are located at an elevation that is above the elevation of the workhead. The force of gravity is used to deliver the components to the workhead. The powered feed track uses vibratory action, air pressure, or other means to force the parts to travel along the feed track toward the assembly workhead.

5. ESCAPEMENT AND PLACEMENT DEVICE

The purpose of the escapement device is to remove components from the feed track at time intervals that are consistent with the cycle time of the assembly workhead. The placement device physically places the component in the correct location at the workstation for the assembly operations by the workhead. These elements are sometimes combined into a single operation mechanism. In other cases, they are two separate devices.

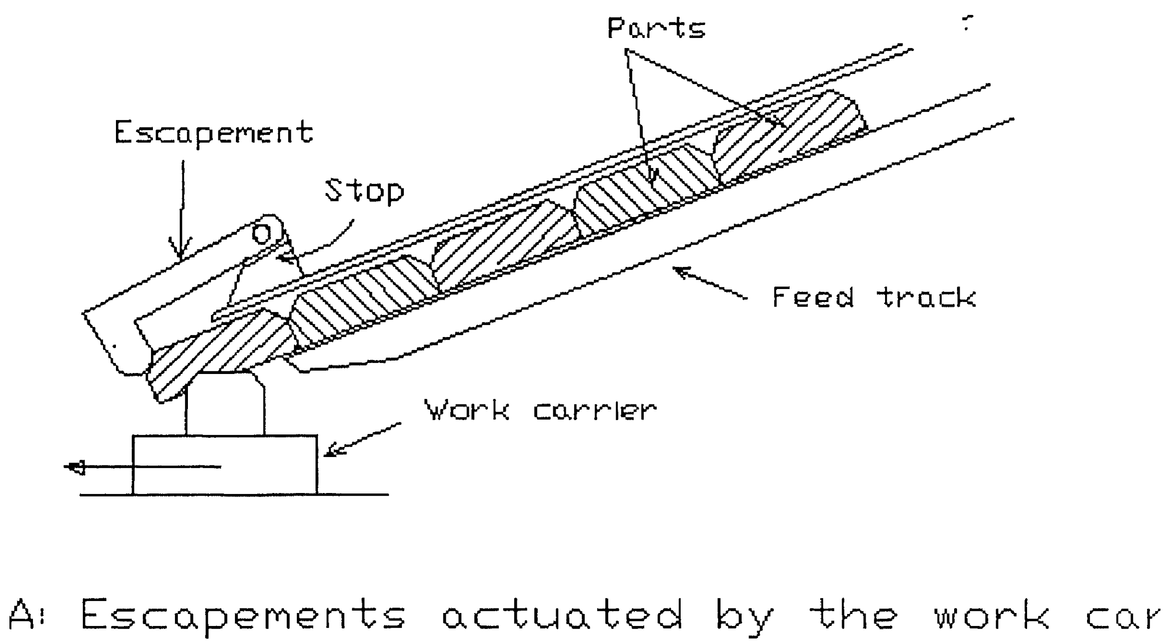
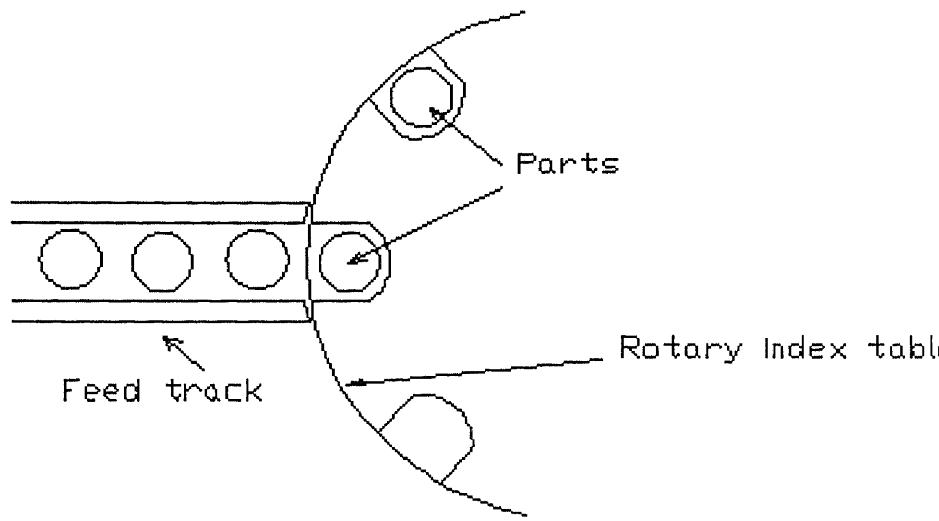
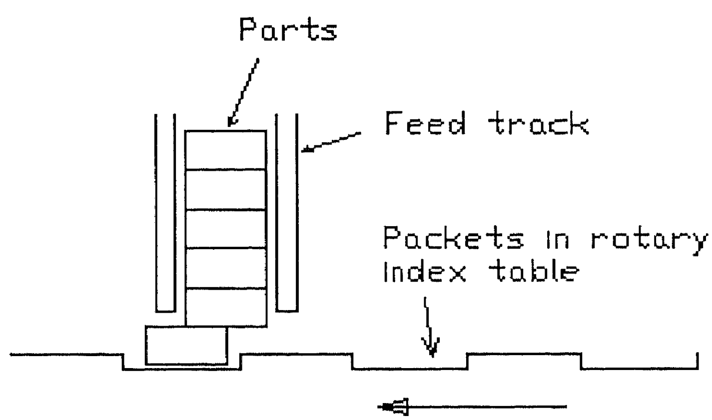


Fig. 12: Escapement actuated by the work carrier



a) Horizontal delivery



b) Vertical delivery

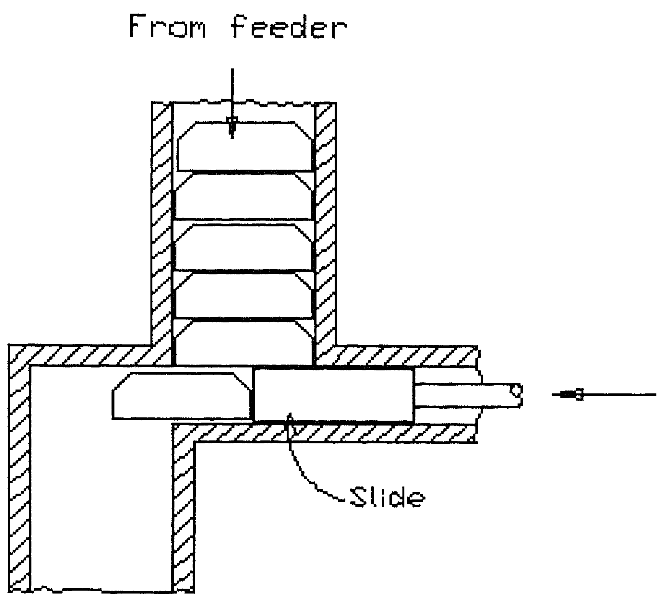
Fig. 13: Feeding of parts onto rotary index table

A. ESCAPEMENTS

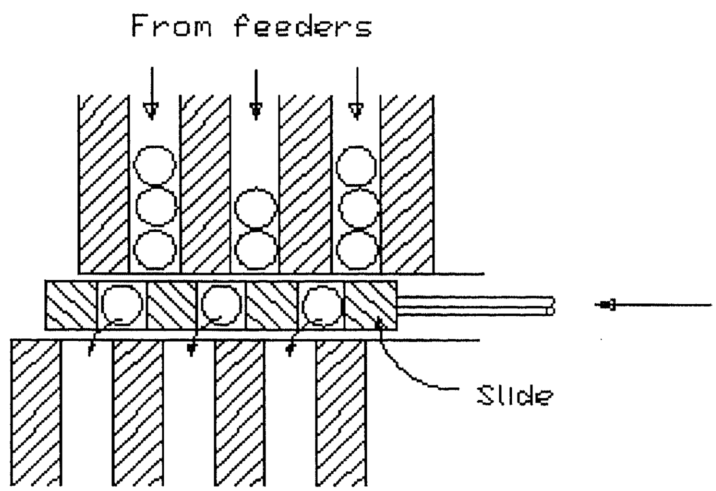
Industrial escapements are frequently not consciously recognized as such. Fixtures on dial tables may perform the function of escaping parts from magazines or feeder tracks; punches on punch presses may escape parts from chutes as the punches travel to perform their forming or fastening function.

i. Slide escapements

Four examples of slide escapements are shown in Fig. 14, Fig. 15 and Fig. 16. It can be seen from the figures that in the slide escapement one or more parts are removed from the feed chute by the action of a cross-slide and that applications of this type of device are restricted to parts which do not interlock with each other. The slide escapement is ideally suited to regulating the flow of spherical, cylindrical or plate-like parts and although in all the figures the feed track enters the escapement vertically, this, whilst desirable, is not necessary. As with the ratchet escapement, parts may be released either singly or in batches from one or a number of feed tracks by the action of a single actuating mechanism. However, a further alterative, not available with the ratchet escapement, is for parts fed from a single feed track to be equally divided between two delivery tracks as shown in Fig. 16. The type of escapement is very useful where two identical parts are to be used in equal quantities and a parts feeder is available which will deliver at a sufficient rate to meet the total requirement.



a: Delivers one part



Slide escapements
operating several feed chutes

Fig. 14: Slide escapements delivering into single feed chute

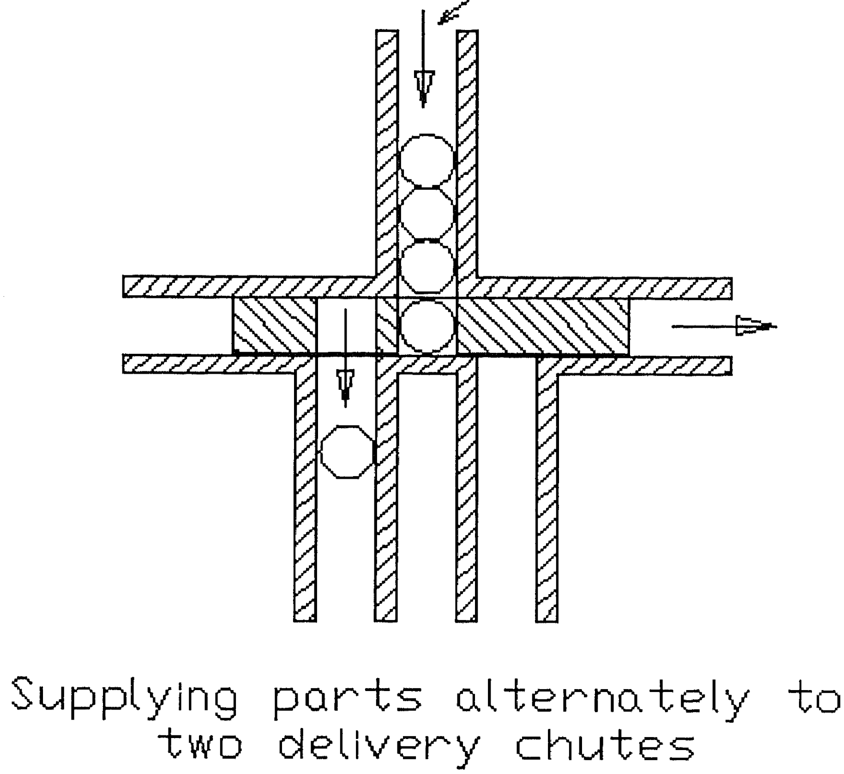
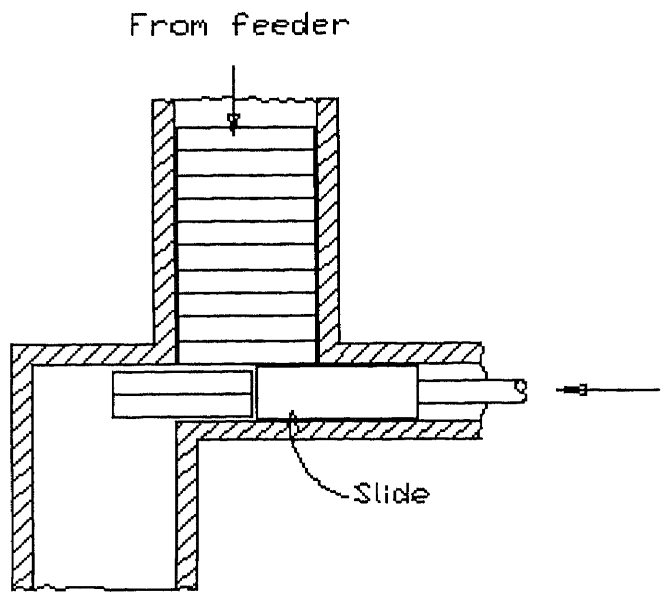


Fig. 15: Slide escapements operating several feed chutes



b: Delivery several parts

Fig. 16: Slide escapements supplying parts alternately to two delivery chutes

ii. Drum escapements

Two Types of drum escapement, usually referred to as drum-spider escapements, are shown in Fig. 17 where in these cases the drum is mounted vertically and the parts are either fed and delivered side by side Fig. 17a or fed end to end and delivered side by side Fig. 17b. In the latter case the parts are fed horizontally to the escapement. One advantage of the vertical drum escapement is that a change in the direction of motion of the parts is easily accomplished. This can be very useful where the horizontal distance between the parts feeder and the workhead is restricted to value which would necessitate very sharp curves in the feed track if an alternative type of escapement were used. Drum escapements may be driven continuously or indexed but usually an indexing mechanism is preferable because difficulties may be encountered in attempting to synchronize a continuous drive to meet the requirements of the workhead.

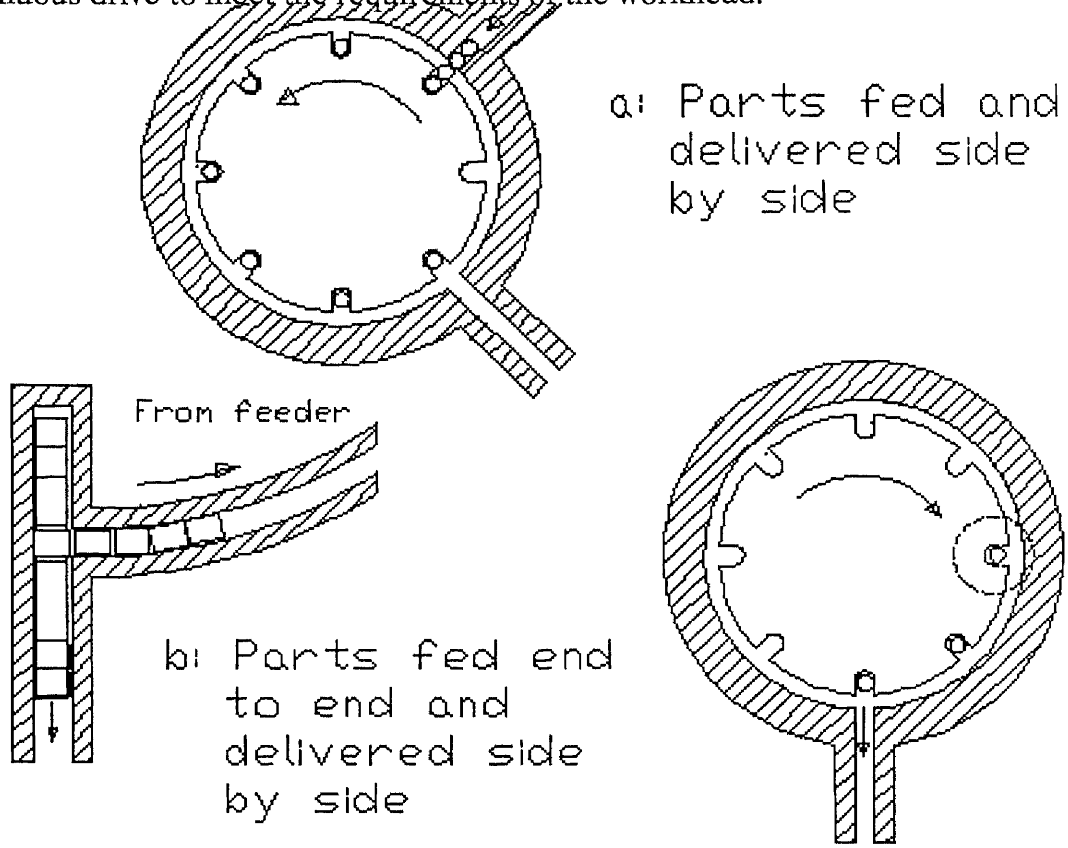


Fig. 17: Drum-spider escapements

B. PARTS PLACING MECHANISMS

For situations where the placing mechanism has to be displaced from the workstation location, the 'pick and place' system is often used. The basic action of this system is shown in Fig. 18a & b where it can be seen that the part is picked up from the feed track by means of a mechanical, magnetic or vacuum hand, depending on the particular application, placed in position in the assembly and released. The transfer arm then returns along the same path to its initial position. Proprietary pick and place mechanisms operate in a variety of ways. Some pick vertically, transfer along a straight path horizontally and place vertically as shown in Fig. 18a. Others pick vertically, transfer round the arc of a circle in a horizontal plane and place vertically as shown in Fig. 18b.

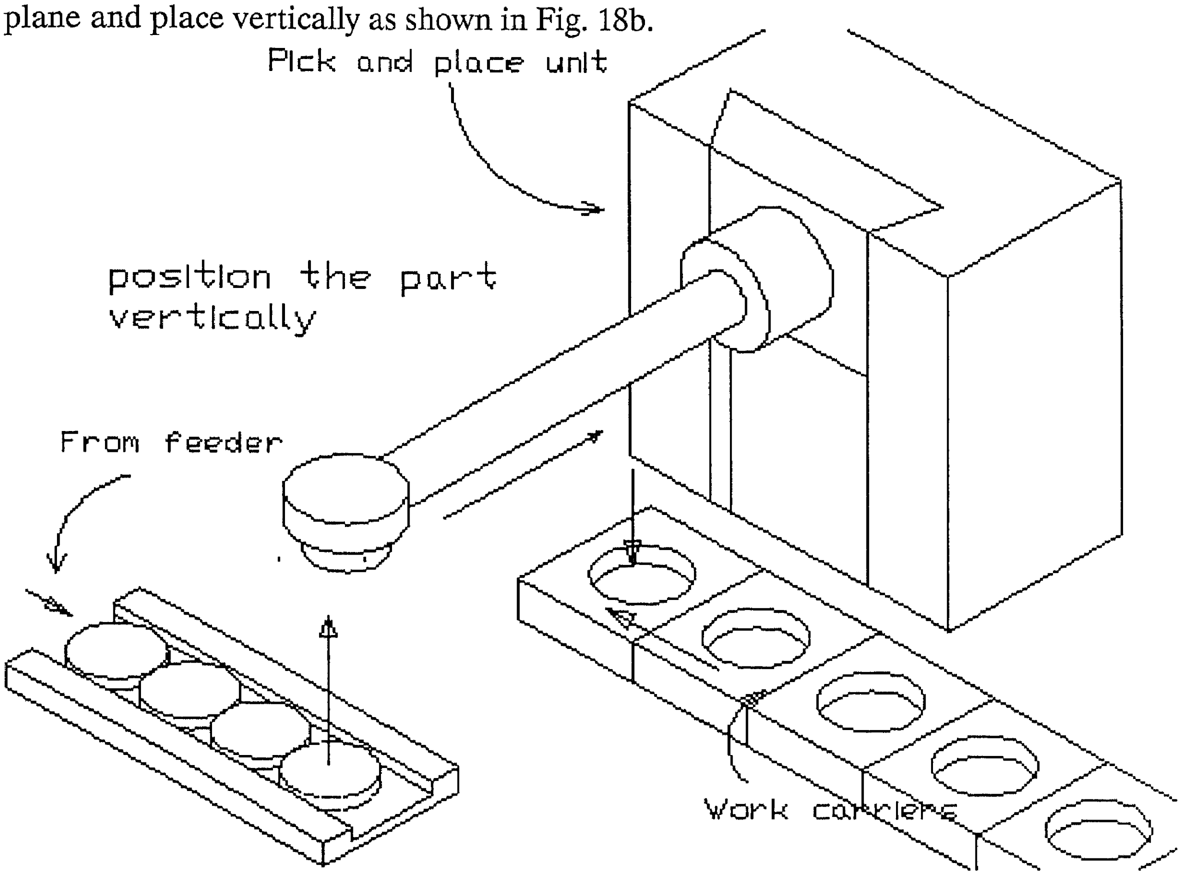


Fig. 18a: Pick and place units which lift and position the part vertically

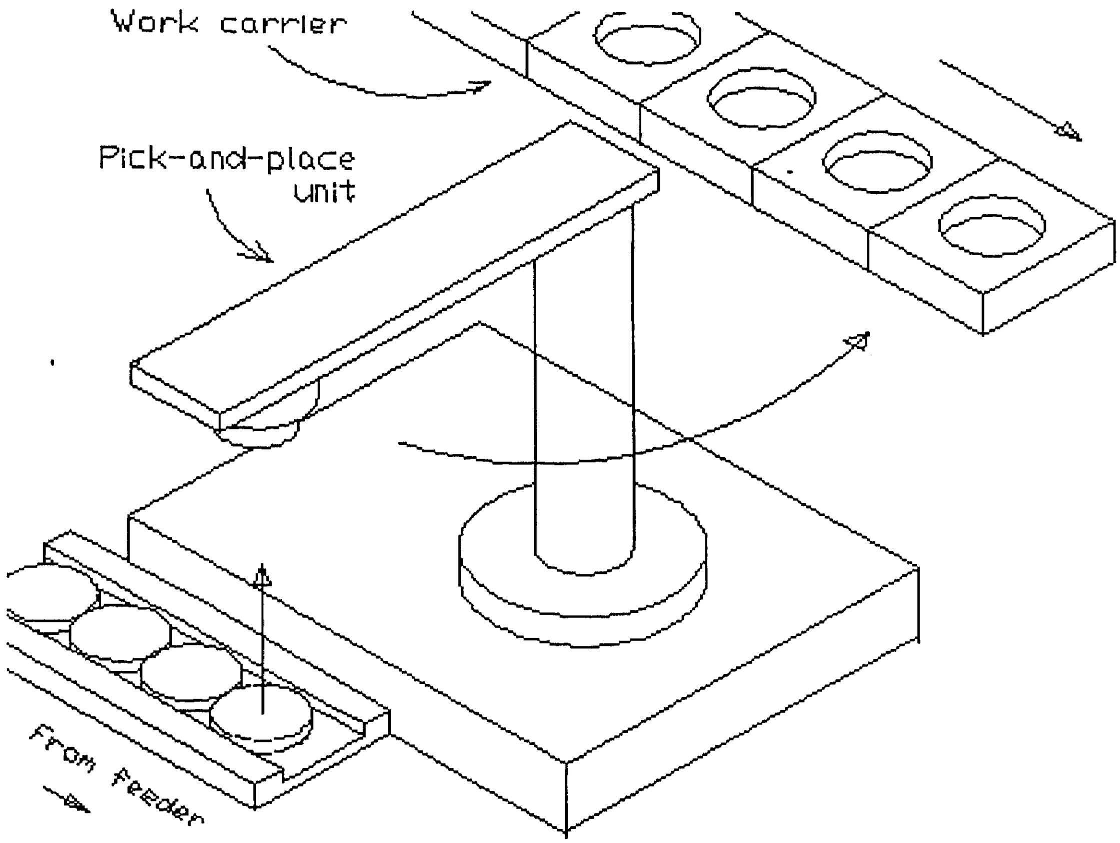


Fig. 18b: Pick and place units which lift and position the part vertically

All of the above are single-purpose placement devices. They are engineered and tooled to perform one series of functions until such time as they are re-tooled for a different job. If the operation requires a variation in the motions or functions from one machine cycle to the next, or if the total number of motions required is great, robot may be the only device to handle the operation.

