COMPUTER AIDED DESIGN AND MANUFACTURING

18ME72

COLLEGE VISION & MISION STATEMENT

VISION

Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

MISSION

- **To keep pace with advancements in knowledge and make the students competitive and capable at the global level.**
- **To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torch bearers of tomorrow's society.**
- **To strive to attain ever-higher benchmarks of educational excellence.**

DEPARTMENTAL VISION & MISIION STATEMENTS

VISION

To impart excellent technical education in mechanical engineering to develop technically competent, morally upright and socially responsible mechanical engineering professionals.

MISSION:

- To provide an ambience to impart excellent technical education in mechanical engineering.
- To ensurestate of-the- art facility for learning, skill development and research in mechanical engineering.
- Toengage students in co-curricular and extra-curricular activities to impart social & ethical values and imbibeleadership quality.

PROGRAM EDUCATIONAL OBJECTIVES (PEO'S)

After successful completion of program, the graduates will be

PEO 1: Graduates will be able to have successful professional career in the allied areas and be proficient to perceive higher education.

PEO 2: Graduates will attain the technical ability to understand the need analysis, design, manufacturing, quality changing and analysis of the product.

PEO 3: Work effectively, ethically and socially responsible in allied fields of mechanical engineering.

PEO 4: Work in a team tomeet personal and organizational objectives and to contribute to the development of the society in large.

PROGRAM OUTCOMES (PO'S)

The Mechanical engineering program students will attain:

PO1.Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems

PO2.Problem analysis: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences

PO3.Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations

PO4.Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions

PO5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations

PO6.The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice

PO7.Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development

PO8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice

PO9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings

PO10.Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions

PO11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments

PO12.Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

PROGRAM SPECIFIC OUTCOMES (PSO'S)

After successful completion of program, the graduates will be

PSO 1: Ability to apply and interpret the acquired mechanical engineering knowledge for advancement in Industrial, Societal, and Environmental arenas.

PSO 2: Ability to meet the needs of Industries in the field of design, manufacturing and testing using mechanical engineering software

Introduction to CIM and Automation

CONTENTS

OBJECTIVES:

1. To understand different types of production systems and their features.
2. To use different mathematical models in production system to analyze production parameters.

1.1. INTRODUCTION

Computer Integrated Manufacturing (CIM) encompasses the entire range of product development and manufacturing activities with all the functions being carried out with the help of dedicated software packages. The data required for various functions are passed from one application software to another in a seamless manner. For example, the product data is created during design. This data has to be transferred from the modeling software to manufacturing software without any loss of data. CIM uses a common database wherever feasible and communication technologies to integrate design, manufacturing and associated business functions that combine the automated segments of a factory or a manufacturing facility. CIM reduces the human component of manufacturing and thereby relieves the process of its slow, expensive and error-prone component. CIM stands for a holistic and methodological approach to the activities of the manufacturing enterprise in order to achieve vast improvement in its performance.

This methodological approach is applied to all activities from the design of the product to customer support in an integrated way, using various methods, means and techniques in order to achieve production improvement, cost reduction, fulfillment of scheduled delivery dates, quality improvement and total flexibility in the manufacturing system. CIM requires all those associated with a company to involve totally in the process of product development and manufacture. In such a holistic approach, economic, social and human aspects have the same importance as technical aspects. CIM also encompasses the whole lot of enabling technologies including total quality management, business process reengineering, concurrent engineering, workflow automation, enterprise resource planning and flexible manufacturing.

The challenge before the manufacturing engineers is illustrated in Fig. 1

Figure 1 Challenges in manufacturing

Manufacturing industries strive to reduce the cost of the product continuously to remain competitive in the face of global competition. In addition, there is the need to improve the quality and performance levels on a continuing basis. Another important requirement is on time delivery. In the context of global outsourcing and long supply chains cutting across several international borders, the task of continuously reducing delivery times is really an arduous task. CIM has several software tools to address the above needs.

Manufacturing engineers are required to achieve the following objectives to be competitive in a global context.

- Reduction in inventory
- Lower the cost of the product

- Reduce waste
- Improve quality
- Increase flexibility in manufacturing to achieve immediate and rapid response to:
  - Product changes
  - Production changes
  - Process change
  - Equipment change
  - Change of personnel

CIM technology is an enabling technology to meet the above challenges to the manufacturing.