CHAPTER 3 ASSEMBLY PROCESS

Assembly involves the joining together of two or more separate parts to form a new entity. The processes used to accomplish the assembly of the components can be divided into two categories:

1. PARTS MATING

In parts mating, two (or more) parts are brought into contact with each other. The variety of parts mating operations include the following assembly situations:

A. PEG-IN-HOLE

This operation involves the insertion of one part (the peg) into another part (the hole). It represents the most common assembly task. Peg-in-hole tasks can be divided into two types: the round peg-in-hole and the square peg-in-hole. the two types are illustrated in Fig. 1.

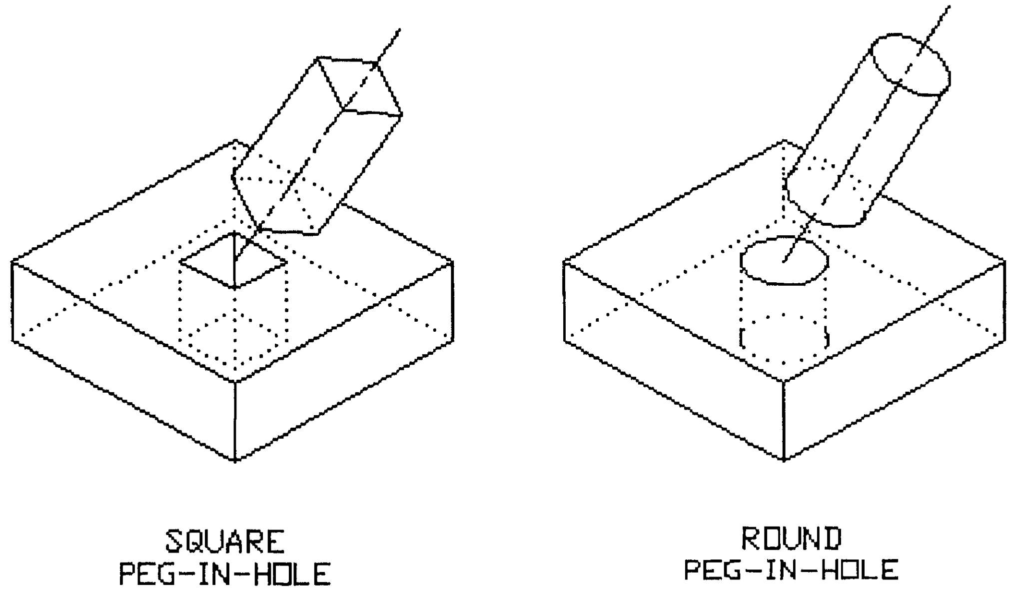


Fig. 1: Two types of peg-in-hole assembly tasks

B. HOLE-IN-PEG

This is a variation of the peg-in-hole task. A typical example of the hole-on-peg task would be the placement of a bearing or gear onto a shaft.

C. MULTIPLE PEG-IN-HOLE

This is another variation on section A except that one part has multiple pegs and the other part has corresponding multiple holes. Consequently, the assembly task always requires the ability of the assembly system to orient the parts in all directions. An example would be the assembly of a microelectronic chip module with multiple pins into a circuit card with corresponding holes. This example represents a common assembly problem in the electronics industry.

D. STACKING

In this type of assembly, several components are placed one on top of the next, with no pins or other devices for locating the parts relative to each other. In a subsequent assembly operation, the group of parts would be joined together. An example of the stacking assembly operation would be a motor armature or a transformer in which the individual laminations are stacked.

2. PARTS JOINING

__In parts joining, two (or more) parts are mated and then additional steps are taken to ensure that the parts will maintain their relationship with each other. This operation can be divided into three categories:

A. MECHANICAL FASTENING

It consists of a wide variety of techniques that employ a mechanical action to hold the components together. These techniques include:

i. Threaded fasteners

These are screws, nuts, bolts, and so on. The use of threaded fasteners is very common in industry and has the advantage of allowing the assembly to be taken apart if necessary. Threaded fasteners are readily used by human assembly workers, but are more difficult for robots and automated systems.

ii. Rivets, crimping, and other methods

The fastener or one of the components to be assembled is mechanically deformed to retain the mating part(s).

iii. Press fits

In this assembly method, there is an interference fit between the two parts that are to be mated. For example, a shaft is fitted into a hole in which the shaft diameter is slightly larger than the hole diameter. To mate the two parts, the shaft must be pressed into the hole under high pressure. Once fitted, the parts are not easily separated.

iv. Snap fits

This method involves a temporary interference of the two parts to be mated which occurs only during assembly. One or both of the parts elastically deform when pressed together to overcome the interference and permit them to snap into place. Once together, the snap fit prevents separation of the two parts. Retainers, C-rings, and snap rings are examples of available commercial hardware in this category. Mating parts can sometimes be designed for assembly by snap fitting without the need for these hardware fasteners.

v. Sewing and stitching

These are used to assemble soft, thin materials such as fabrics, cloth, leather, and thin flexible plastics.

B. JOINING METHODS

Joining method generally refers to the process of welding, brazing and soldering. In these processes, molten metal is used to fuse the two or more components together.

i. Welding:

The process of welding includes a variety of joining techniques whose common feature is that fusing and melting occur in the metal parts being joined. In some welding operations, filler metal is added to promote the joining action between the parent metals. Some of the welding processes used in industry for assembly include resistance welding, arc welding, friction welding, laser beam welding, and electron beam welding.

ii. Brazing and soldering:

Brazing and soldering are joining processes that make use of a filler metal which becomes molten for the joining process, but the metal components themselves do not melt. The distinction between brazing and soldering is usually defined by the melting point of the filler metal used in the processes. In brazing, the melting point of the filler is above $450^{O}C$, and in soldering the filler melting point is below $450^{O}C$. Because there is no fusing of the parent metals in brazing and soldering, these processes do not create as strong an assembly connection as in welding.

iii. Adhesive bonding

Adhesive bonding involves the use of an adhesive material to join components together. The use of adhesives is growing rapidly today as an assembly technology in industry, and new adhesives are being developed to satisfy new applications.

a. Thermoplastic:

Thermoplastic adhesives are easy to apply but cannot withstand high-temperature applications.

b. Thermosetting:

The use of thermosetting adhesives involves a chemical reaction that is brought on by a chemical hardener and/or heat. This assembly process is therefore more complicated than with thermoplastic adhesives, but the resulting bonds are generally stronger and capable of withstanding higher temperatures in service.

CHAPTER 4 AUTOMATED ASSEMBLY MACHINE

In automated assembly the various individual assembly operations are generally carried out at separate workstations. For this method of assembly, a system is required for transferring the partly completed assemblies from workstation to workstation, it also orients and locates the parts in the correct position for processing at each station.

1. WORKPART TRANSFER SYSTEM

The most appropriate type of transport system for a given application depends on such factors as:

i. The type of operation to be performed.

ii. The number of automated stations on the line.

iii. The weight and size of the workparts.

iv. Whether manual stations are included on the line.

v. Production rate requirements.

vi. Balancing the various process times on the line.

vii. Material handling and supply.

viii. Desired material flow.

ix. Tooling concept.

x. Motive power.

xi. Controls.

The general methods of transporting workpieces can be classified into four categories as shown as Fig. 1.

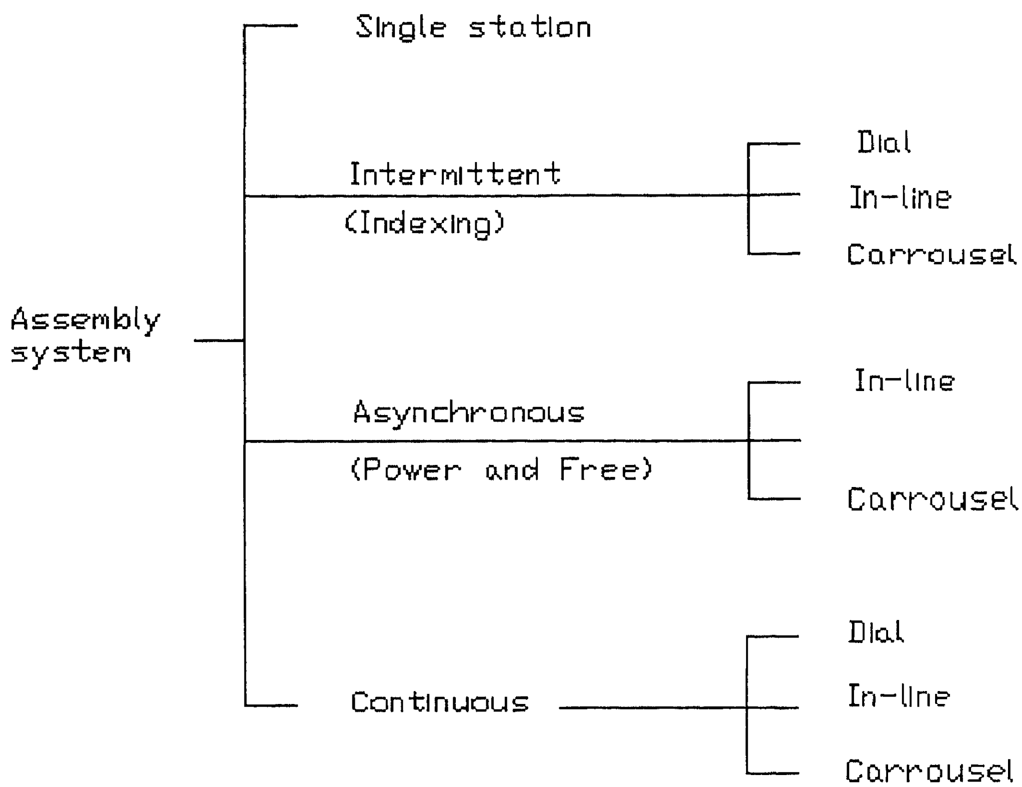


Fig. 1: Workpart transfer system

A. SINGLE-STATION SYSTEM:

The assembly operations are performed at a single location. The typical operation involves the placement of the base part at the workstation where various components are added to the base. The components are delivered to the station by feeding mechanisms, and one or more workheads perform the various assembly and fastening operations. The single-station cell is sometimes selected as the configuration for robotic assembly applications. Parts are fed to the single station and the robot adds them to the base part and performs the fastening operations.

B. INTERMITTENT TRANSFER SYSTEM:

In this method the workpieces are transported with an intermittent or discontinuous motion. The workstations are fixed in position and the parts are moved between stations and then registered at the proper locations for processing.

a. Dial-type configuration

In the typical application of dial-type configuration, base parts are loaded onto fixtures or nests that are attached to the circular dial. Components are added and/or fastened at the various workstations located around the periphery of the dial. The number of fixtures, or stations, is dependent upon the number of operations required.

The cycle consists of the process time plus indexing time. The indexing cycle time may be controlled through some uniform timing device, often used to pace an operator, or the index may be controlled on a "demand-type of basis" in which all working stations must complete their function before the dial will index.

The dial index machine offers many advantages such as the minimum floor space required, minimum number of fixtures, high speed operation. Limitations include physical size, torque required to index fixtures and parts, available space for part loading and such auxiliary equipment as hopper feeders.

A dial machine as shown as Fig. 2a.

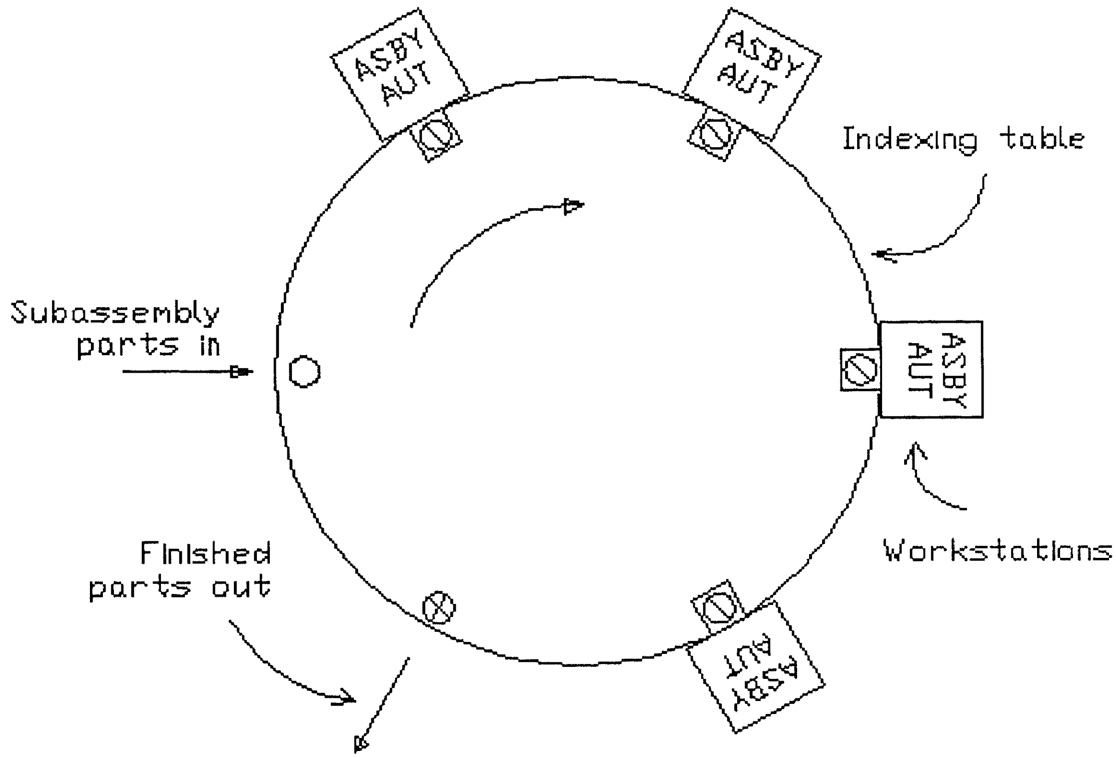


Fig. 2a: Intermittent Transfer System (dial configuration)

b. In-line configuration

The in-line configuration consists of a series of automated workstations located along an in-line transfer system. All fixtures or holding devices are moved at the same time and over the same distance resulting in all fixtures sequentially passing all stations in a straight line. Indexing intervals may be controlled by timers or they may be controlled on a "demand type basis" indexing only when all stations have completed their individual functions.

Limitations of this kind of machines include the accumulative inefficiency of many stations and the necessity for the slowest operation pacing the line.

Indexing mechanisms include air and hydraulic cylinders, Geneva motions, barrel cams, and hydro-static drives.

A in-line configuration as shown as Fig. 2b.

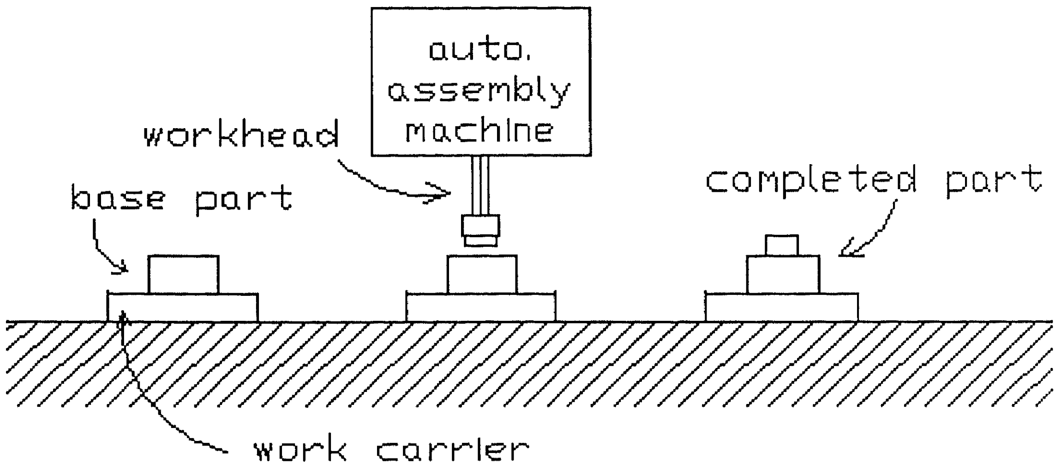


Fig. 2b: Intermittent Transfer System (in-line configuration)

c. Carrousel configuration

Like the in-line configuration, machines in this type consist of a series of fixtures or holding devices attached to chain or steel belts, or moved by fingers from one work station to another. All parts are indexed at the same time for the same distance on either a timed or demand-type basis.

Advantages of the carrousel include utilization of all the fixtures in the system; operations may be performed on all sides of the machine; and pieces are returned to the starting point. The carousel configuration is illustrated in Fig. 3.

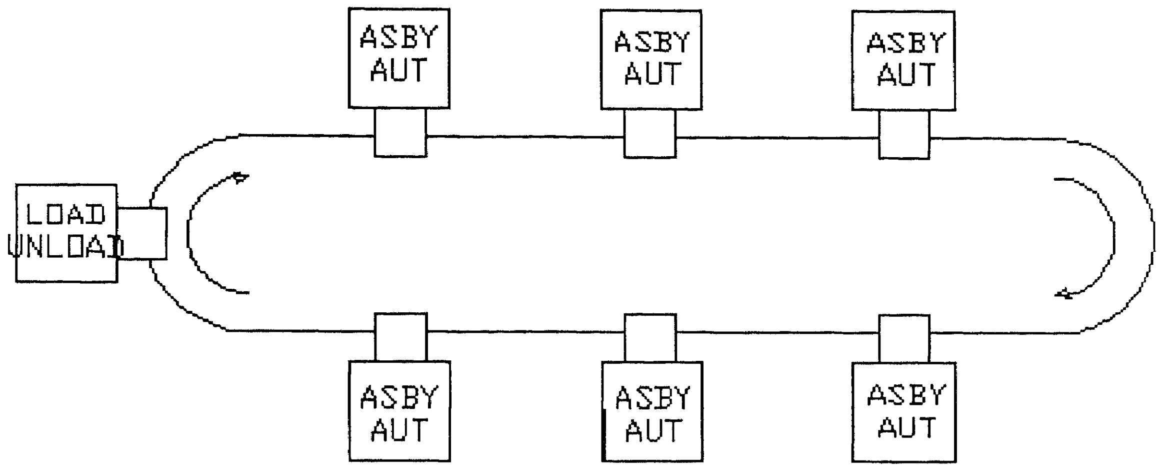


Fig. 3: Carousel assembly system

C. ASYNCHRONOUS TRANSFER SYSTEM:

This system of transfer, also referred to as a "power-and-free system," allows each workpart to move to the next station when processing at the current station has been completed. Each part moves independently of other parts. Hence, some parts are being processed on the line at the same time that others are being transported between stations.

Asynchronous transfer systems offer the opportunity for greater flexibility than do the other two systems, and this flexibility can be a great advantage in certain circumstances. In-process storage of workparts can be incorporated into the asynchronous systems with relative ease. Power-and-free system can also compensate for line balancing problems where there are significant differences in process times between stations

A disadvantage of this system is that the cycle rates are generally slower than for the other types.

a. In-line configuration

Disadvantages of space requirements and the unusable pallets which must be returned to the starting point.

b. Carrousel configuration

Advantage is utilization of all the pallets in less floor space.

D. CONTINUOUS TRANSFER SYSTEM:

With the continuous method of transfer, the workparts are moved continuously at constant speed whilst the workheads index backwards and forwards as shown as Fig. 4. In this case the assembly operations are carried out during the period when the workheads are moving forward; the workheads then return quickly to their initial positions, ready to repeat the operations during the next cycle. Continuous transfer systems are relatively easy to design and install and can achieve a high rate of production.

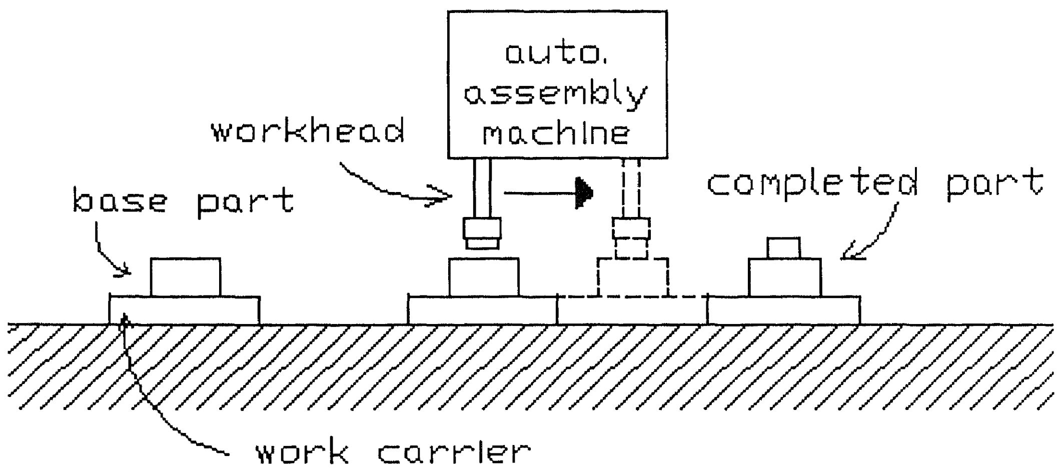


Fig. 4: Continuous transfer system

CHAPTER 5 CONTROL SYSTEM

Control is an essential ingredient in any automated production system. Transfer lines, numerical control, industrial robots, and material handling all require some form of control to ensure their successful operation.

1. CONTROL FUNCTIONS

The purposes of the various components of a control system may be arbitrarily broken down into ten categories to assist the manufacturing engineer in understanding the system:

A. ACTUATE

Actuation of a motion is the basic function of controls. Something must tell our control that it is time to go to work, usually a sensor which detects a pallet or part is in position.

B. INSPECT

It is important to know parts presence in the feed track and actual placement of the part in the assembly. Such "presence-checks" are usually made by limit switches, or noncontact devices such as proximity switches, photo-electric devices, magnetic detectors, etc. More sophisticated inspections may check additionally for dimensional integrity, hardness, leak rates, or any of a multitude of quality parameters.

C. COUNT AND STOP

A count-and-stop device which will permits the machine to keep running if the malfunction is temporary. Generally, the value of the part will indicate whether 3 or

10 or more bad assemblies can be passed along for rejection at the end of the machine. If the malfunction repeats beyond the pre-set number, the device will stop the machine, signal the operator.

D. REMEMBER

A "memory" system stores the fact that a bad assembly is in the mill. This may be mechanical "flags" on the pallets, latching relays transferring their data as the parts progress through the machine, magnetic coding of pallets or memory transferred through a programmable controller or computer.

E. LOCK-OUT

A "lockout" feature on all assembly stations can, through communication with the memory, automatically prevent any station subsequent to the malfunction from operating. No additional work will be performed on that part only as desired and programmed into the memory system.

F. INDICATE

An indicator panel indicates what is happening to the assembly system. In the event of a machine stoppage, the point of the malfunction is obvious as well as the action required.

G. RECORD

Production control has uses for production records. Departmental performance evaluation requires up-time and rate records. Quality control needs permanent records for reasons of warranty and government mandated records. Maintenance can benefit from machine performance records. Electric or mechanical counter are used to record the data normally, and computer saves these information for printout or analysis.