1.2. EVOLUTION OF COMPUTER INTEGRATED MANUFACTURING

Computer Integrated Manufacturing (CIM) is considered a natural evolution of the technology of CAD/CAM which by itself evolved by the integration of CAD and CAM. Massachusetts Institute of Technology (MIT, USA) is credited with pioneering the development in both CAD and CAM. The need to meet the design and manufacturing requirements of aerospace industries after the Second World War necessitated the development these technologies. The manufacturing technology available during late 40's and early 50's could not meet the design and manufacturing challenges arising out of the need to develop sophisticated aircraft and satellite launch vehicles. This prompted the US Air Force to approach MIT to develop suitable control systems, drives and programming techniques for machine tools using electronic control.

The first major innovation in machine control is the Numerical Control (NC), demonstrated at MIT in 1952. Early Numerical Control Systems were all basically hardwired systems, since these were built with discrete systems or with later first generation integrated chips. Early NC machines used paper tape as an input medium. Every NC machine was fitted with a tape reader to read paper tape and transfer the program to the memory of the machine tool block by block. Mainframe computers were used to control a group of NC machines by mid *60's*. This arrangement was then called Direct Numerical Control (DNC) as the computer bypassed the tape reader to transfer the program data to the machine controller. By late 60's mini computers were being commonly used to control NC machines. At this stage NC became truly soft wired with the facilities of mass program storage, offline editing and software logic control and processing. This development is called Computer Numerical

Control (CNC). Since 70's, numerical controllers are being designed around microprocessors, resulting in compact CNC systems. A further development to this technology is the distributed numerical control (also called DNC) in which processing of NC program is carried out in different computers operating at different hierarchical levels - typically from mainframe host computers to plant computers to the machine controller. Today the CNC systems are built around powerful 32 bit and 64 bit microprocessors. PC based systems are also becoming increasingly popular.

Manufacturing engineers also started using computers for such tasks like inventory control, demand forecasting, production planning and control etc. CNC technology was adapted in the development of co-ordinate measuring machine's (CMMs) which automated inspection. Robots were introduced to automate several tasks like machine loading, materials handling, welding, painting and assembly. All these developments led to the evolution of flexible manufacturing cells and flexible manufacturing systems in late 70's.

Evolution of Computer Aided Design (CAD), on the other hand was to cater to the geometric modeling needs of automobile and aeronautical industries. The developments in computers, design workstations, graphic cards, display devices and graphic input and output devices during the last ten years have been phenomenal. This coupled with the development of operating system with graphic user interfaces and powerful interactive (user friendly) software packages for modeling, drafting, analysis and optimization provides the necessary tools to automate the design process.

CAD in fact owes its development to the APT language project at MIT in early 50's. Several clones of APT were introduced in 80's to automatically develop NC codes from the geometric model of the component. Now, one can model, draft, analyze, simulate, modify, optimize and create the NC code to manufacture a component and simulate the machining operation sitting at a computer workstation.

If we review the manufacturing scenario during 80's we will find that the manufacturing is characterized by a few islands of automation. In the case of design, the task is well automated. In the case of manufacture, CNC machines, DNC systems, FMC, FMS etc provide tightly controlled automation systems. Similarly computer control has been implemented in several areas like manufacturing resource planning, accounting, sales, marketing and purchase. Yet the full potential of computerization could not be obtained unless all the segments of manufacturing are integrated, permitting the transfer of data across various functional modules. This realization led to the concept of computer integrated manufacturing. Thus the implementation of CIM required the development of whole lot of computer technologies related to hardware and software.

1.3. CIM HARDWARE AND CIM SOFTWARE

CIM Hardware comprises the following:

i. Manufacturing equipment such as CNC machines or computerized work centers, robotic work cells, DNC/FMS systems, work handling and tool handling devices, storage devices, sensors, shop floor data collection devices, inspection machines etc.

ii. Computers, controllers, CAD/CAM systems, workstations / terminals, data entry terminals, bar code readers, RFID tags, printers, plotters and other peripheral devices, modems, cables, connectors etc.,

CIM software comprises computer programmes to carry out the following functions:

- Management Information System
- Sales
- Marketing
- Finance
- Database Management
- Modeling and Design
- Analysis
- Simulation
- Communications
- Monitoring
- Production Control
- Manufacturing Area Control
- Job Tracking
- Inventory Control
- Shop Floor Data Collection

- Order Entry
- Materials Handling
- Device Drivers
- Process Planning
- Manufacturing Facilities Planning
- Work Flow Automation
- Business Process Engineering
- Network Management
- Quality Management

1.4. NATURE AND ROLE OF THE ELEMENTS OF CIM SYSTEM

Nine major elements of a CIM system are in Figure 2 they are,

- Marketing
- Product Design
- Planning
- Purchase
- Manufacturing Engineering
- Factory Automation Hardware
- Warehousing
- Logistics and Supply Chain Management
- Finance
- Information Management