H. COMPUTE

An assembly may consist of measurement of several parameters and computation made to determine which of many components is required to make an acceptable part in selective assembly. Performance of an assembly may only be measured by computer analysis. It may be necessary to integrate temperature, pressure, flow, etc., to determine whether given a part meets the specifications.

I. INTERFACE

Interfacing with central computers for management information is one feature which should be considered when approaching the project.

2. TYPES OF CONTROLS

Automatic assembly controls may be divided into six main categories:

A. MECHANICAL

Mechanical controls are those devices such as levers, gears, cams pulleys and linkages which cause a specified motion or sequence of motions to occur. The major advantages lie in the simplicity of design, ease of maintenance, high speed operation, long life, ease of visual recognition of malfunctions of many sets of limit switches, relays, solenoid valves and cylinders.

The major disadvantages lie in their inflexibility and the problems associated with any change of sequence or motion in the assembly machine or system.

B. FLUID POWER

Fluid power controls have two categories: pneumatic controls and hydraulic controls.

Flexibility and low cost are generally associated with pneumatic controls while hydraulic controls are used where higher forces are involved.

C. ELECTRO-MECHANICAL

The electro-mechanical devices sense and/or alter electrical current to cause a specific motion or sequence of motions to occur.

For years, the standard for automatic assembly control was the conventional electromagnetic relay. The basic purpose of the electrical control, of course, is to provide a machine which has a maximum productivity level while at the same time providing for safety and ease in maintenance.

D. SOLID STATE

Devices which modify a large current in one circuit with a small current in another circuit with no moving parts. Also devices which sense a presence, motion, pressure or other condition and modify a current with no moving parts. The failure rate of electro-mechanical devices probably was the prime reason for the development and acceptance of solid state control devices.

Though more costly, solid state devices have provided much higher speeds in switching, space savings and energy savings over conventional relays. Plug-in designs make for rapid replacement if required.

E. PROGRAMMABLE LOGIC CONTROLLER

Automatic assembly has influenced the evolution of the programmable logic controller. Without PLC's, automatic assembly would not be nearly as sophisticated as it is today. For instance, the level of testing and gaging so common in today's assembly systems would not be practical without PLC's. The PLC consists of computer hardware which is programmed to simulate the operation or the individual logic and sequence elements that might be contained in a bank of relays, timers, counters, and other hard-wired components.

The PLC uses two techniques:

i. The first technique required Boolean Equations. In some instances, a control orientated language such as "Test Input" or "Set Output" is required.

ii. The main software technique that really made the PLC succeed was the introduction of a relay ladder format that provided the PLC with a familiar means of programming.

There are significant advantages in using a programmable logic controller rather than conventional relays, timers, counters, and other hardware elements. These advantages include:

i. Programming the PLC is easier than wiring the relay control panel.

ii. The PLC can be reprogrammed. Conventional controls must be rewired and are often scrapped instead.

iii. PLCs take less floor space then relay control panels.

iv. The PLC can be connected to the plant computer systems more easily than relays can.

F. COMPUTER

The methods of implementing computer process control can be classified into three categories:

i. Preplanned control

It refers to the use of the computer for directing the process or equipment to carry out a predetermined series of operational steps. The control sequence must be developed in advance (programmed) to cover the variety of process conditions that might be encountered. This control strategy often uses feedback control loops to make certain that each step in the operation sequence has been completed before proceeding to the next step.

ii. Direct digital control

Direct digital control (DDC) involves the replacement of the conventional analog control devices with the digital computer. The regulation of the process is accomplished by the digital computer on a time-shared, sampled-data basis rather than by many individual analog elements, each working in a continuous dedicated fashion. With DDC, the computer calculates the desired values of the input variables, and then these calculated values are applied directly to the process. DDC was originally perceived as a more efficient means of carrying out the same types of control actions as the analog elements that it replaced. The digital computer is considerably more versatile with regard to the variety of control calculations that it can be programmed to perform. Hence, direct digital control offers not only the opportunity for greater efficiency in doing the same job than analog control, it also opens up the possibility for increased flexibility in the type of control action, as well as the option to reprogram the control action should that become desirable.

Components include transducers, sensors, process interface devices, digital computer, analog-to-digital and digital-to-analog converters, and multiplexers to share signals from different loops with the same computer.

iii. Supervisory computer control

Supervisory computer control denotes a control system in which the computer seeks to optimize some performance objective for the process. Supervisory control represents a higher level of control than preplanned control, direct digital control, or the more conventional analog control. IN general, these three types of control systems can be considered to be process-level computer control methods, in that they operate directly on the process. This relationship between supervisory control and the process-level control techniques is illustrated in Fig. 1.

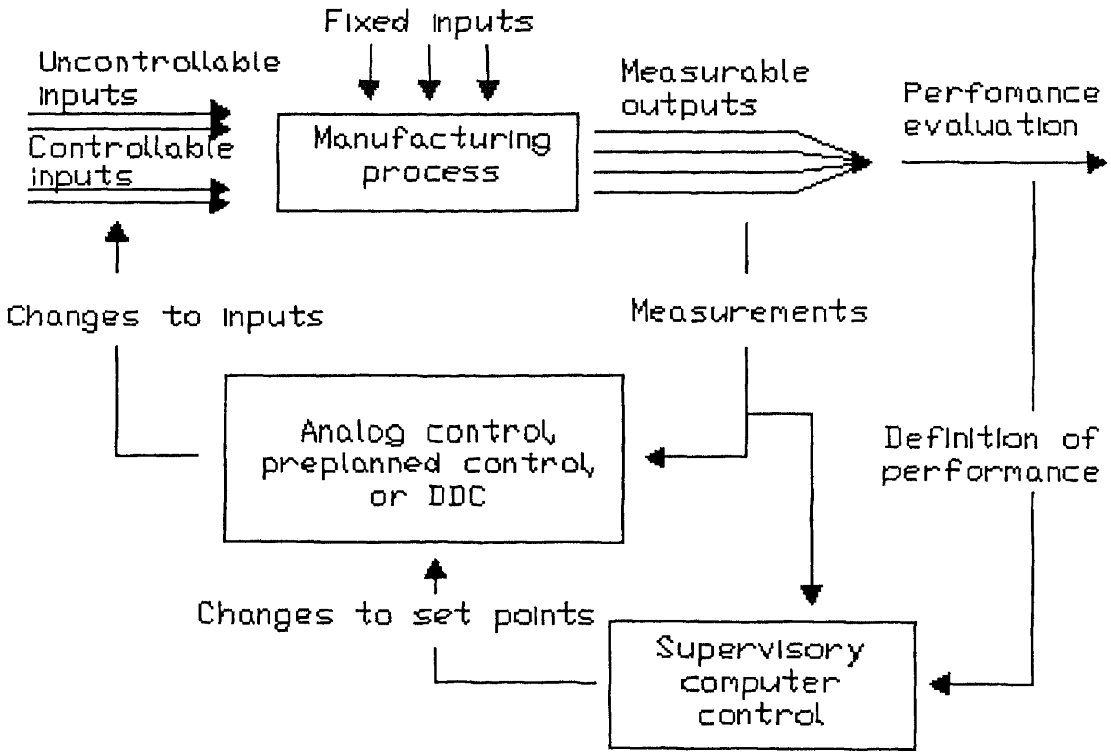


Fig. 1: Relationship between supervisory computer control and process-level computer control

CHAPTER 6 ROBOT APPLICATION

Automated assembly systems have traditionally been applied to high-volume products in which a large investment is made in custom-engineered equipment, designed to perform the specific operations required for those products. However, over 70 percent of products manufactured in the United States are produced in batches. In these cases, it is not economically feasible to make large investments in specialized assembly equipment. Programmable and flexible systems, including robotic, must be applied to these low and medium volume assembly operations if automation is to be successfully achieved. (Robots are usually at a disadvantage in the high-production situations because they cannot perform as quickly as the fixed automation system.)

1. ROBOT APPLICATIONS

Robots are employed in a wide assortment of applications in industry. Today most of the applications are in manufacturing to move materials, parts, and tools of various types. For the present, most industrial applications of robots can be divided into the following three categories:

a. MATERIAL HANDLING APPLICATION:

Material handling applications are those in which the robot moves materials or parts from one location and orientation to another. To accomplish the transfer, the robot is equipped with a gripper type end effector. The gripper must be designed to handle the specific part or parts to moved in the application. In nearly all material handling applications, the parts must be presented to the robot in a known position and orientation. This requires some form of material handling device to deliver the parts into the workcell in this defined position and orientation.

Future robots, equipped with appropriate sensors, may be able to deal with random entry of parts into the cell.

The robot-centered cell is most commonly used for this application category. The workcell consists of one or more production machines, the robot, and a material handling mechanism for delivering parts into and/or out of the cell.

b. PROCESSING APPLICATIONS

This category includes spot welding, arc welding, spray painting, various machining and other rotating spindle processes. Processing applications are those in which the robot performs a processing operation on the part. A distinguishing characteristic of this category is that the robot is equipped with some type of tool as its end effector. To perform the process, the robot must manipulate toe tool relative to the part during the work cycle. In these instances, either a gripper or a quick-change mechanism is used to exchange the tools during the work cycle.

c. ASSEMBLY AND INSPECTION

Assembly and inspection are growing application areas for industrial robotics. Assembly and inspection applications can involve both the handling of materials and manipulation of a tool. For example, assembly operations typically involve the addition of components to build the product, which requires material handling. In some cases, the fastening of the components requires a tool to be used by the robot. Similarly, some robot inspection operations require that parts be manipulated and other applications require that an inspection tool be manipulated.

Assembly and inspection are traditionally labor-intensive activities in industry. For these reasons, they are logical candidates for robotic applications. However, assembly work typically involves diverse and sometimes difficult tasks, often requiring adjustments to be made in parts that do not quite fit together. A sense of feel is often required to achieve the close fitting of parts that is required. Inspection work requires high precision and patience, and human judgment is often needed to determine whether a product is within quality specifications or not.

The most appealing area for the application of industrial robots for assembly is in the production of a mixture of similar products or models in the same workcell or assembly line. Examples of these kinds of products include electric motors, small appliances, and various other small mechanical and electrical products. In these examples, the basic configuration of the different models is the same, but there are variations in size, geometry, options, and other features. These types of products are often made in batches on manual assembly lines. However, the pressure to reduce inventories has made mixed-model assembly lines more attractive. Robots can be used to substitute for some or all of the manual workstations on these lines.

2. ROBOT CELL DESIGN

Industrial robot applications usually involve several pieces of hardware in addition to the robot. These other hardware components include conveyors, pallets, machine tools, fixtures, and so on. It is important that the equipment in the cell be organized into an efficient layout. There are three basic types of workcell layout:

a. ROBOT-CENTERED CELL

The robot locates at the approximate center of the workcell, and the other pieces of equipment are arranged around it. This type of cell layout is suited to installations in which there is a single robot servicing one or more production machines.

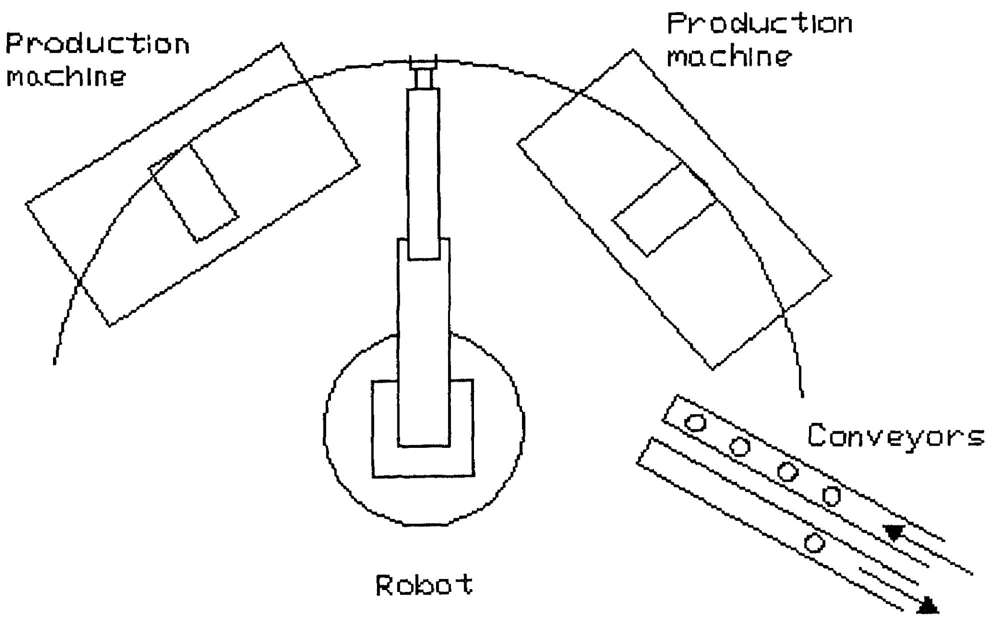


Fig. 1: Robot-centered cell

b. IN-LINE ROBOT CELL

In this arrangement, one or more robots are located along an in-line conveyor or other material transport system. The work is organized so that parts are presented to the robots by the transport system, and each robot performs some processing or assembly operation on each part. The in-line robot cell design is typified by the welding lines used to spot-weld car bodies in the automotive industry.

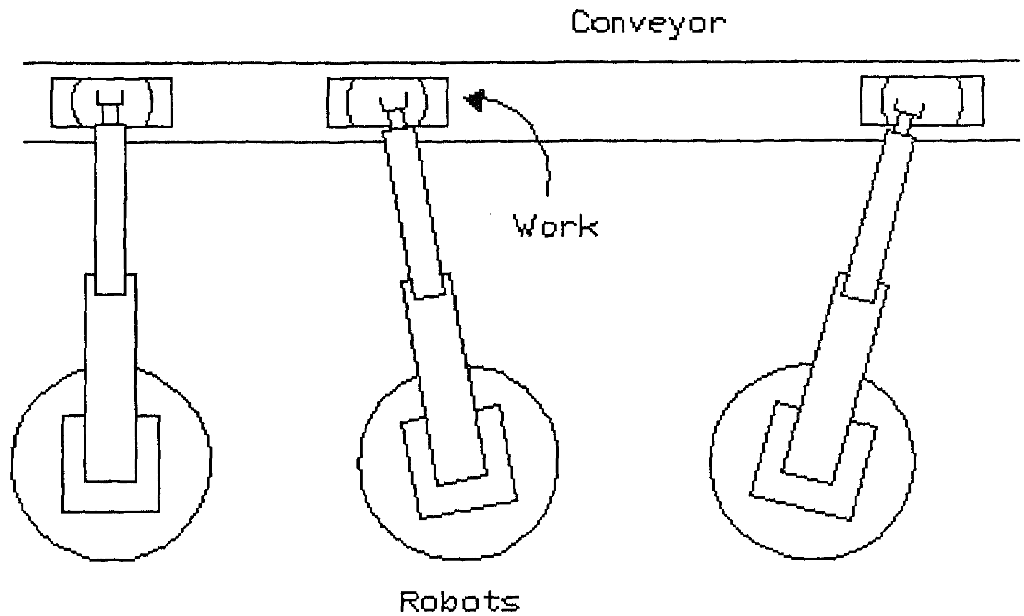


Fig. 2: In-line robot cell

c. MOBILE ROBOT CELL

In this arrangement, the robot is provided with a means of being transported within the cell to perform various tasks at different locations. The transport mechanism consists of either a floor-mounted or overhead rail system that allows the robot to be moved along a linear path. The mobile robot cell is appropriate in installations where the robot must service more than one workstation, and the workstations cannot be located around the robot in a robot-centered cell arrangement.

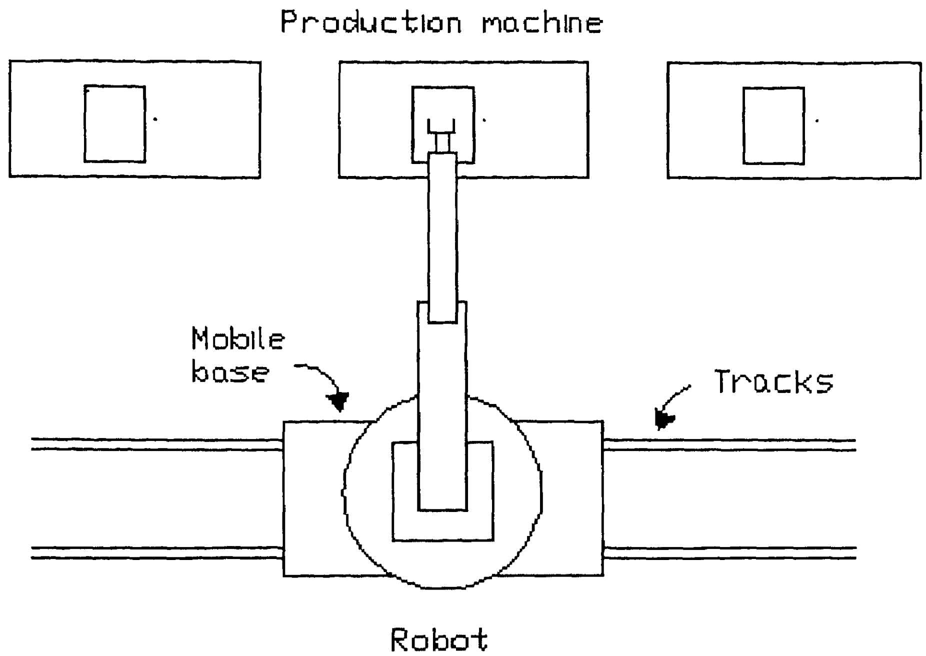


Fig. 3: Mobile robot cell

3. ROBOT CONTROL SYSTEMS

_In order to operate, a robot must have a means of controlling its drive system to properly regulate its motions. commercially available industrial robots can be classified into four categories according to their control systems:

a. Limited-sequence robots

Limited-sequence robots are controlled by setting limit switches and/or mechanical stops to establish the endpoints of travel for each of their joints.

Applications for this type of robot generally involve simple motions, such as pick-and-place operations.

b. Playback robots with point-to-point control

Point-to-point robots are capable of performing motion cycles that consist of a series of desired point locations and related actions. The robot is taught each point, and these points are recorded into the robot's control unit. During playback, the robot is controlled to move from one point to another in the proper sequence. Point-to-point robots do not control the path taken by the robot to get from one point to the next.

c. Playback robots with continuous path control

Continuous-path robots are capable of performing motion cycles in which the path following by the robot is controlled. This is usually accomplished by making the robot move through a series of closely spaced points which describe the desired path. Some robots have the capability to follow a smooth, curved path that has been defined by a programmer who manually moves the arm through the desired motion cycle.

d. Intelligent robots

Intelligent robots have the capability to play back a programmed motion cycle as well as interact with its environment in a way that seems intelligent. Intelligent robots can alter their programmed cycle in response to conditions that occur in the workplace. They can make logical decisions based on sensor data received from the operation. The robots in this class have the capacity to communicate during the work cycle with humans or computer-based systems.

4. ROBOT PROGRAMMING

There are various methods used for programming robots. The two basic categories of greatest commercial importance today are leadthrough programming and textual language programming.

a. Leadthrough programming

Leadthrough programming requires the operator to move the robot arm through the desired motion path during a teach procedure, thereby entering the program into the controller memory. Powered and manual are two methods of performing the leadthrough teach procedure.

Powered leadthrough is commonly used as the programming method for playback robots with point-to-point control. Using the teach pendant, the programmer power drives the robot arm to the desired positions, in sequence, and records the positions into memory. Powered leadthrough is the most common programming method in industry at this time.

Manual leadthrough is convenient for programming playback robots with continuous path control in which the continuous path is an irregular motion pattern such as in spray painting. This programming method requires the operator to physically grasp the end-of-arm or tool attached to the arm and manually move through the motion sequence, recording the path into memory.

The advantage offered by the leadthrough methods is that they can be readily learned by shop personnel. It is not necessary for the programmer to possess a background in computer programming.

The disadvantages of the leadthrough programming methods are that it requires use of the robot must be interrupted during the leadthrough programming procedures, and it is limited in terms of the decision-making logic that can be incorporated into the program.

b. Textual programming

The textual programming provides some important functions that leadthrough programming cannot readily accomplish:

i. Enhanced sensor capabilities, including the use of analog as well as digital inputs and outputs.

ii. Improved output capabilities for controlling external equipment.

iii. Program logic control far beyond the capabilities of leadthrough methods.

iv. Computations and data processing similar to computer programming languages.

v. Communications with other computer systems.

An enhancement of textual language programming is to enter the program completely off-line, without the need for a teach pendant to define point locations in the program. The potential advantage of this method is that the programming can be accomplished without taking the robot out of production.

CHAPTER 7 AUTOMATED MATERIAL HANDLING

The purpose of material handling in a factory is to move raw materials, work-in-process, 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, efficiently at low cost, in a timely manner, accurately, and without damage to the materials. The cost of material handling is a significant portion of the total cost of production. Estimates of handling cost run as high as two-thirds of the total manufacturing cost.

1. PRINCIPLES OF MATERIAL HANDLING SYSTEM DESIGN

Certain principles have been developed to provide guidance in the design of a materials handling system:

A. UNIT LOAD PRINCIPLE

Materials to be moved should be aggregated into a larger unit size, and the unit size should be the same for all materials. The materials are typically placed on a pallet or other standard-sized container for convenience in handling. The materials and container are referred to as the unit load. The unit load should be as large as practical.

B. AVOID PARTIAL LOADS

Transport the full unit load whenever possible rather than partial loads. Load the material handling equipment to its maximum safe limit.

C. SHORTEST DISTANCE PRINCIPLE

Movements of materials should be over the shortest distances possible. Realization of this principle generally depends on the plant layout design.

D. STRAIGHT-LINE FLOW RULE

The material handling path should be in a straight line from point of origination to point of destination.

E. MINIMUM TERMINAL TIME PRINCIPLE

Movement of a unit load consists of the move time plus the time required for loading, unloading, and other activities that do not involve actual transport of the materials. Minimize these nonmove times.

F. GRAVITY PRINCIPLE

Use gravity to assist the movement of materials to the extent possible, at the same time giving consideration to safety and risk of product damage.

G. CARRY LOADS BOTH WAYS

The handling system should be designed and scheduled, to the extent possible, to carry loads in both directions. Return trips with empty loads are wasteful.

H. MECHANIZATION PRINCIPLE

Manual handling of materials should be avoided. The handling process should be mechanized where possible to increase efficiency and economy.

I. SYSTEMS PRINCIPLE

Integrate the materials handling system with other systems in the facility, including receiving, inspection, storage, production and assembly, packaging, warehousing, shipping, and transportation.

J. SYSTEMS FLOW PRINCIPLE

Integrate the flow of material with the flow of information in handling and storage systems. The information for each item moved should include identification, origination point, and destination point.

K. PART ORIENTATION PRINCIPLE

In automated production systems, the orientation of the workpart should be established and maintained throughout the material handling process.