Figure 2 Major elements of CIM systems

i. ***Marketing:*** The need for a product is identified by the marketing division. The specifications of the product, the projection of manufacturing quantities and the strategy for marketing the product are also decided by the marketing department. Marketing also works out the manufacturing costs to assess the economic viability of the product.

ii. ***Product Design:*** The design department of the company establishes the initial database for production of a proposed product. In a CIM system this is accomplished through activities such as geometric modeling and computer aided design while considering the product requirements and concepts generated by the creativity of the design engineer. Configuration management is an important activity in many designs. Complex designs are usually carried out by several teams working simultaneously, located often in different parts of the world. The design process is constrained by the costs that will be incurred in actual production and by the capabilities of the available production equipment and processes. The design process creates the database required to manufacture the part.

iii. ***Planning:*** The planning department takes the database established by the design department and enriches it with production data and information to produce a plan for the production of the product. Planning involves several subsystems dealing with materials, facility, process, tools, manpower, capacity, scheduling, outsourcing, assembly, inspection, logistics etc. In a CIM system, this planning process should be constrained by the production costs and by the production equipment and process capability, in order to generate an optimized plan.

iv. ***Purchase:*** The purchase departments is responsible for placing the purchase orders and follow up, ensure quality in the production process of the vendor, receive the items, arrange for inspection and supply the items to the stores or arrange timely delivery depending on the production schedule for eventual supply to manufacture and assembly.

v. ***Manufacturing Engineering:*** Manufacturing Engineering is the activity of carrying out the production of the product, involving further enrichment of the database with performance data and information about the production equipment and processes. In CIM, this requires activities like CNC programming, simulation and computer aided scheduling of the production activity. This should include online dynamic scheduling and control based on the real time performance of the equipment and processes to assure continuous production activity. Often, the need to meet fluctuating market demand requires the manufacturing system flexible and agile.

vi. ***Factory Automation Hardware:*** Factory automation equipment further enriches the database with equipment and process data, resident either in the operator or the equipment to carry out the production process. In CIM system this consists of computer controlled process machinery such as CNC machine tools, flexible manufacturing systems (FMS), Computer controlled robots, material handling systems, computer controlled assembly systems, flexibly automated inspection systems and so on.

vii. ***Warehousing:*** Warehousing is the function involving storage and retrieval of raw materials, components, finished goods as well as shipment of items. In today's complex outsourcing scenario and the need for just-in-time supply of components and subsystems, logistics and supply chain management assume great importance.

viii. ***Finance:*** Finance deals with the resources pertaining to money. Planning of investment, working capital, and cash flow control, realization of receipts, accounting and allocation of funds are the major tasks of the finance departments.

ix. ***Information Management:*** Information Management is perhaps one of the crucial tasks in CIM. This involves master production scheduling, database management, communication, manufacturing systems integration and management information systems.

Definition of CIM

Joel Goldhar, Dean, Illinois Institute of Technology gives CIM as a computer system in which the peripherals are robots, machine tools and other processing equipment.

Dan Appleton, President, DACOM, Inc. defines CIM is a management philosophy, not a turnkey product.

Jack Conaway, CIM Marketing manager, DEC, defines CIM is nothing but a data management and networking problem.

The computer and automated systems association of the society of Manufacturing Engineers (CASA/SEM) defines CIM is the integration of total manufacturing enterprise by using integrated systems and data communication coupled with new managerial philosophies that improve organizational and personnel efficiency.

CIM is recognized as Islands of Automation. They are

1. CAD/CAM/CAE/GT
2. Manufacturing Planning and Control.
3. Factory Automation
4. General Business Management

CASA/SME's CIM Wheel is as shown in figure 4

Figure 4 CASA/SME's CIM Wheel

1.5. Conceptual model of manufacturing

The computer has had and continues to have a dramatic impact on the development of production automation technologies. Nearly all modern production systems are implemented today using computer systems. The term computer integrated manufacturing

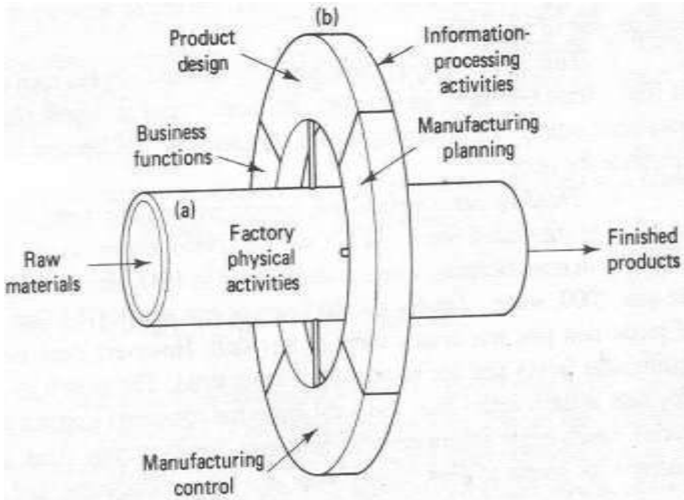
(CIM) has been coined to denote the pervasive use of computers to design the products, plan the production, control the operations, and perform the various business related functions needed in a manufacturing firm. *CAD/CAM* (computer-aided design and computer-aided manufacturing) is another term that is used almost synonymously with CIM.