2. TYPES OF MATERIAL HANDLING EQUIPMENT

The material handling equipment can be divided into two categories in automated production systems:

A. CONVEYORS

Large family of handling devices, often mechanized, sometimes automated, designed to move materials between specific locations over a fixed path, generally in large quantities or volumes, such as gravity conveyors and powered conveyors. The powered conveyors are frequently used as components in automated systems of material movement and storage. Conveyor systems are typically associated with high production where the flow of materials is along a fixed path. The major types of conveyors are the following:

i. Roller conveyors

ii. Skate-wheel conveyors

iii. Belt conveyors

iv. Chain conveyors

v. Overhead trolley conveyors

vi. Slat conveyors

vii. In-floor towline conveyors

viii. Cart-on-track conveyors

B. AUTOMATED GUIDED VEHICLE SYSTEMS (AGVs)

Battery-powered, automatically steered vehicles designed to follow defined pathways. Some are capable of automatically loading and unloading unit loads. Usually interfaced with other automated systems to achieve full benefits of integrated automation. An AGV system is suitable in applications where different materials must be moved form various load points to various unload points. The AGV system therefore holds the promise of being a suitable means of automating the material handling function in bath production and even job shops. AGV systems are being used in a growing number of assembly-line applications. In these applications, the production rate is relatively low (perhaps 4 to 10 min per station in the line) and there are a variety of different models made on the production line. Between the workstations, components are kitted and placed on the vehicle for the assembly operations that are to be performed on the partially completed product at the next station. The workstations are generally arranged in parallel configurations to add to the flexibility of the line.

The main components of the AGVs are:

i. The truck or tractor, pallet truck, tow skid basic type.

ii. The floor system with the installation of the wire guidance system, and the information transfer system.

iii. The load transfer equipment which can be both on board the truck and/or in a stationary position, including the station structure.

iv. The truck and traffic control system.

The industry is continually working to develop new AGV systems in response to new application requirements. An example of a new evolving AGVs design involves the placement of a robotic manipulator on an automated guided vehicle to provide a mobile robot for performing complex handling tasks at various locations in a plant. These robot-vehicles are seen as being useful in clean rooms in the semiconductor industry.

CHAPTER 8 AUTOMATED STORAGE SYSTEMS

Storage systems are finding increased application in assembly. The storage system is used to store parts for assembly of the product or its subassemblies. When an order for assembly is received, the required components are retrieved from storage, collected into kits, and delivered to the production floor for assembly.

1. ADVANTAGES OF AUTOMATED STORAGE SYSTEM

Installation of an automated storage system may be achieved the following objectives:

i. Increase storage capacity

ii. Increase floor space utilization

iii. Recover space for manufacturing facilities

iv. Improve security and reduce pilferage

v. Reduce labor cost in storage operations

vi. Increase labor productivity in storage operations

vii. Improve safety in storage function

viii. Improve control over inventories

ix. Increase stock rotation

x. Improve customer service

xi. Support of just-in-time production

xii. Act as buffer storage

xiii. Compatible with automatic identification systems

xiv. Greater control and tracking of materials

2. CAROUSEL STORAGE SYSTEMS

A carousel storage system is a series of bins or baskets fastened to carriers that are connected together and revolve around a long, oval track system. The track system is similar to a trolley conveyor system. Its purpose is to position bins at a load/unload station at the end of the oval. The typical operation of the storage carousel is mechanized rather than automated. The load/unload station is manned by a human worker who activates the powered carousel to deliver a desired bun to the station. One or more parts are removed from the bin, and the cycle is repeated. A typical carousel storage system is illustrated in Fig. 1.

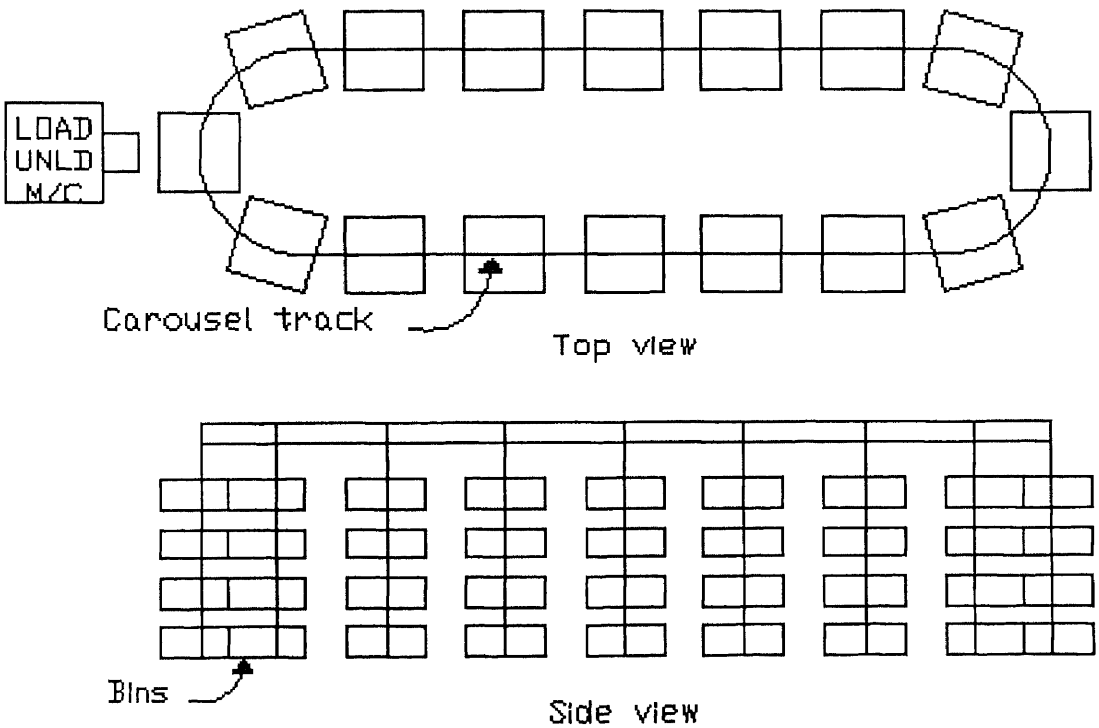


Fig. 1: Layout and elevation of a typical storage carousel

Computer controls are implemented using various computer configurations, from microprocesser-based controllers for individual carousels to centralized dedicated mini-computers that control multiple carousels. The features that are provided by means of computer control include the capability to maintain data on bin locations, items in each bin, and inventory control records.

A carousel storage system used with assembly workstations is shown in Fig. 2. Workstations located around the continuously moving carousel load and unload work from the storage bins during the course of their assembly operations.

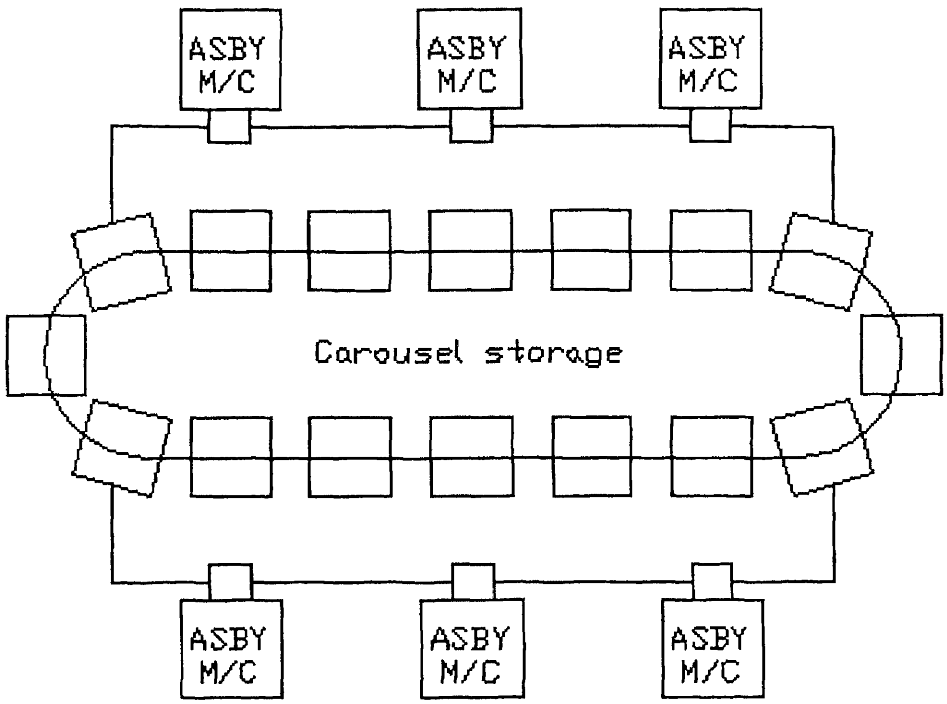


Fig. 2: Carousel storage used with assembly workstations

3. AUTOMATED STORAGE/RETRIEVAL SYSTEMS

The AS/RS 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/R systems. the P&D stations can be manually operated or interfaced to some form of automated handling system, such as a conveyor system or AGVs. A typical AS/RS is illustrated in Fig. 3.

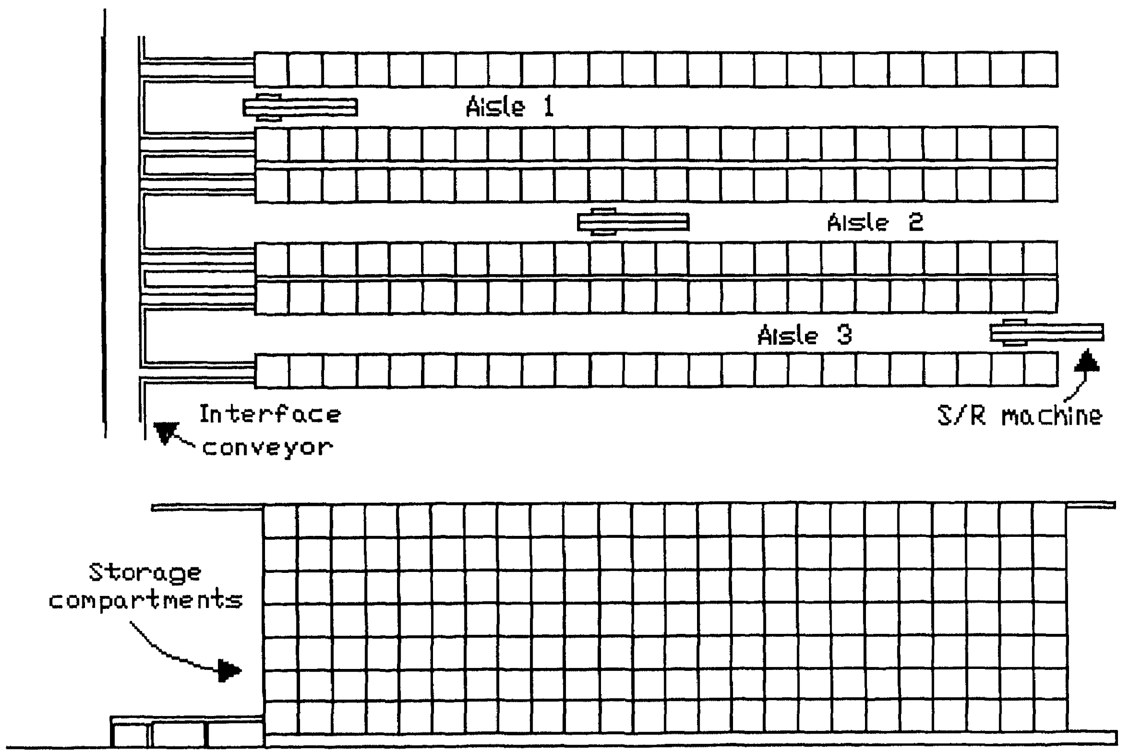


Fig. 3: Layout and elevation of a typical unit load AS/RS

Computer controls and programmable controllers are used to determine the required location and guide the S/R machine to its destination. Computer control permits the physical operation of the AS/RS to be integrated with the supporting information and record-keeping system. Storage transactions can be entered in real time, inventor records can be accurately maintained, system performance can be monitored, and communications can be facilitated with other factory computer systems. These automatic controls can be superseded or supplemented by manual controls when required under emergency conditions or for man-on-board operation of the machine.

An AS/RS used with assembly workstations is shown in Fig. 4. An AGVs might be used to delivery unit loads (e.g., individual parts on pallets or tote pans of parts) to the individual machine in a batch production plant.

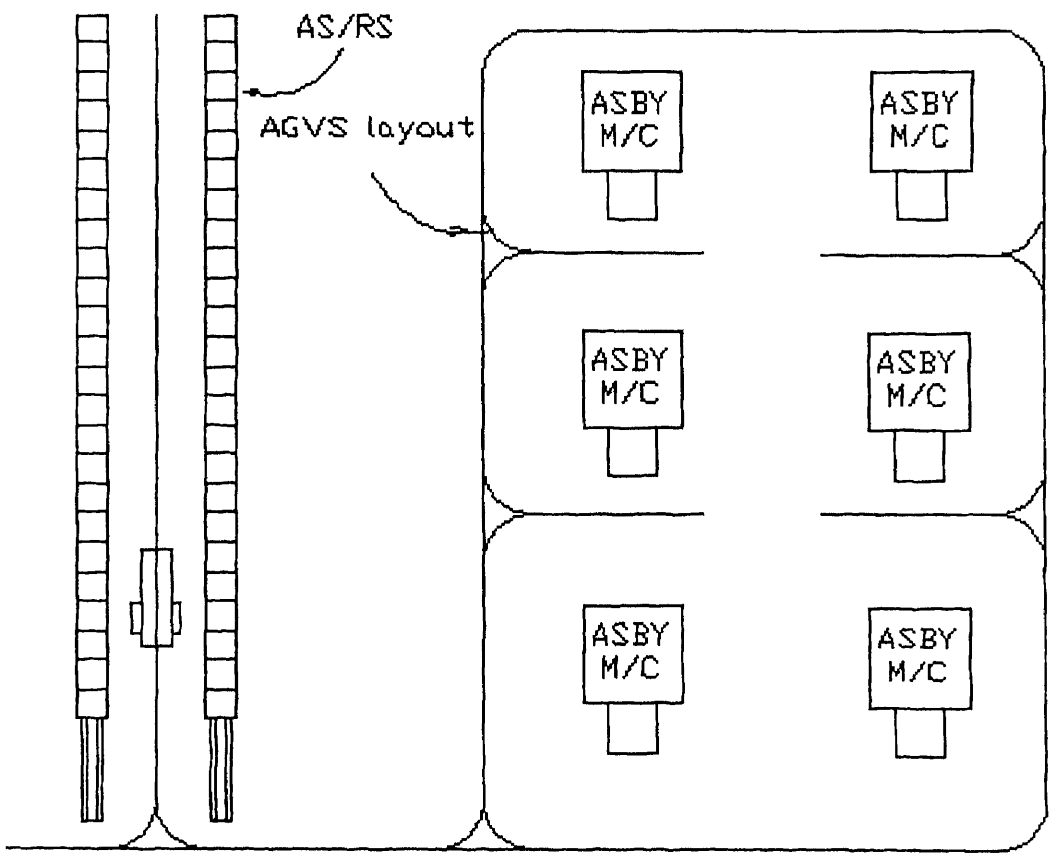


Fig. 4: AS/RS used to deliver unit load to machine cell

4. INTERFACING HANDLING AND STORAGE WITH MANUFACTURING

The interface problems of storage and manufacturing system can be divided into two categories:

A. INFORMATION INTERFACE

The Information interface is concerned with the flow of information that must accompany the movement and storage of materials in the factory. It encompasses the problems of materials identification and tracking, inventory control, production scheduling, and the data communications required to coordinate and control the various systems in the plant.

B. MECHANICAL INTERFACE

The mechanical interface deals with the problems of transferring parts and loads between storage systems, material handling systems, and production systems. The load transfer function is an integral part of any material handling system. The design of the mechanical interface depends on the type of handling equipment used, the system that is to be interfaced with the handling system, and whether the load/unload procedure is to be done manually or automatically. In automatic load transfer, the positional accuracy will determine whether the transfer operation can be accomplished successfully. The following value provide tolerances on stopping accuracies required for different mechanical interfaces:

Interface	*Tolerance (in.)*
Manual load/unload	± 3
Conveyor/AGVS interface (automatic)	± 1
AS/RS load/unload (automatic)	± 0.25
Machine tool interface (automatic)	± 0.01

Accuracies of ± 0.01 in. are possible with certain types of conveyors and guided vehicles, but they require some type of positive location mechanism to accomplish the accuracy. The design of the locator device is often based on using a tapered pin that seats in a mating hole in the carrier. As the pin is pressed into the hole, it forces the carrier into accurate alignment at the station.

CHAPTER 9 SIMULATION

There has been a dramatic increase in the use of simulation in manufacturing during the past few years. Increased international and national competition in many industries has resulted in a greater emphasis on using automation to improve productivity and quality and also to reduce cost. Since automated systems are often quite complex, they typically can be analyzed only by a powerful tool like simulation. Reduced computing costs and improvements in simulation languages have also led to increased use of simulation. Finally, the availability of graphical animation has resulted in greater understanding and use of simulation by industries.

1. THE ADVANTAGES AND DISADVANTAGES OF SIMULATION

Here are some of the advantages of simulation:

i. Realism.

ii. Nonexistent systems.

iii. Time compression.

iv. Deferred specification of objectives.

v. Experimental control.

vi. Reproducibility of random conditions.

vii. Training.

viii. Winning over the client.

ix. Inexpensive insurance.

Along with its many advantages, simulation is subject to important disadvantages. Among them are these:

i. Failure to produce exact results.

ii. Lack of generality of results.

iii. Failure to optimize.

iv. Long lead times.

v. Costs for providing a simulation capability.

vi. Misuse of simulation.

2. OBJECTIVES IN SIMULATION OF MANUFACTURING SYSTEMS

A. BENEFITS OF SIMULATION IN MANUFACTURING

The general benefit of simulation in manufacturing is that it allows managers to obtain a system wide view of the effect of changes on their manufacturing system (whether it exists or not). Specific benefits of simulation in manufacturing are increased throughput, reduced in-process inventories, increased utilization of machines and workers, increased on-time deliveries and reduced capital requirements.

B. MANUFACTURING ENVIRONMENTS IN WHICH SIMULATION IS APPLIED

The following are three situations in which simulation is applied in manufacturing:

i. New equipment and buildings are required.

ii. New equipment is required in an old building.

iii. Upgrading of existing equipment or its operation.

C. MANUFACTURING ISSUES THAT SIMULATION IS USED TO ADDRESS

i. The need for and the quantity of equipment and personnel.

ii. Performance evaluation.

iii. Evaluation of operational procedures.

D. MEASURES OF PERFORMANCE USED IN MANUFACTURING SIMULATION STUDIES

i. Throughput.

ii. Time in system for jobs.

iii. Time jobs spend in queues.

iv. Time that jobs spend being transported.

v. Sizes of in-process inventories.

vi. Utilizations of equipment and personnel.

vii. Proportion of time that a machine is blocked.

viii. Proportion of jobs produced which must be reworked or scrapped.

xi. Return on investment for a new or modified manufacturing system.

x. Payback period.

3. SIMULATION SOFTWARE

Simulation modelling involves creating a model using computer software. There are three basic possibilities to obtain a working model:

A. WRITE YOUR OWN PROGRAM, IN A GENERAL-PURPOSE COMPUTER LANGUAGE SUCH AS FORTRAN, PASCAL AND C ETC.

The advantages of using a general-purpose language are that the language is probably already known by the analyst, that the required computer execution time may be less than for a model written in a simulation language since the program is tailor-made for the application. The disadvantage is it takes a long time to develop.

B. ACQUIRE A SIMULATION PACKAGE AND WRITE THE MODEL IN THAT LANGUAGE

The principal advantage of these systems is that, several man-years having generally gone into their development, they provide powerful aids to modeling. They also provide a structure within which the model will be developed and once a programmer is used to this way of thinking. Their cost may be considerable, up to about $60,000, but this is small in comparison to the benefits which can be obtained from their use. Because of the need to acquire skill in their use, packages may be more appropriate for use by someone who is going to specialize in simulation rather than the manufacturing engineer who has many responsibilities and regards simulation as just one of his tools. The following list of functions which should be provided by a simulation package:

i. The timing control mechanism.

ii. A data base or file structure.

iii. A method of defining the initial conditions in the model.

iv. Random number generation and sample from distributions.

v. Record observations, analyze results and print reports.

vi. Display histograms and other forms of chart of results.

vii. Error checks and diagnostics.

viii. Display the state of the model at any point in time.

C. ACQUIRE AND USE AN ALREADY WRITTEN GENERIC MODEL

A generic model is a model of a specific type of system written in such a way that certain parameters can be altered by the user through the data. For example, a generic manufacturing system model might ask the user to define the number of machines in the system to be modelled, and then proceed using that information. The authors of these kind of models have studies a large number of systems and have included in the program as many as possible of the features which that type of system may exhibit. This avoids completely any computer programming, and only requires a data deck to be "punched-up" by the user, so they are usually easily learned by non-specialits, such as manufacturing engineers. The disadvantage is incapable of handling some special features of real systems.

4. APPROACHING TO MODELLING

There are three main approaches to modeling:

A. THE ACTIVITY-BASED APPROACH

A diagram representing the flow of the logic performed by the "executive" routine is given in Fig. 1. After initializing the model, the executive routine searches for the next time when an activity is due to be completed, and moves its clock to that time. The changes which result from that activity completion are performed, and then a scan of the activities is dome to see which, if any, can be started at that time. After scanning all the activities, the clock time is advanced again until the run is complete.

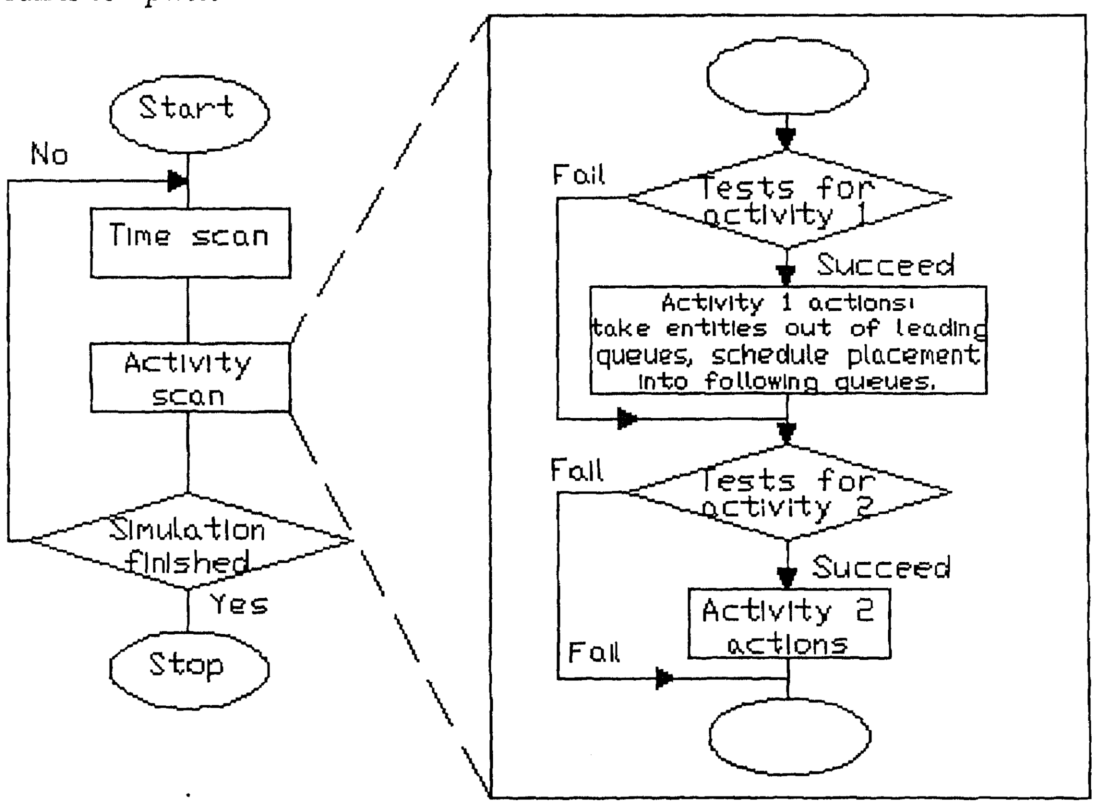


Fig. 1: Flow diagram for activity-based executive program

B. THE EVENT-BASED APPROACH

Fig. 2 gives a flow-chart for an event-based executive. In the event approach a program segment is written to define every event in the model. After initializing the model, the executive routine scans the times for each scheduled bound event and moves the clock to the time of the next event to occur. It then calls the routine to process the changes to be made to the model as a result of that event. There will be a routine for each bound event. Following a bound event, the conditions may allow one or more conditional events to occur. There will normally be a routine for each conditional event, which includes the tests to determine whether the conditions permit that event to occur, and if so the actions to be performed. These actions include making the changes resulting from the event, which corresponds to an activity beginning, and scheduling the bound event corresponding to the end of the activity.

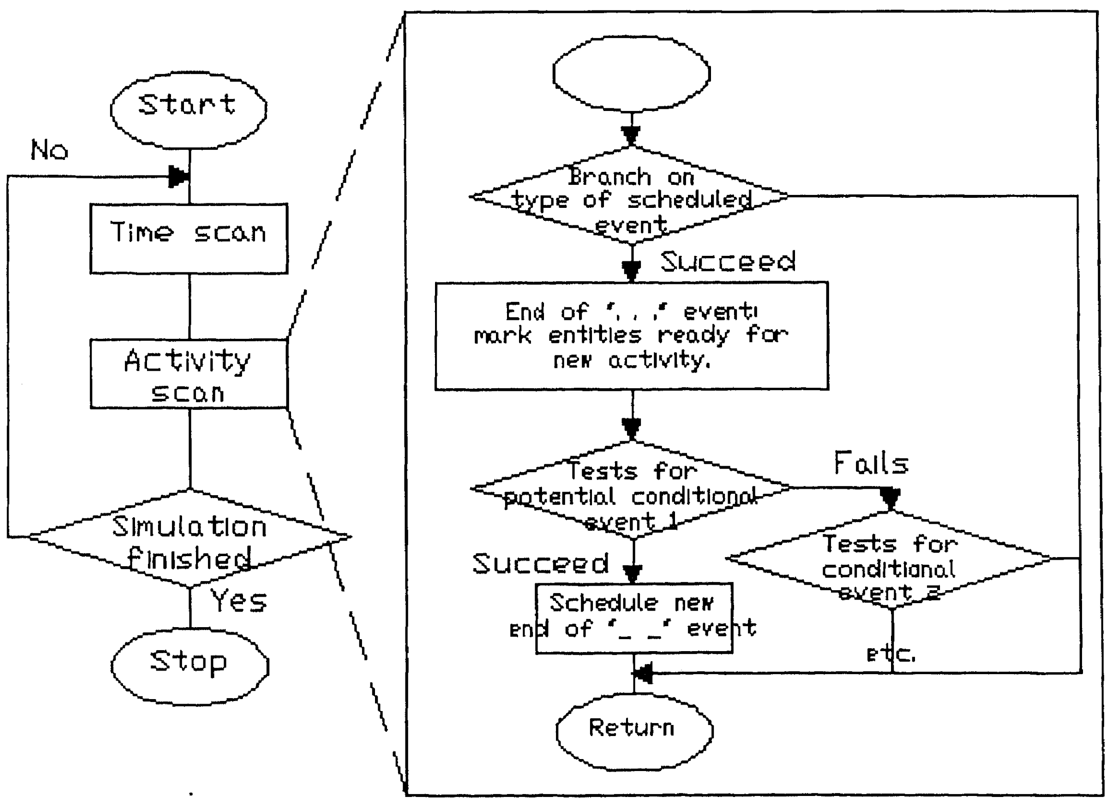


Fig. 2: Flow diagram for event-based executive program

C. THE PROCESS-BASED APPROACH

In this approach, also known as the process-interaction approach, the entities are classified into transactions or customers and facilities or resources, corresponding roughly to temporary and permanent entities. Process routines are defined which describe the processes undergone by each transaction. A process routine typically includes the creation of the entity, and then a series of queueing for, seizing and then releasing the facilities it requires in its passage through the system, and finally the destruction or disposal of the entity.

5. JUST-IN-TIME CONTROL SYSTEMS

Most manufacturing firms are embracing the ideals of Just-in-time manufacture. This requires a new approach to organizing manufacturing operations. Flexible manufacturing is a key technique for achieving the reduction in lead time and work in progress levels which JIT methods aim at. One of the effects of this change is that manufacturing systems are now required to operate on a pull method rather than on a push basis. This change in approach demands a re-think about simulation modelling of manufacturing systems. As with manufacturing systems, many simulation models are based on the push principle. Jobs to be processed arrive in the system -- they are pushed into it. Then the logic of the model tests the queues and discovers whether operations can take place, so that the job is pushed one further stage along its way to completion. Finally the job reaches the completion of its last operation and leaves the system. To implement the JIT approach we need a method of pulling work through the system. To do this in a simulation model is no easier or no more complicated than it is in real life -- the decision rules must be framed to suit. New packages will be developed which approach the model building process from this standpoint.

CHAPTER 10 SYSTEM DESIGN AND PROBLEM STATEMENT

The previous chapters discuss most of the automated assembly concepts and equipment. The task of a manufacturing engineer is to implement these concepts to the design of an optimal manufacturing system. Although there is no clear concept of a manufacturing system, the manufacturing engineers depends upon the viewpoint, the nature of the industry, the latest available technologies and the type of product to design a system.

1. FLEXIBLE ASSEMBLY SYSTEM

The competition of the world market and the development of new technologies change the environment of industry. Manufacturing engineers must devise new strategies to deal with this new environment. The old strategy of mass production is no longer seen as valid and is being discarded in favour of a strategy which facilitates flexibility, reduced design cycle time, reduced time to market for new products and reduced order cycle time to the customer for existing products. Some important characteristics of this new environment are:

i. Increased product diversity.

ii. Greatly reduced product life cycles.

iii. Decreased labor cost.

iv. Short throughput time.

A. FLEXIBLE ASSEMBLY SYSTEM

The characteristics of the new environment can not be fulfilled by conventional automated assembly systems. This systems are mainly designed for assembling large quantities of one product. Product changes or supplementary versions, which often result in a new assembly sequence, therefore usually necessitate complex conversion measures with regard to the existing system, sometimes it is impossible to adapt the assembly system to the new assembly sequence. For a solution of the mentioned problem, fully automated, flexible assembly systems have been developed by many manufacturers. The purposes of the system are to achieve a highest possible degree of automation together with a highest possible flexibility of the assembly system. Flexible system can also be thought of as a distributed management information system linking together intelligent sub-systems of machining, welding, painting, flame cutting, sheet metal manufacturing, inspection, assembly materials handling and storage processes.

The required features of the flexible automated assembly system are:

i. Automatic operation of the overall system -- unmanned factory.

ii. Assembly of different products/assemblies in any desired piece numbers and batch sizes.

iii. Automatic material flow.

iv. Automatic resetting and changeover.

v. Workpieces identification.

vi. Positioning and orientation.

All subsystems of the flexible assembly systems are working automatically and to a high extent, applicable on various products. The flexible linking structure guarantees less break-downs and makes the assembly system independent of specific assembly processes. An automatic material flow between warehouse, respectively preceding and subsequent manufacturing sectors and the assembly system as well as an automatic resetting of the sub-systems to carry out new tasks enables a fully automated operation of the whole system. Identification of workpieces guarantees the trouble-free performance of order-picking, pelletization and assembly operations.

B. THE ECONOMIC JUSTIFICATION OF FAS

FAS provides the following benefits if designed and used successfully:

i. Greater productivity, which means a greater output and a lower unit cost.

ii. Quality is improved because the product is more uniform and consistent.

iii. The intelligent, self-correcting system (i.e. machines equipped with sensory feedback systems) increase the overall reliability of production.

iv. The flexible materials handling and storage system provides an automated inventory system with considerably lower levels of stock and materials handling.

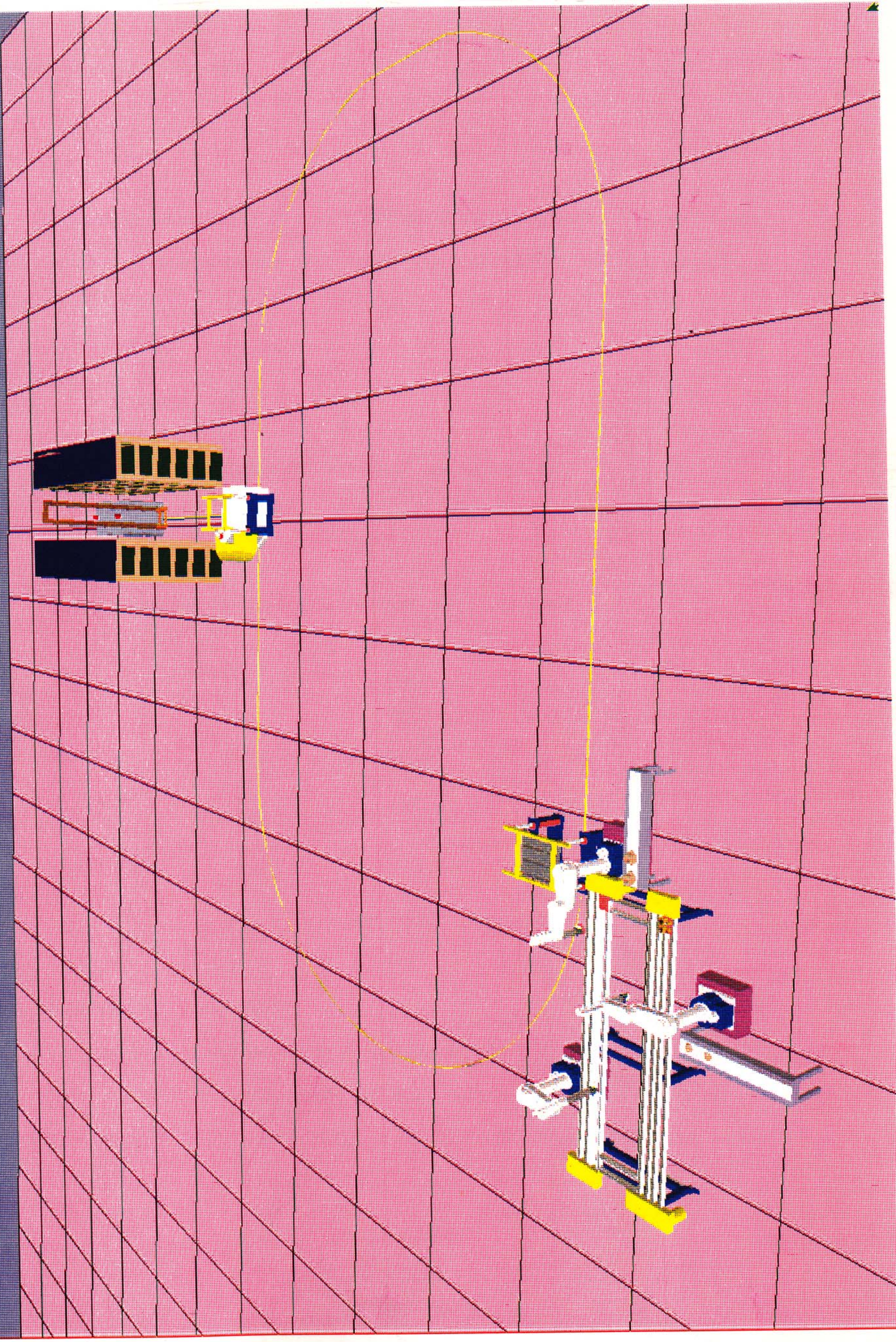
v. Parts can be randomly produced in batches of one or in reasonably high numbers and the lead time can be reduced.

2. STATEMENT OF THE PROBLEM

Future flexible assembly systems will be designed for automatic operation in 3 shifts with automatic flow of materials between warehouse and assembly system as well as automatic resetting for different products. The systems will be programmable assembly cells and order-picking cells with industrial robots, and a flexible interlinking system with automated guided vehicles.

A. WORKCELL LAYOUT

Based on the concepts of flexible assembly system, a particular automatic assembly system is arranged as per attached figure. It comprises three robots, AS/RS, AGV, automatic material loading/unloading mechanism and conveyor systems.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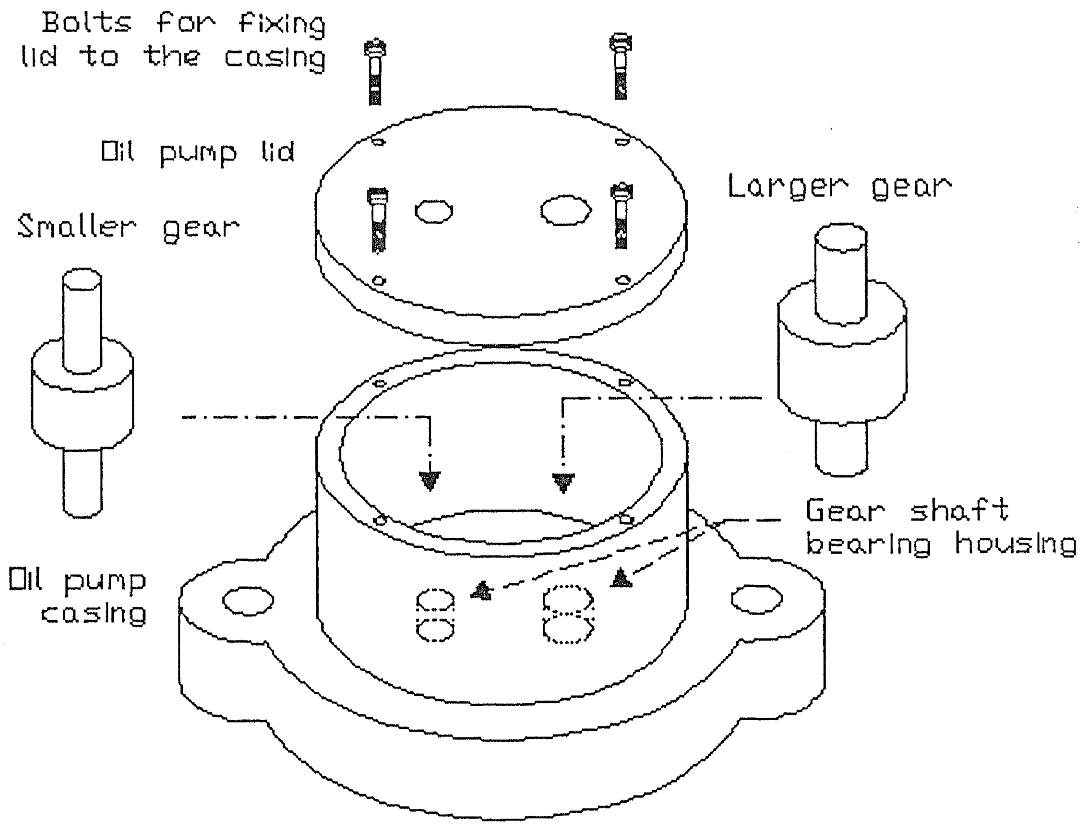

Fig. 2: Oil pump components

C. OPERATION OF THE SYSTEM

A robot picks a pump casing from a supply conveyor and places it on a jig on the inner loop conveyor. The pump casing is then transferred to the second robot for gears and

lid assembly. The unfinished pump moves along the loop to the third robot, the task of this robot is fastening. The completed assembly pump is then moved to the first robot, this robot picks and places it on the pallet. A AGV transfers the pallet to AS/RS for storage.

D. SYSTEM APPROACH

As mentioned in chapter 9, simulation is a powerful tool to assess the performance of a complex production systems and to identify their design flaws and operation problems, especially animated graphics computer software.

The cost of the basic Adept robot used at RPI, without the vision system or specialized software, is approximately US$60,000. The cost of the conveyor system is approximately US$35,000. In this high investment situation, simulation is a good way to study the system before installation or to avoid the interruption of the production.

A user friendly animation package -- IGRIP will be used to build and analysis the assembly system. The assembly operation will be observed briefly, as well as part design, feeding and orientation etc..

CHAPTER 11 IGRIP SIMULATION SYSTEM

The use of animated computer graphics is becoming a powerful tool for the simulation and analysis of the manufacturing workcell and complete flexible factory design. It gives the manufacturing engineer the ability to design the most flexible and cost effective work cells through simulation. Complete factory layout and simulation in real or accelerated time will provide the basis for production control and material handling processes promoting perfect "Just in Time" manufacturing.

1. INTRODUCTION OF IGRIP SOFTWARE PACKAGE

IGRIP software package is a computer graphics system used for workcell layout, simulation and off-line programming.

Devices used in the workcells may be added by modeling them within the Part Modeler. Parts generated on other CAD systems may be read in via the IGES, DES or other input data translators that are provided with the IGRIP package.

Parts are put together to define devices with multiple degree of freedom. A device has both geometric and non-geometric information stored with it. Non-geometric information including kinematics, dynamics, velocities etc. can be entered through interactive menus.

A workcell is composed of devices, positioned relative to each other. Devices used in the workcell may be selected from a library of robots, conveyors, tables, end-effectors, and other devices provided with the system, or modeled by the user.

IGRIP has the capability to generate robot programs interactively. Once the workcell has been created, programs can be developed with the sure observing immediate program statement execution. Several devices can be simulated simultaneously. Input/Output signaling can be set up between devices during a simulation. In addition, collisions between any of the devices in the cell may be detected, displayed, and recorded automatically as the simulation proceeds.

2. ADVANTAGES AND DISADVANTAGES OF IGRIP

A. ADVANTAGES

i. off-line programming

After a program is created in computer terminal, and the operation is correctly and smoothly, the program can be downloaded to the machines or robots. So the production of the machines and robots can not be interrupted. It saves production time and cost.

ii. Observation

IGRIP uses CAD system to build the model as per real world system, so some constraints or obstacles of the system are found easily. This function provides IGRIP as a powerful tool for plant layout design.

B. DISADVANTAGES

i. High installation cost

The hardware and software of IGRIP cost US$160,000. Compare with other simulation package such as GPSS, SIMAN, WITNESS or SIMFACTORY, the cost of these packages is US$10,000 - US$30,000 only.

ii. Time consuming for building the model

Programer must spend long time to study the manufacturing system, take measurement of the machines or robots, find out the degree of freedom of the motion components of the machine, define the path of movement, and the speed, compare with other system, sometimes cycle time is the only element to run a simulation model.

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CHAPTER 12 EXAMINATION OF THE SYSTEM HARDWARE AND SOFTWARE

The assembly system as per attached graph in chapter 10 consists of two components -- hardware and software.

1. EXAMINATION OF THE HARDWARE SYSTEM

There is one AGV, one AS/RS, one conveyor system (two conveyors transfer sub-assembly parts is not under consideration), two automatic material loading/unloading mechanism, and three robots.

A. THE COMPONENTS OF THE SYSTEM

i. AGV

AGV transfers completed assembly part from robot assembly cell to AS/RS for storage.

It communicates with robot, AS/RS, and material handling mechanisms. After it receives a signal from robot, it moves along the guide path from its home position to assembly workcell. After a pallet is loaded on the platform by loading mechanism, it moves to AS/RS.

ii. Conveyor System

The conveyor system is configured into inner loop and outer linear tracks. The inner loop transfer base part of the assembly component, when it moves along the loop, it stops at each robot location, the robot picks sub-assembly part from outer track for assembly.

The conveyor system is power-and-free type. The assembly part carrier is held at work station while the installation is completed and then release by a robot. This type of conveyor system is very suitable for manual assembly system. The conveyor may be stopped by a worker using a "quality stop", at his or her work station. The workers are responsible for maintaining quality standards in their area, so if they need more time to complete the work, they have the ability to halt the line to effect corrections.

The model of the conveyor system is based on the configuration of the conveyor system of 'Center for Advanced Technology in Automation and Robotics, Rensselaer Polytechnic Institute'. Supplementary information is enclosed in Appendix 2.

iii. AS/R System

The AS/RS machine likes a forklift. It connects with material handling mechanism, when it receives a signal from the mechanism, it moves forward to pick the pallet which contains some completed assembly parts and then moves backward to a specified location of the shelf for storage.

iv. Material Handling Mechanisms

One mechanism in workcell grabs the pallet, when it receives a signal from AGV, it moves downward and releases the pallet on the platform of the AGV. Another mechanism in AS/RS receives a signal from AGV, it lowers to grab the pallet and sends a signal to AS/RS.

v. Robot

One robot picks the pump housing on the inner loop of the conveyor system, it also picks the completed oil pump and places it on the pallet and sends a signal to AGV.

The second robot's task consists of manipulating the gears from their initial position and inserting them into their respective bearing housings and then grasps the lid for assembly. Because there are screws fastening, so the third robot holds screw driver is arranged in the down stream of the production line.

The SCARS (Selective Compliance Assembly Robot Arm) type robot Adapt1.Q12.A5 robot is selected. The configuration of SCARS provides substantial rigidity for the robot in the vertical direction, but compliance in the horizontal plane. This makes it ideal for many assembly tasks.

B. ASSEMBLY OPERATION

i. Gear Assembly

In order for the robot's assembly task to be successful, it is necessary that the trajectory of the gear shaft follows a predefined path relative to the bearing housing. It is therefore necessary to utilize sensing to indirectly and directly obtaining the correct position and orientation of the gear shaft and the oil pump casing before the gear insertion. Direct measurements includes measuring the relative orientation of the gear shaft with respect to the bearing housing during the insertion process. In these instances the sensing operation is being used to verify and calibrate the manipulation. A RCC (Remote Center Compliance) is necessary for gear insertion.

ii. Lid assembly

A sensor indicates that the lid is to be located, then the robot moves to grasp it. The robot then approaches the pump housing, and aligns the lid's coordinate frame with that of the pump housing. The robot raises and loweres the lid to ensure the lid is mated with pump housing and the gear shafts are inserted into the lid's bearing housings.

iii. Securing the Lid With Bolts

There are two ways in which a robot can perform the screw-fastening operation:

a. It can drive the screw by advancing and simultaneously rotating its wrist.

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easily creat simple objects by invoking CAD Primitives. CAD Primitives include BLOCK, CYLINDER, CONE, WEDGE, PIPE, SPHERE, and Surface of Revolutic (SOR), which all produce ploygon based data. Insert line, Circle, and Helix operators produce wire frame data that can be polygonalized if desired. Each invocation of these primitive operators produces a "new", that is, additional object in the scene which may be independently selected and operated on separately from the other objects in the scene. For example, objects can be translated and rotated relative to each other in the creat part workspace. Objects can be saved together as one static entity or as separate entities.

The decomposition drawing is enclosed, there are thirty eight pieces to compose the mechanism. The mechanism seperates into two parts, the upper and the lower part. The upper part has up and down movement, and the lower part do not have any movement. When the mechanism creates in CAD stage, it is important to separate these two parts in two different files, otherwise, the upper part can not have a motion or two parts move as one part.

ii. Device

The upper and lower part of the mechanism are retrieved, and comprise these two parts as one device, then define the degree of freedom (DOF) and kinematic for the upper part, in order to program the motion of this part later. These two parts must in the correct location according to the workcell layout.

iii. Layout

Path and tag points are created to control the motion path and record the positions. Input/Output connections permit devices' activities to be coordinated with other activities in the workcell.

Tag points and I/O connections act as sensors, relays, or limit switches in real world manufacturing system.

iv. Motion

The Graphic Simulation Language, GSL -- procedural language is used to construct programs for the devices in a simulation to govern their actions and behavior. GSL syntax is similar to that of Pascal, with specific enhancements for device motion, display control, viewpoint choreography, and simulation environment inquires.

v. Miscellaneous

Other menus such as Dimension, User, Analysis and System support the model building and analysis.

B. PROGRAMMING

Compare with the model building, programming is a easy task. You do not type a text, most of the commands you can see on screen. You move a mouse to a desired command then press a mouse button, the on-line intruction will tell you the sequences step by step. Most of the command inputs just press a few times of mouse button. There are eleven programs for this automated assembly system:

i. Program for AGV
ii. Program for robot1
iii. Program for robot2
iv. Program for robot3
v. Program for gearsupply
vi. Program for caseing supply
vii. Program for AS/RS and flok
viii. Program for material handling mechanism (at AS/RS)
ix. Program for material handling mechanism (at robotic cell)
x. Program for pallet

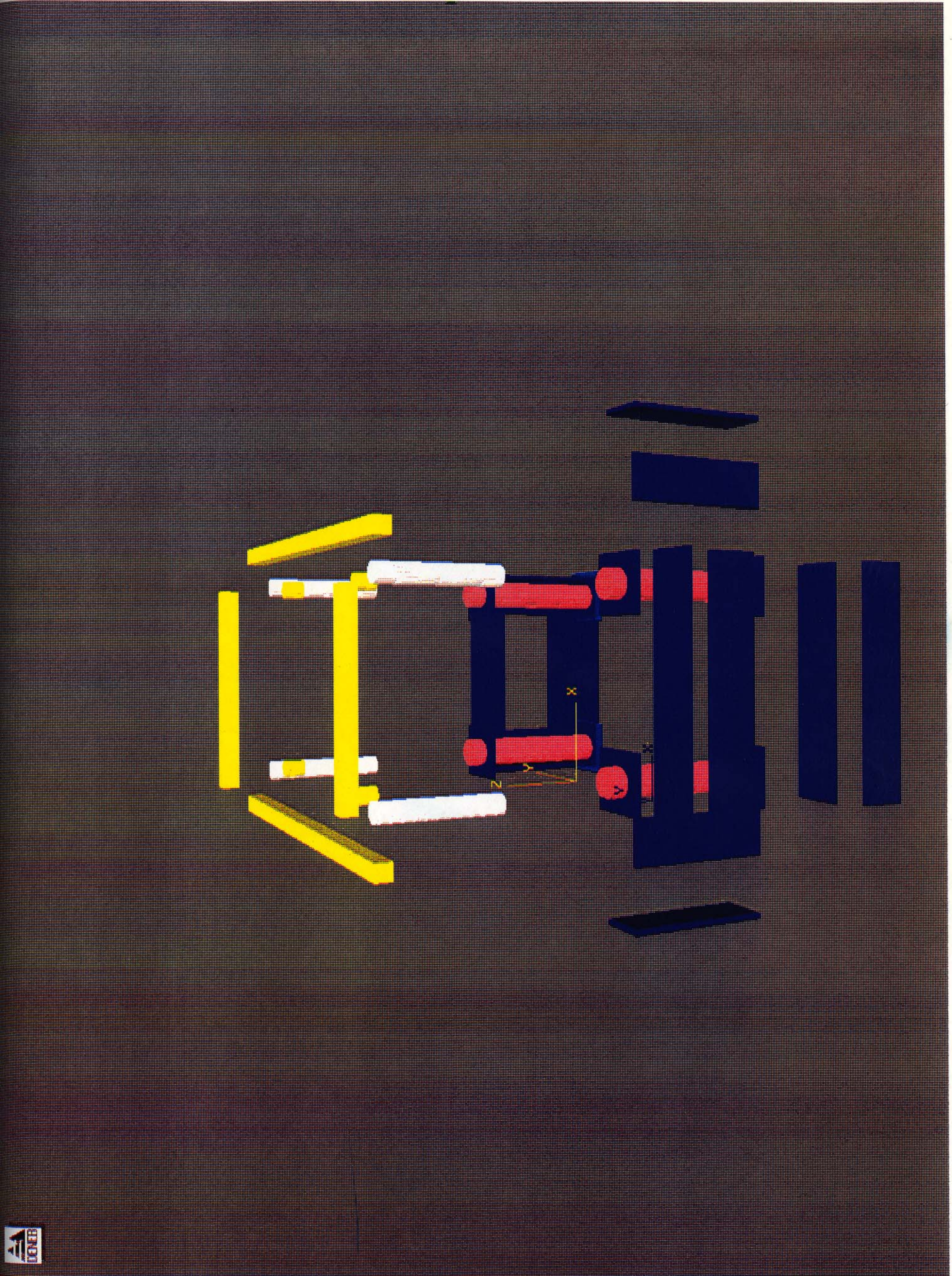
The programs are attached in Appendix 1.

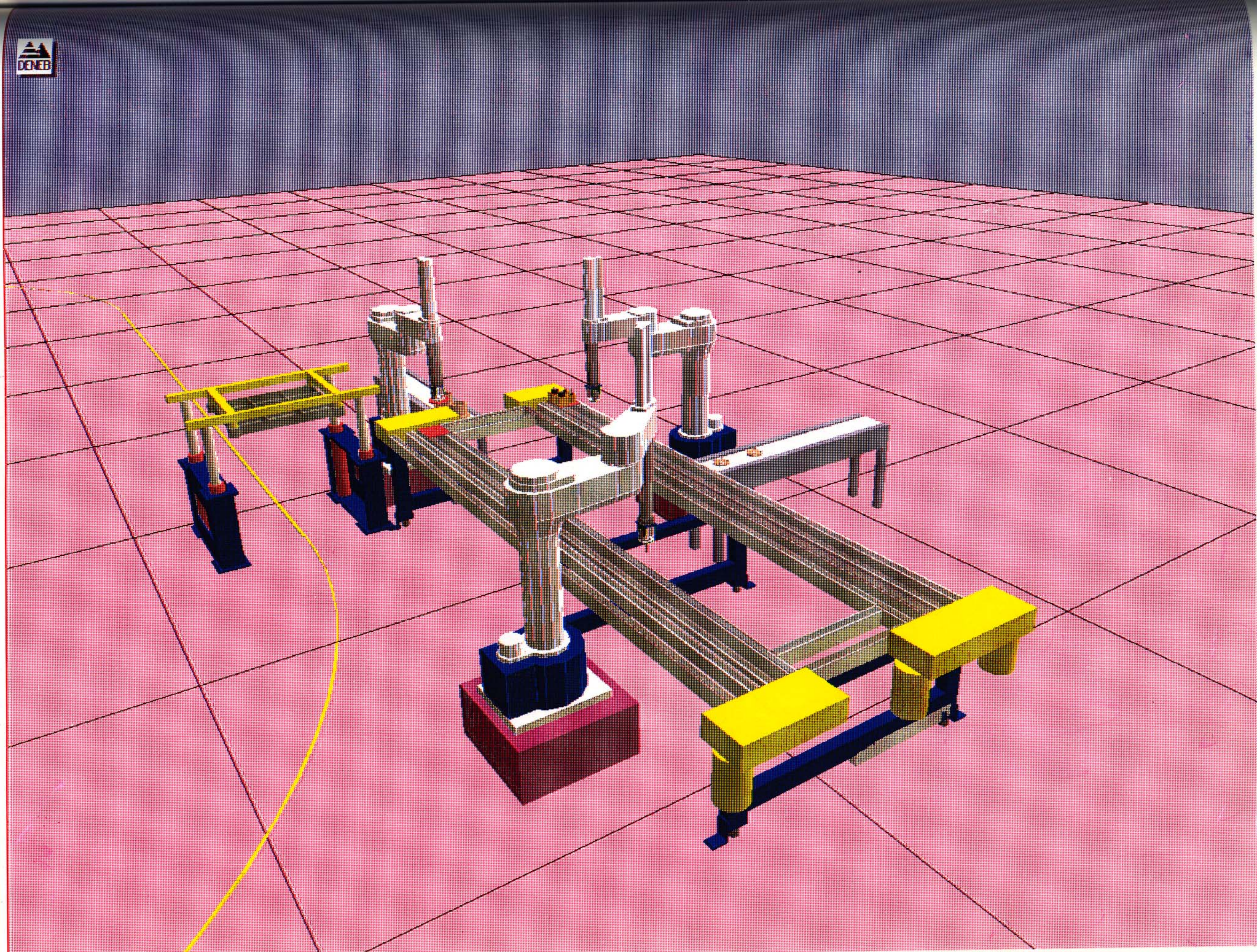
The conveyor system does not have program, the movement is jig and fixture (plates transfer base parts and sub-assembly parts along the conveyor system), not the conveyor system.

The IGRIP package is available in Room 2320 Informtech Building, NJIT. The program of this thesis is under the user *ijp1597*, workcell directory *khk*, and the file name is *msthesis*.

C. RESULT ANALSYIS

As mentioned in Chapter 11, IGRIP does not provide any statistical analysis result, such as down time, idle time, production rate and efficiency. The main purpose of using IGRIP in this thesis is to get hands-on experience to implement animated computer graphic in manufacturing.

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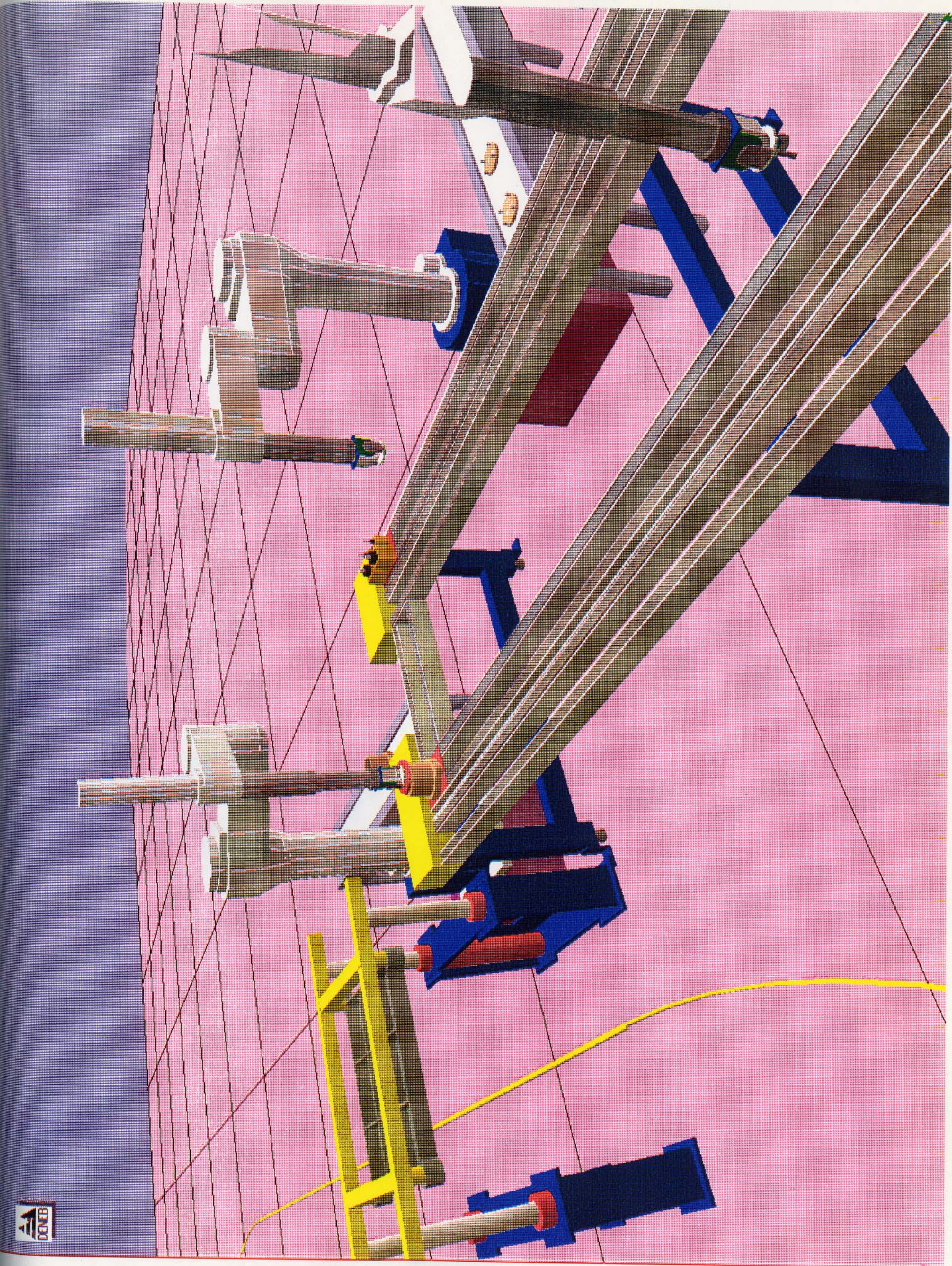
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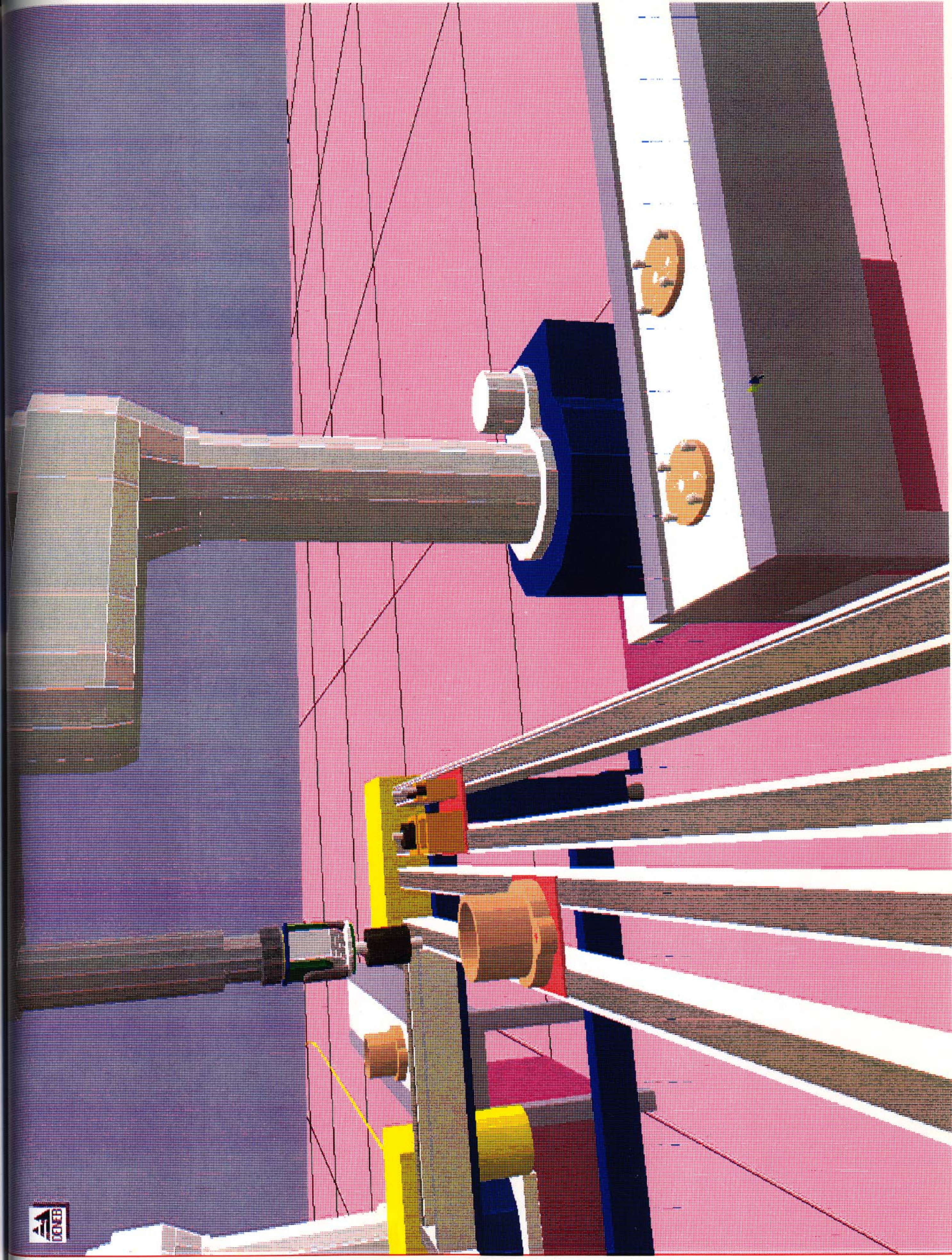
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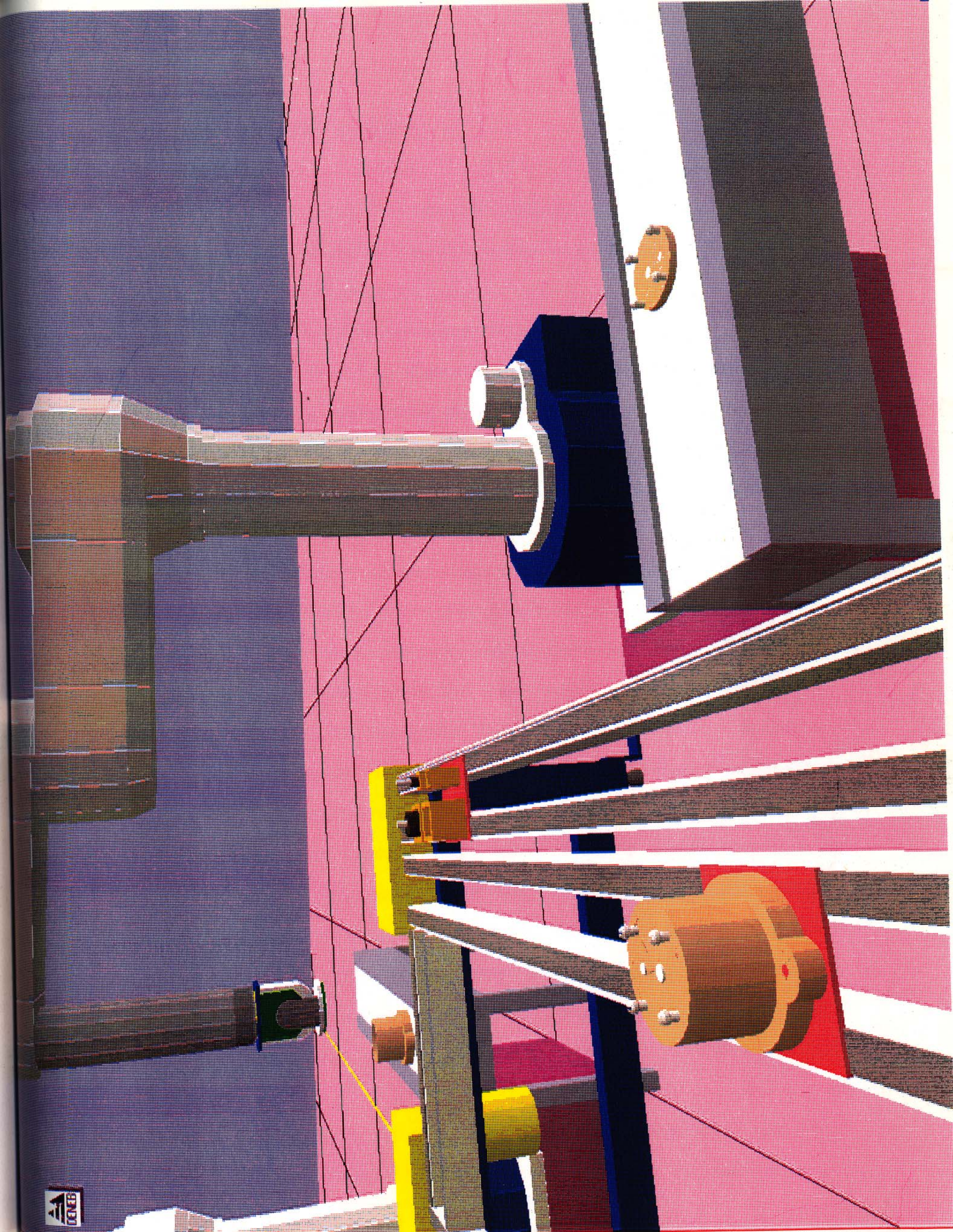

CHAPTER 13 CONCLUSION

The main purpose of simulation of flexible manufacturing system are:

i. To access the capacity and equipment utilization in the system.

ii. To identify the bottlenecks in the system.

iii. To compare the performance of alternative designs.

iv. To ensure that there are no fundamental weakness in the FMS design.

v. To develop operating strategies for work scheduling and job sequencing.

The speed of the conveyor system is constant (12 meter/min). After running the simulation model, the AGV is the bottleneck of the system. According to the JIT concept -- Balance the flow, not the capacity, to reduce the work-in-process in this system, the robots alter the work schedule to match the cycle of the AGV. But the capital investment of the robots is very high, the utilization of the robot must increase. The first and the second robot use the similar end-effector, in this case, if the work load of the system is not very heavy, maybe one robot can handle the customer requirement. Or the system allows robot to change tool during the operation, the center robot cell is the good configuration. If a universal tool is developed for the operation requirement, it saves time for tool changing as well as robot investment, material transportation and space.

Charlie Duncheon, Vice president of Apept Technology, Inc. points out that "New technology lets us design new and better products almost overnight. We take computer-aid design (CAD) information and simultaneously create assembly technology to bring the product to market as soon as possible. If we design it today, we want to build it today. There's no time anymore to ship parts back and forth across the pond."

Some manufacturers can not afford the equipment to assemble automatically. Competition forces the assembly industries to go overseas for cheap manual assembly. New technologies in the automated assembly is moving very fast, companies are able to justify domestic assembly rather than offshore assembly. This justification is based upon reduced labor expense because of the utilization of robot, material handling system and computer, etc..

There are another important reasons for automating :

i. Increased productivity.

ii. Safety.

iii. Reduced human errors.

iv. Improved product quality.

v. Reduced manufacturing lead time.

vi. Reduction of in-process inventory.

Previously, most people discuss automated assembly, and now, they consider flexible assembly. This thesis discusses the advantages of automated and flexible assembly and how to achieve these benefits. But the assembly improvements are not the only consideration of the business. The new concept -- Computer Integrated Manufacturing (CIM) is introduced recently. The ideal CIM system applies computer technology to all of the operational functions and information processing functions in manufacturing from order receipt, through design and production, to product shipment. Some writers even suggest that it includes service and field support after the sale.

Engineers have the technology knowledge in their field is not enough in today environment, they must have the overall knowledge of the whole business operation.

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APPENDIX 1: GSL PROGRAMS

1. Program for AGV

```
PROGRAM  agv

VAR
-------------------- Main Declaration Section
agvpath  : PATH
agv1     : POSITION
path1    : POSITION
path2    : POSITION
path3    : POSITION

BEGIN MAIN
--------------------------------------------------------
  MOVE ALONG agvpath FROM 2 TO 3
  MOVE ALONG agvpath FROM 3 TO 4
  MOVE ALONG agvpath FROM 4 TO 5
  MOVE ALONG agvpath FROM 5 TO 6
  MOVE ALONG agvpath FROM 6 TO 7
  MOVE ALONG agvpath FROM 7 TO 8
  MOVE ALONG agvpath FROM 8 TO 9
  MOVE ALONG agvpath FROM 9 TO 10
  MOVE ALONG agvpath FROM 10 TO 11
  MOVE ALONG agvpath FROM 11 TO 12
  MOVE ALONG agvpath FROM 12 TO 13
  MOVE ALONG agvpath FROM 13 TO 14
  MOVE ALONG agvpath FROM 14 TO 15
  MOVE ALONG agvpath FROM 15 TO 16
  MOVE ALONG agvpath FROM 16 TO 17
  MOVE ALONG agvpath FROM 17 TO 18
  MOVE ALONG agvpath FROM 18 TO 19
  MOVE ALONG agvpath FROM 19 TO 20
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  MOVE ALONG agvpath FROM 22 TO 23
  MOVE ALONG agvpath FROM 23 TO 24
  MOVE ALONG agvpath FROM 24 TO 25
  MOVE ALONG agvpath FROM 25 TO 26
  MOVE ALONG agvpath FROM 26 TO 27
  MOVE ALONG agvpath FROM 27 TO 28
  MOVE ALONG agvpath FROM 28 TO 29
  MOVE ALONG agvpath FROM 29 TO 30
  MOVE ALONG agvpath FROM 30 TO 31
  MOVE ALONG agvpath FROM 31 TO 32
  MOVE ALONG agvpath FROM 32 TO 33
  MOVE ALONG agvpath FROM 33 TO 34
  MOVE ALONG agvpath FROM 34 TO 35
  MOVE ALONG agvpath FROM 35 TO 36
  MOVE ALONG agvpath FROM 36 TO 37
  MOVE ALONG agvpath FROM 37 TO 38
  MOVE ALONG agvpath FROM 38 TO 39
```

```
 MOVE ALONG agvpath FROM 39 TO 40
 MOVE ALONG agvpath FROM 40 TO 41
 MOVE ALONG agvpath FROM 41 TO 42
 MOVE ALONG agvpath FROM 42 TO 43
 MOVE ALONG agvpath FROM 43 TO 44
 DOUT[ 1 ] = ON
 DELAY 3000
 WAIT UNTIL DIN[ 1 ] = = ON
 ATTACH device 'Dummy#14' AT TAG POINT agv1
 MOVE ALONG agvpath FROM 44 TO 45
 MOVE ALONG agvpath FROM 45 TO 46
 MOVE ALONG agvpath FROM 46 TO 47
 MOVE ALONG agvpath FROM 47 TO 48
 MOVE ALONG agvpath FROM 48 TO 49
 MOVE ALONG agvpath FROM 49 TO 50
 MOVE ALONG agvpath FROM 50 TO 51
 MOVE ALONG agvpath FROM 51 TO 52
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 MOVE ALONG agvpath FROM 68 TO 69
 MOVE ALONG agvpath FROM 69 TO 70
 MOVE ALONG agvpath FROM 70 TO 71
 MOVE ALONG agvpath FROM 71 TO 72
 MOVE ALONG agvpath FROM 72 TO 73
 MOVE ALONG agvpath FROM 72 TO 74
 MOVE ALONG agvpath FROM 74 TO 75
 MOVE ALONG agvpath FROM 75 TO 76
 MOVE ALONG agvpath FROM 76 TO 77
 MOVE TO path1
 RELEASE 'Dummy#14'
 DOUT[ 2 ] = ON
 DELAY 2000
 MOVE TO path3
---------------------------------------------------------
-------------------- END MAIN --------------------
END agv
```

2. Program for robot1

```
PROGRAM robot1

VAR
-------------------- Main Declaration Section
upcasege : POSITION
upbiggr1 : POSITION
upsmallgr1 : POSITION
biggr1 : POSITION
housegear1 : POSITION
housegear2 : POSITION
house : POSITION
housecover1 : POSITION
cover1 : POSITION
cover1bolt1 : POSITION
cover1bolt2 : POSITION
cover1bolt3 : POSITION
cover1bolt4 : POSITION
smallgr1 : POSITION

BEGIN MAIN
------------------------------------------------------------
 ATTACH device 'Dummy#31' AT TAG POINT cover1bolt2
 ATTACH device 'Dummy#30' AT TAG POINT cover1bolt1
 ATTACH device 'Dummy#35' AT TAG POINT cover1bolt3
 ATTACH device 'Dummy#32' AT TAG POINT cover1bolt4
 WAIT UNTIL DIN[ 4 ] = = ON
 WAIT UNTIL DIN[ 3 ] = = ON
 MOVE TO upbiggr1
 MOVE TO biggr1
 GRAB 'Dummy#16' AT LINK 5
 MOVE TO upbiggr1
 MOVE TO upcasegr
 MOVE TO housegear1
 RELEASE 'Dummy#16'
 ATTACH device 'Dummy#16' AT TAG POINT housegear1
 MOVE TO upcasegr
 MOVE TO upsmallgr1
 MOVE TO smallgr1
 GRAB 'Dummy#25' AT LINK 5
 MOVE TO upsmallgr1
 MOVE TO upcasegr
 MOVE TO housegear2
 RELEASE 'Dummy#25'
 ATTACH device 'Dummy#25' AT TAG POINT housegear2
 MOVE TO upcasegr
 MOVE TO sidecon2
 MOVE TO cover1
 GRAB 'Dummy#23' AT LINK 5
 MOVE TO sidecon2
 MOVE TO upcasegr
 MOVE TO house
 RELEASE 'Dummy#23'
 ATTACH device 'Dummy#23' AT TAG POINT housecover1
 DOUT[ 3 ] = ON
```

```
  MOVE HOME
------------------------------------------------------------
-------------------- END MAIN --------------------
END robot1
```

3. Program for robot2

```
PROGRAM robot2

VAR
------------------ Main Declaration Section
fasten1bolt1 : POSITION
fasten1bolt2 : POSITION
fasten1bolt3 : POSITION
fasten1bolt4 : POSITION
screw1 : POSITION
screw2 : POSITION
screw3 : POSITION
screw4 : POSITION
house1bolt1 : POSITION
house1bolt2 : POSITION
house1bolt3 : POSITION
house1bolt4 : POSITION
upcasegr : POSITION

BEGIN MAIN
------------------------------------------------------------
  GRAB 'Dummy#33' AT LINK 5
  WAIT UNTIL DIN[ 4 ] = = ON
  RELEASE 'Dummy#31'
  RELEASE 'Dummy#30'
  RELEASE 'Dummy#35'
  RELEASE 'Dummy#32'
  MOVE TO upcasegr
  MOVE TO screw1
  GRAB 'Dummy#35' AT LINK 5
  MOVE TO fasten1bolt3
  RELEASE 'Dummy#35'
  ATTACH device 'Dummy#35' AT TAG POINT house1bolt3
  MOVE TO upcasegr
  MOVE TO screw2
  GRAB 'Dummy#32' AT LINK 5
  MOVE TO fasten1bolt4
  RELEASE 'Dummy#32'
  ATTACH device 'Dummy#32' AT TAG POINT house1bolt4
  MOVE TO upcasegr
  MOVE TO screw3
  GRAB 'Dummy#30' AT LINK 5
  RELEASE 'Dummy#30'
  ATTACH device 'Dummy#30' AT TAG POINT house1bolt1
  MOVE TO upcasegr
  MOVE TO screw4
  GRAB 'Dummy#31' AT LINK 5
```

```
  MOVE TO fasten1bolt2
  RELEASE 'Dummy#31'
  ATTACH device 'Dummy#31' AT TAG POINT house1bolt2
  MOVE HOME
  DOUT[ 4 ] = ON
----------------------------------------------------------
-------------------- END MAIN --------------------
END robot2
```

4. Program for robot3

```
PROGRAM robot3

VAR
------------------ Main Declaration Section
upcasetray : POSITION
comppart : POSITION
comppart2 : POSITION
comppart3 : POSITION
casetray : POSITION
house : POSITION
house2 : POSITION
inloop6 : POSITION
sidecon : POSITION
cover1 : POSITION

BEGIN MAIN
----------------------------------------------------------
  MOVE TO sidecon
  MOVE TO house
  GRAB 'Dummy#19' AT LINK 5
  MOVE TO sidecon
  MOVE TO upcasetray
  RELEASE 'Dummy#19'
  ATTACH device 'Dummy#19' AT TAG POINT casetray
  DOUT[ 1 ] = ON
  MOVE HOME
  WAIT UNTIL DIN[ 1 ] = = ON
  MOVE TO cover1
  GRAB 'Dummy#19' AT LINK 5
  MOVE TO comppart
  MOVE TO comppart2
  RELEASE 'Dummy#19'
  ATTACH device 'Dummy#19' AT TAG POINT comppart3
  MOVE TO comppart
  MOVE HOME
  DOUT[ 2 ] = ON
----------------------------------------------------------
-------------------- END MAIN --------------------
END robot3
```

5. Program for gearsupply

```
PROGRAM gearsupply

VAR
------------------- Main Declaration Section
outloop1 : POSITION
inloop : POSITION
outloop12 : POSITION
gearsupply1 : POSITION
gearsupply2 : POSITION
smallgrsup1 : POSITION
smallgrsup2 : POSITION

BEGIN MAIN
----------------------------------------------------------
 ATTACH device 'Dummy#16' AT TAG POINT gearsupply1
 ATTACH device 'Dummy#25' AT TAG POINT smallgrsup1
 ATTACH device 'Dummy#21' AT TAG POINT gearsupply2
 ATTACH device 'Dummy#22' AT TAG POINT smallgrsup2
 WAIT UNTIL DIN[ 2 ] = = ON
 MOVE ALONG outloop1 FROM 1 TO 2
 RELEASE 'Dummy#16'
 RELEASE 'Dummy#25'
 RELEASE 'Dummy#21'
 RELEASE 'Dummy#22'
 DOUT[ 4 ] = ON
 DELAY 8000
 WAIT UNTIL DIN[ 4 ] = = ON
 MOVE TO outloop1
----------------------------------------------------------
-------------------- END MAIN --------------------
END gearsupply
```

6. Program for caseing supply

```
PROGRAM casetray

VAR
-------------------- Main Declaration Section
inloop1 : POSITION
inloop2 : POSITION
inloop3 : POSITION
inloop4 : POSITION
inloop5 : POSITION
inloop6 : POSITION

BEGIN MAIN
----------------------------------------------------------
 WAIT UNTIL DIN[ 1 ] = = ON
 MOVE TO inloop1
 DOUT[ 2 ] = ON
 MOVE TO inloop2
 DOUT[ 3 ] = ON
```

```
 DELAY 10000
 WAIT UNTIL DIN[ 3 ] = = ON
 MOVE TO inloop3
 MOVE TO inloop4
 MOVE TO inloop5
 DOUT[ 4 ] = ON
 DELAY 10000
 WAIT UNTIL DIN[ 4 ] = = ON
 MOVE TO inloop6
 DOUT[ 1 ] = ON
---------------------------------------------------------
--------------------- END MAIN ---------------------
END casetray
```

7. Program for AS/RS and flok

a. Program for AS/RS

```
PROGRAM asrs

VAR
-------------------- Main Declaration Section
asrsrail1 : PATH
asrsrail1 : POSITION
asrsrail2 : POSITION
asrsrail3 : POSITION
flok1 : POSITION
flok2 : POSITION
flok3 : POSITION

BEGIN MAIN
---------------------------------------------------------
 ATTACH device 'Dummy#13' AT TAG POINT flok1
 WAIT UNTIL DIN[ 3 ] = = ON
 MOVE ALONG asrsrail FROM 3 TO 2
 RELEASE 'Dummy#13'
 DOUT[ 5 ] = ON
 DELAY 1000
 WAIT UNTIL DIN[ 5 ] = = ON
 ATTACH device 'Dummy#13' AT TAG POINT flok2
 MOVE ALONG asrsrail FROM 2 TO 1
 DOUT[ 6 ] = ON
 DELAY 2000
 WAIT UNTIL DIN[ 6 ] = = ON
 MOVE ALONG asrsrail FROM 1 TO 3
 RELEASE 'Dummy#13'
 DOUT[ 7 ] ON
 DELAY 1000
 WAIT UNTIL DIN[ 7 ] = = ON
 ATTACH device 'Dummy#13' AT TAG POINT flok1
---------------------------------------------------------
--------------------- END MAIN ---------------------
END asrs
```

b. Program for flok

```
PROGRAM flok

VAR
-------------------- Main Declaration Section
flok1 : POSITION
flok2 : POSITION
flok3 : POSITION
flokgrab1 : POSITION

BEGIN MAIN
---------------------------------------------------------
  WAIT UNTIL DIN[ 5 ] = = ON
  MOVE TO flok2
  DOUT[ 5 ] = ON
  WAIT UNTIL DIN[ 6 ] = = ON
  ATTACH device 'Dummy#14' AT TAG POINT FLOKGRAB1
  DELAY 1000
  DOUT[ 6 ] = ON
  WAIT UNTIL DIN[ 7 ] = = ON
  MOVE TO flok3
  RELEASE 'Dummy#14'
  DOUT[ 16 ] = ON
  DELAY 1000
  WAIT UNTIL DIN[ 16 ] = = ON
  MOVE TO flok1
  DOUT[ 7 ] = ON
---------------------------------------------------------
--------------------- END MAIN ---------------------
END flok
```

8. Program for material handling mechanism (at AS/RS)

```
PROGRAM jet1

VAR
-------------------- Main Declaration Section
support1 : POSITION
support2 : POSITION
pallet1 : POSITION

BEGIN MAIN
---------------------------------------------------------
  WAIT UNTIL DIN[ 2 ] = = ON
  MOVE TO support2
  ATTACH DEVICE 'Dummy#14' AT TAG POINT pallet1
  DELAY 2000
  MOVE TO support1
  DOUT[ 3 ] = ON
  RELEASE 'Dummy#14'
  DELAY 2000
```

```
------------------------------------------------------------
-------------------- END MAIN --------------------
END jet1
```

9. Program for material handling mechanism (at robotic cell)

```
PROGRAM jet2

VAR
-------------------- Main Declaration Section
support21 : POSITION
suppoet22 : POSITION
pallet2 : POSITION

BEGIN MAIN
------------------------------------------------------------
 ATTACH device 'Dummy#14' AT TAG POINT pallet2
 WAIT UNTIL DIN[ 2 ] = = ON
 WAIT UNTIL DIN[ 1 ] = = ON
 MOVE TO support22
 RELEASE 'Dummy#14'
 DELAY 500
 MOVE TO support21
 DOUT[ 1 ] = ON
------------------------------------------------------------
-------------------- END MAIN --------------------
END jet2
```

10. Program for pallet

```
PROGRAM pallet

VAR
-------------------- Main Declaration Section
storage1 : POSITION

BEGIN MAIN
------------------------------------------------------------
 WAIT UNTIL DIN[ 16 ] = = ON
 MOVE TO storage1
 DOUT[ 16 ] = ON
------------------------------------------------------------
-------------------- END MAIN --------------------
END pallet
```

APPENDIX 2

Information of an automation assembly system from RPI

Center for Advanced Technology in
Automation and Robotics
Rensselaer Polytechnic Institute
Troy, New York

The CAT's Small Lot Assembly System

General Overview

When robots were initially applied to assembly, high volume production lines were the first to be automated. Along these lines robots were often simply substituted for manual assembly stations. In such serial assembly systems, each robot assembled one part on each subassembly. This resulted in improved production but two disadvantages were noted. First, large amounts of capital were needed for such a system since a different robot was needed for each assembly task. Secondly, since the process was still linear, if any one robot malfunctioned the entire process stopped.

A recent concept has been to apply a robot to small lot assembly. The basic idea of small lot robotic assembly is to organize one or two robots around a conveyor system that shuttles tools, parts, and partially completed assemblies to and from the robots. The enclosed figure shows two versions of the small lot assembly system that is being developed at the Center for Manufacturing and Technology Transfer (CMP) with funding from the Center for Advanced Technology.

Assembly will begin with a train of palletized parts presented to the robot in the outer leg of the conveyor. Each pallet carries one type of part (A, B, C, ...). In some systems, tooling for the robot will also be available from this leg. The robot then takes the first part, Part A, from the first pallet and assembles it into the first pallet in the assembly loop. When this is done, the second assembly pallet is presented to the robot, and Part A is added. All of the assembly pallets are then shuttled past the robot under the direction of the programmable logic controller, which is running the cell. Once all of the assemblies have Part A installed, the pallet for Part B will be presented to the robot. Assembly continues as Part B is installed into each of the assembly pallets as they are shuttled past the robot. In this way a product can be assembled in small lot sizes.

Enabling Technologies

The facility at CMP uses several robotic technologies in order to demonstrate small lot assembly. The more important technologies are listed below.

Assembly Robot Capabilities

The CMP has selected a SCARA robot configuration since in typical mechanical and electrical assemblies up to 80% of joining processes are from a single direction. An Adept Robot is currently installed. This robot has a high repeatability, (+/- .002), as well as one of the fastest point-to-point cycle times. Special features of this robot also include task-level programming, a force feedback wrist, and a well-integrated vision system. The cost of the basic robot, without the vision system or specialized software, is approximately $60 K.

Vision
Vision can assist the assembly process by locating parts as well as alignment features. The cost of the vision system used on this system is $30 K.

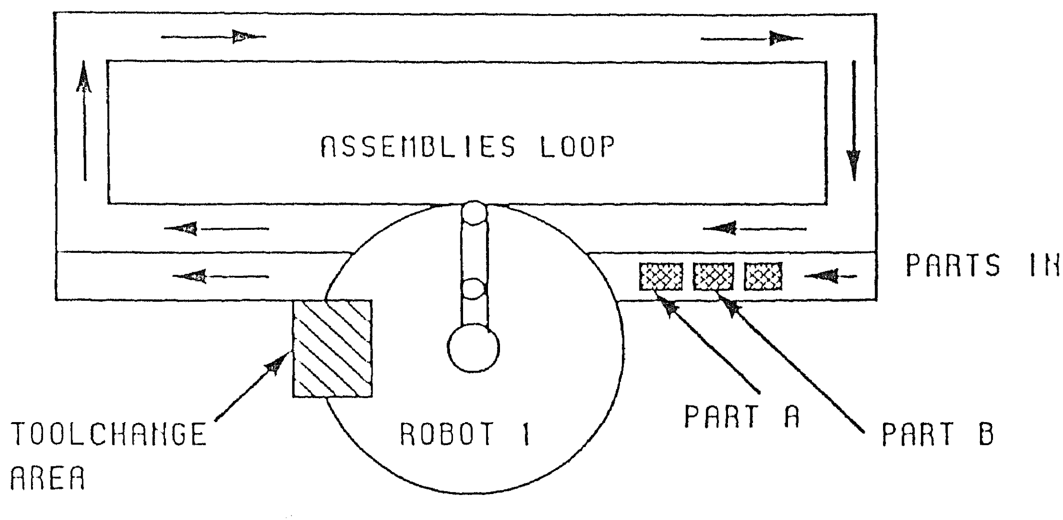
Task Level Programming
Adept offers a series of prewritten programs that are used to automatically perform an assembly function. Robot users can also write programs to meet their individual needs by using Adept's AIM programming language. For example the task command, "Snap_fit", was written at RPI and will command the robot to locate a snap fastener from a designated area and grasp it in a certain manner. The robot will then insert the snap fastener into a designated hole, ensuring that the insertion force is within a certain range.

Programmable Logic Controller (PLC)
An Allen Bradley PLC is used to control and coordinate the actions of the robot(s), conveyor, and sensors. This unit can be programmed off-line by means of an IBM PC or clone.

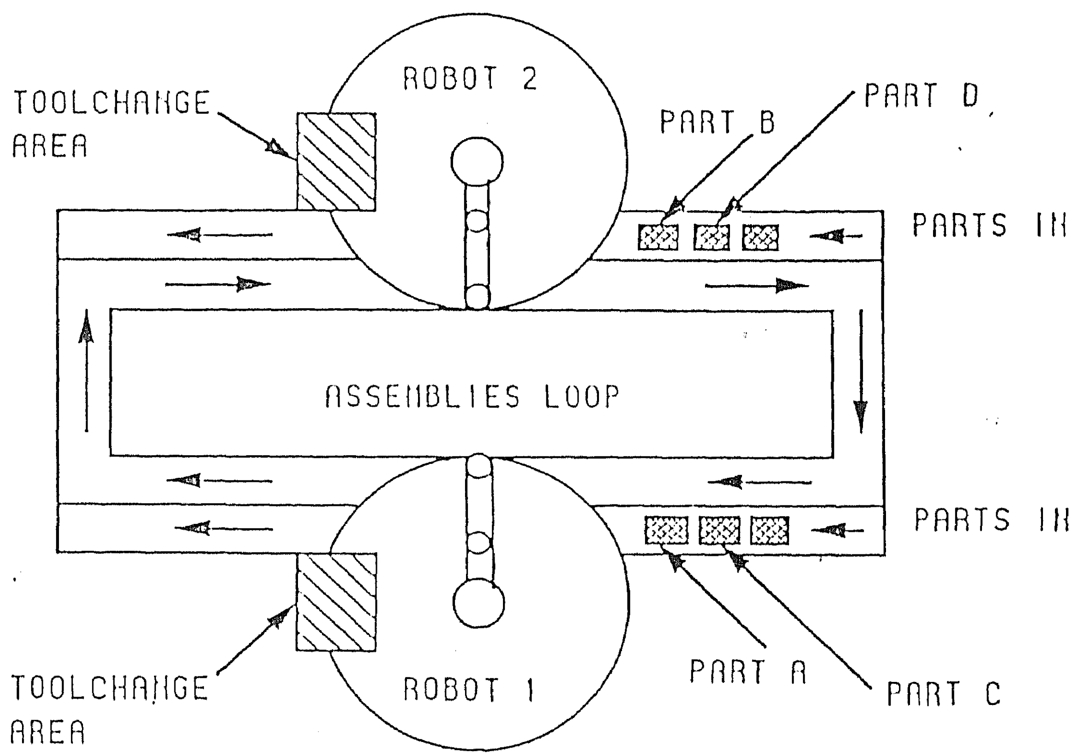
Gripper Exchange System
A key component of a robot assembly cell is the end effector tooling. Historically, end effectors were developed as individual hands and grippers and then branched into two schools of design choice. The first was the multi-gripper turret. This system uses from four to eight individual tools on one turret and is indexed pneumatically or by a servo motor. While useful, this system is complex, somewhat unwieldy, and detracts from the robot payload. The second school of design was the exchange tooling system. In such a system, individual end-of-arm tools are locked onto a master effector with provisions to transfer control signals such as pneumatics and electric sensor feedback. Exchange tooling is available from several manufacturers. The exchange system at CMP is manufactured by Applied Robotics Inc. The cost of their XChange system is approximately $1700 for the robot adapter and $370 for each tooling adapter.

Conveyor/Pallet System
The conveyor used by CMP's assembly system is manufactured by Menziken of Switzerland. It is configured into an endless inner loop to transfer assembly pallets, and two outer linear tracks to transfer part and possibly tool pallets. One of the advantages of this system is that it is modular so that systems of various size can be configured or an existing conveyor can be expanded by adding work stations. Also, conveyor components are available in a wide variety of sizes so that different assembly weights and sizes can be accommodated. The cost of the conveyor system used at CMP was approximately $35K including sensors, controls and the PLC.

Remote Center Compliance (RCC) Wrist
These are robotic wrist devices that allow error in either lateral or angular position during assembly. They are located between a robot's face plate and its end effector, and they essentially "soak up" small positioning errors of either the robot or the fixture.



Small Lot Assembly With One Robot



Small Lot Assembly With Two Robots

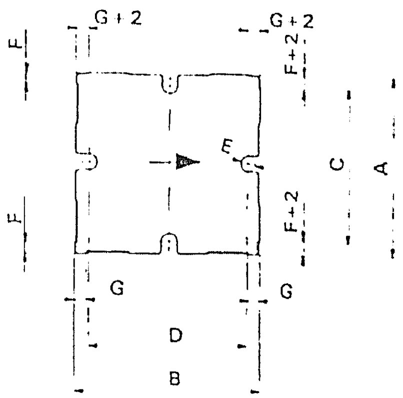
Transport plates TP

Tl are base plates which are used to carry and transport the work piece carriers and the work piece in the LTS system.
Depending on the precision that is required there is a type A and type C that can be chosen.
Plate material:
Qual. A: steel 1011 SAE bare
Qual. C: steel 1045 SAE

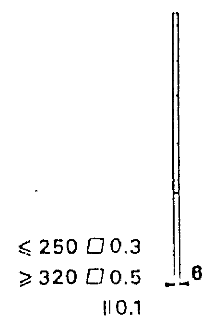
Quality class A and C

Dimension	Tolerance (mm)	Positioning precision (mm)
A, B	±0.2	
C, D ≤250	0 / -0.02	± 0.03
C, D ≥320	0 / -0.02	± 0.05
E	Ø16 $^{+0.018}_{0}$ Ø25 $^{+0.021}_{0}$	

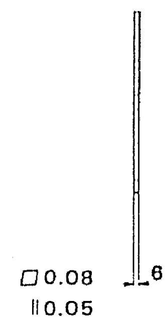
Quality class C is ground on both sides (flatness tolerance 0.08 mm)



Quality class A+C



Quality class A

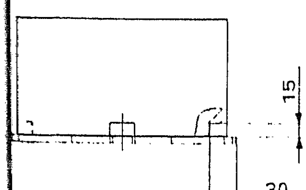


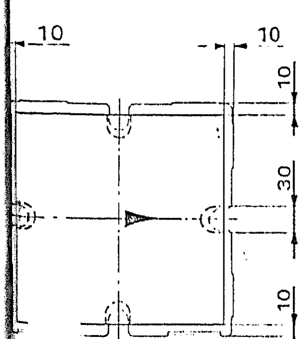
Quality class C

Transport plate width A (mm)	Transport plate length B (mm)	Dimension C (mm)	D (mm)	Stop pin E (mm)	F (mm)	G (mm)
160	160	132	132	16	12.5	12.5
	200		172	16		12.5
200	160	172	132	16	12.5	12.5
	200		172	16		12.5
	250		222	16		19.5
250	200	222	172	16	19.5	12.5
	250		222	16		19.5
	320		292	25		19.5
	400		372	25		19.5
320	250	292	222	25	19.5	19.5
	320		292	25		19.5
	400		372	25		19.5
400	250	372	222	25	19.5	19.5
	320		292	25		19.5
	400		372	25		19.5

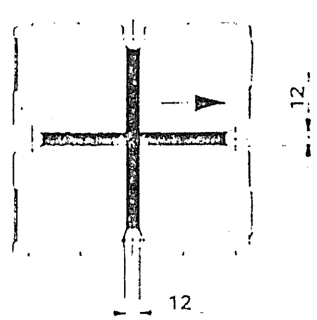
Order example: TP – C – 250 / 320 – WE

Transport plate
Type A or C
Width A (mm)
Length B (mm)
(Drill pattern for lift rotation unit)

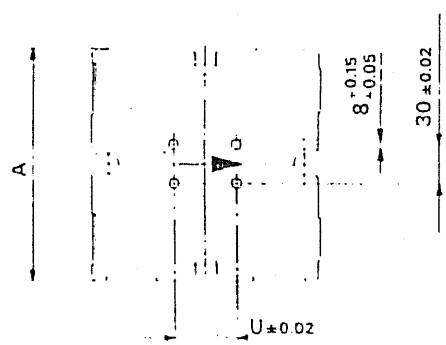




The free room which is given on the drawing (edge) must not be used for the work piece holder.



To guarantee the function of the proximity switches as per the arrangement illustrated on pages 33 + 34 there must be no holes in the black marked area.

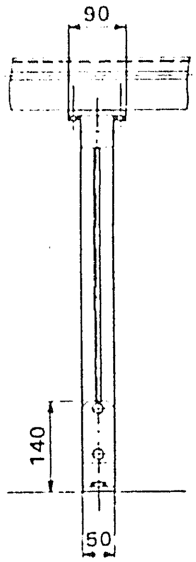


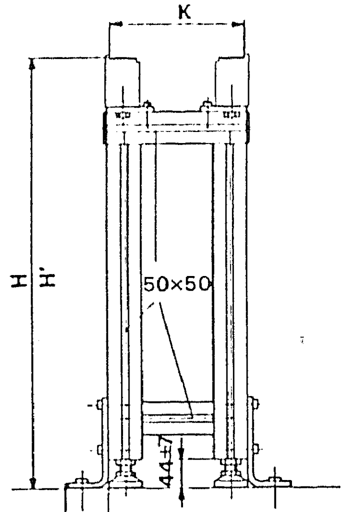
A (mm)	160	200	250	320	400
U 0.02 (mm)	50	90	140	210	290

Drill pattern for WE (see page 27)

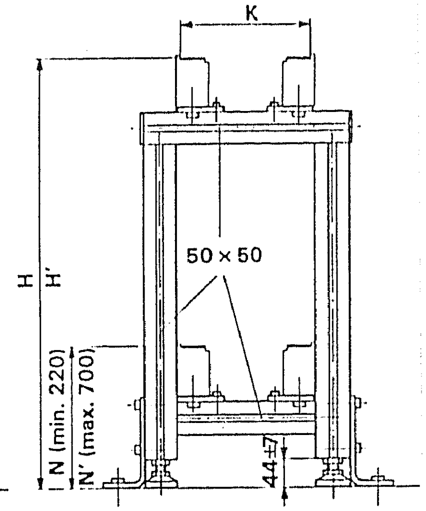
Support legs BS

The support legs are the supporting elements for the linear tracks. They are anodized aluminium profiles allowing a fast and problemfree setup. They are implemented at the start and end of each line, as well as at each track connection and as supports every 3000 mm inbetween to prohibite any sagging of the tracks. For stabilization reasons they must be fastened to the floor. Depending on the arrangement of the LTS, four types of support legs are available.





One track support legs BS-E



Support legs for in-line configuration BS-L

The following dimensions are standard: working height H = 980 mm on linear tracks
(height over belt) H = 987 mm on cross transfers
return track height N = 220 mm
table support height G = 221 mm

Other dimensions to be defined on order

Order example:
One track support leg BS-E

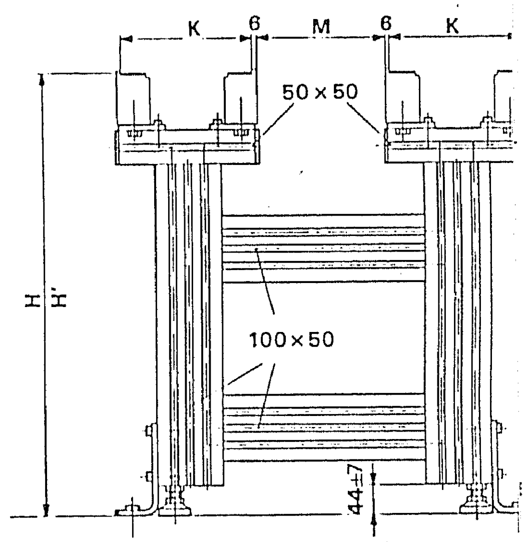
BS-E-320-. . .

One track support leg
Transport track width K (mm)
* Support leg height H' (mm)

Order example:
Support legs for in-line configuration BS-L

BS-L-250-. . .-. . .

Support legs for in-line
Transport track width K (mm)
* Lower level height N' (mm)
* Support leg height H' (mm)

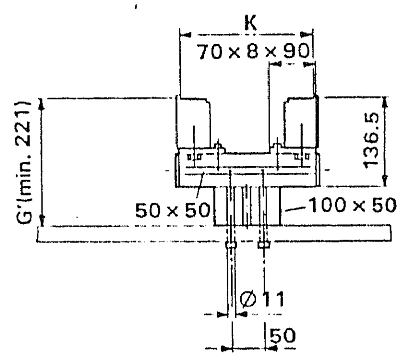


Support legs for double track configuration BS-P

Order example:
Support legs for double track configuration BS-P

BS-P-400-600-. . .

Support legs for double track
Transport track width K (mm)
Distance between tracks M = 30–3000 mm
* Support leg height H' (mm)



Support legs for table configuration BS-T

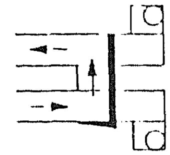
Order example:
Support legs for table configuration BS-T

BS-T-160-. . .

Support legs for table
Transport track width K (mm)
* Table support height G' (mm)

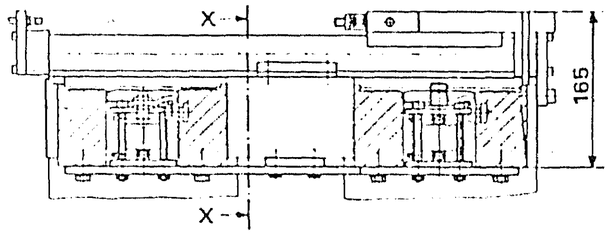
* if not standard height (see above)

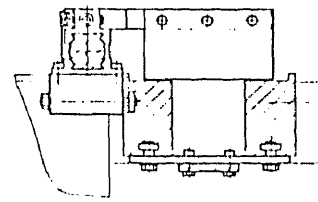
Pneumatic cross transfers QTP



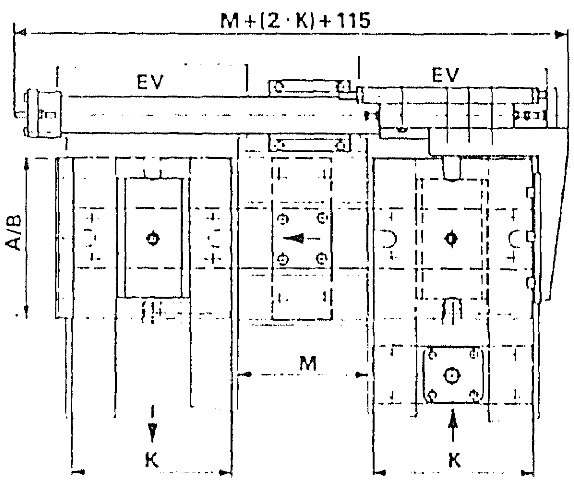
T neumatic cross transfer QTP is an alternative to the QTK or the TBL. It is used where the cycle time is secondary. The standard version is used at the end of the line.
Function: The first transport plate (TP-1) is driven to the end stop (EV), the prestop is then lifted (prestop is not included) and keeps back the next TP (TP-2). The two special pneumatic cylinders at both ends of main track are lifted together. Then the cross pneumatic cylinder will push the TP-1 over to the second track. When the TP-1 is in place both lift cylinders will lower and the TP-1 will be carried out of position. At the same time the cross cylinder moves back to the starting position and the device is ready for the next cycle.
The move in and out of the TP's is controlled by two proximity switches (which are not included in the part).

Transport track width K (mm)	TP-width A or TP-length B (mm)	Distance M (mm)
160	160	163 313 600
	200	163 313 600
200	160	163 313 600
	200	163 313 600
	250	163 313 600
250	200	163 313 600
	250	163 313 600
	320	163 313 600
	400	163 313 600





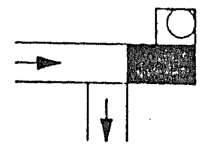
Schnitt X-X



der example: QTP-200/250-313-PNP

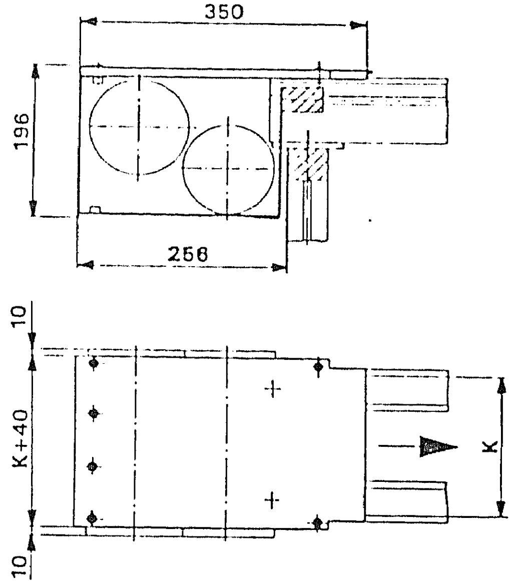
eumatic cross transfer
nsport track width K (mm)
width A or length B (mm)
ce between two tracks M (mm)
ity switch function (PNP or NPN)

Endcases EV

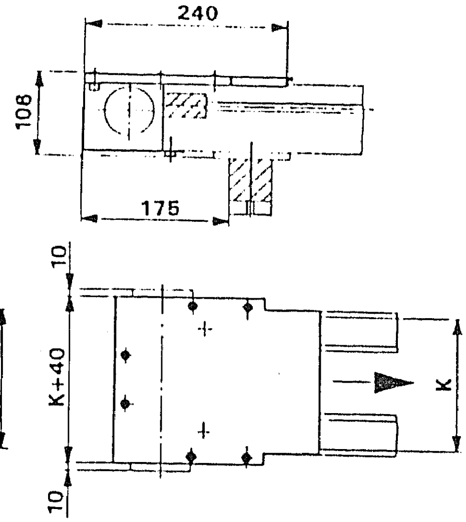


ic and metal covers for the drive and idling units on the linear tracks which accomplish two functions:

1) accident protection
2) stop for transport plate



heavy version **S**



light version **L**

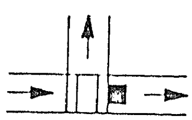
Order example: EV – L – 320

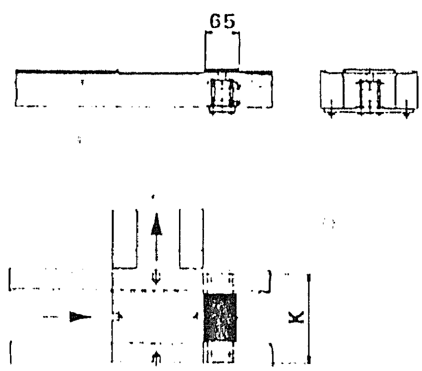
Endcase
L = light / S = heavy version
Transport track width K (mm)

Fix stops

Bypass stop ABS

This type of stop is used where a transit point exists. That is where the transport plates (TP) are either transfered on to a cross transfer or continues on a main track.
The approach is controlled with a proximity switch.





Order example: ABS – 250

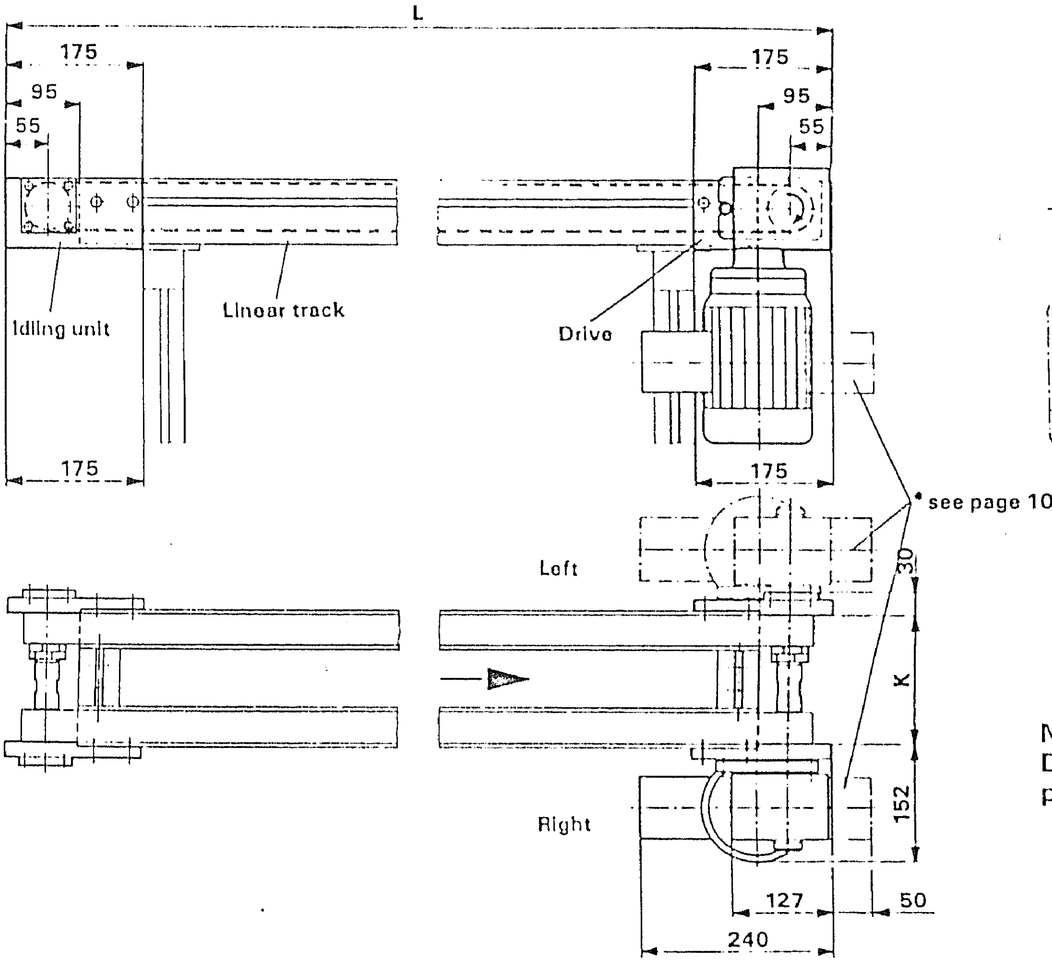
Bypass stop
Transport track width K (mm)

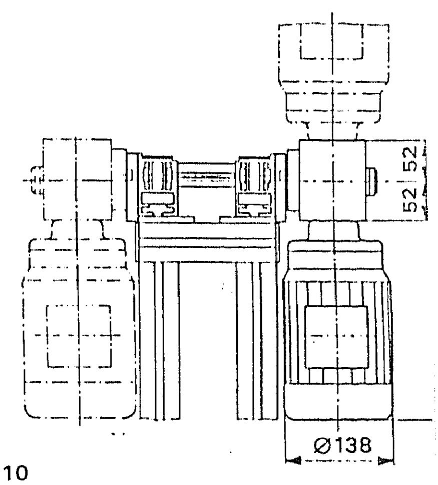
Transport track light TBL

This track has the same assembly as TBS, only the loading weight is limited to 100 kg. The length per drive unit maybe up to 30 000 mm. The track lengths can be ordered up to max. 6000 mm. On each track length there must be a support leg, when intermediate drives are used 2 legs are needed per intermediate drive (see page 9).

When using the TBL for a cross transfer the minimum length is according to the electronic control position 1 page 34:

Transport plate width A (s. page 8) (mm)	min. TBL-length for cross transfer (mm)
160	360
200	400
250	450
320	520
400	600





Note
Dimensions of motors can vary pending on US motor manufacture

Attention: At cross transfers, motors must be built on as described on page 23.

Order example: TBL-200-....-([1]/../..)-LH-9 -KG

- Transport track light
- Transport track width K (mm)
- Total track length L (max. 30 000 mm)
- Division of track (mm)
- Motor (R=right/L=left)
- Motor (H=hanging/S=standing)
- Speed (v=9 or 12 m/min.)
- (Connection box turned 180°)

[1] The first dimension is the motor end.

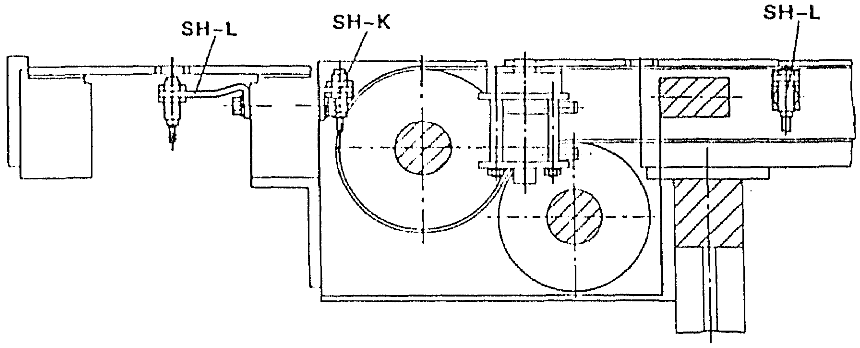
Proximity switches with brackets SH

The contact free proximity switches (PNP=Positive logic or NPN=Negave logic) control, check and sense the transport plates which are being transported on the LTS. The signal from proximity switches is sent out either when the switch is covered with a plate or uncovered.
Depending on the purpose of the switches they are either used for the separating accumulation control, or presence control. Size of proximity switch: M12×1 mm. They are delivered with brackets.
Different brackets are required depending on the track location where the switches have to be mounted.

a) **Long bracket** SH–L (proximity switch M12 x 1) for all linear and cross tracks depending on width of track.

Order example: SH – L – 320 – NPN

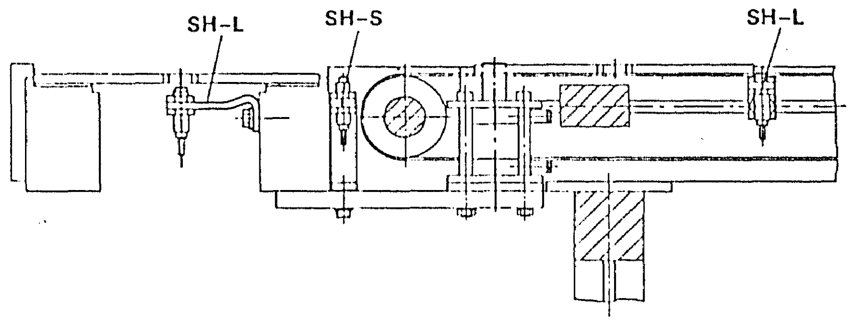
- Proximity switch
- Long bracket
- Track width K (mm)
- Proximity switch function (PNP or NPN)



b) **Short bracket** SH–K (proximity switch M12 x 1) for the beginning and end of the cross tracks in the heavy version and for the cross transfer rollers.

Order example: SH – K – PNP

- Proximity switch
- Short bracket
- Proximity switch function (PNP or NPN)



c) **Special bracket** SH–S (proximity switch M12 x 1) for the beginning and end of the cross track in light version.

Order example: SH – S – NPN

- Proximity switch
- Special bracket
- Proximity switch function (PNP or NPN)