Let us attempt to define the relationship between automation and CIM by developing a conceptual model of manufacturing. In a manufacturing firm, the physical activities related to production that take place in the factory can be distinguished from the infor-mation-processing activities, such as product design and production planning, that usually occur in an office environment. The physical activities include all of the manufacturing processing, assembly, material handling, and inspections that are performed on the prod-uct. These operations come in direct contact with the product during manufacture. They touch the product. The relationship between the physical activities and the information-processing activities in our model is depicted in Figure 5. Raw materials flow in one end of the factory and finished products flow out the other end. The physical activities (processing, handling, etc.) take place inside the factory. The information-processing functions form a ring that surrounds the factory, providing the data and knowledge required to produce the product successfully. These information-processing functions include (1) certain business activities (e.g., marketing and sales, order entry, customer billing, etc.),

(2) product design, (3) manufacturing planning, and (4) manufacturing control. These four functions form a cycle of events that must accompany the physical production activities but which do not directly touch the product.

Now consider the difference between automation and CIM. Automation is concerned with the physical activities in manufacturing. Automated production systems are designed to accomplish the processing, assembly, material handling, and inspecting activities with little or no human participation.

In the figure 5 Model of manufacturing, showing (a] the factory as a processing pipeline where the physical manufacturing activities are performed, and (b) the information-processing activities that support manufacturing as a ring that surrounds the factory concerned more with the information-processing functions that are required to support the production operations. CIM involves the use of computer systems to perform the four types of information-processing functions. Just as automation deals with the physical activities, CIM deals with automating the information-processing activities in manufacturing.



1.6. AUTOMATION

Automation is a technology concerned with the application of mechanical, electronic, and computer-based systems to operate and control production.

This technology includes:

- Automatic machine tools to process parts
- Automatic assembly machines
- Industrial robots
- Automatic material handling and storage systems
- Automatic inspection systems for quality control
- Feedback control and computer process control
- Computer systems for planning, data collection, and decision making to support manufacturing activities

1.7. TYPES OF AUTOMATION

Automated production systems are classified into three basic types:

1. Fixed automation
2. Programmable automation
3. Flexible automation

Fixed automation

Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. The operations in the sequence are usually simple. It is the integration and coordination of many such operations into one piece of equipment that makes the system complex. The typical features of fixed automation are:

High initial investment for custom-engineered equipment
High production rates
Relatively inflexible in accommodating product changes

The economic justification for fixed automation is found in products with very high demand rates and volumes. The high initial cost of the equipment can be spread over a very large number of units, thus making the unit cost attractive compared to alternative methods of production.

Programmable automation

In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations. The operation sequence is controlled by a program, which is a set of instructions coded so that the system can read and interpret them. New programs can be prepared and entered into the equipment lo produce new products. Some of the features that characterize programmable automation include:

1. High investment in general-purpose equipment
2. Low production rates relative to fixed automation
3. Flexibilitytodealwith changes in product configuration
4. Most suitable for batch production

Automated production systems that are programmable are used in low and medium-volume production. The parts or products are typically made in batches. To produce each new batch of a different product, the system must be reprogrammed with the set of machine instructions that correspond to the new product. The physical setup of the machine must also be changed over: Tools must be loaded, fixtures must be attached to the machine table, and the required machine settings must be entered. This changeover procedure takes time. Consequently, the typical cycle for a given product includes a period during which the setup and reprogramming takes place, followed by a period in which the batch is produced.

Flexible automation

Flexible automation is an extension of programmable automation. The concept of flexible automation has developed only over the last 15 to 20 years, and the principles are still evolving. A flexible automated system is one that is capable of producing a variety of products (or parts) with virtually no time lost for changeovers from one product to the next. There is no production time lost while reprogramming the system and altering the physical setup (tooling, fixtures and machine settings). Consequently, the system can produce various combinations and schedules of products, instead of requiring that they be made in separate batches.

The features of flexible automation can be summarized as follows:

1. High investment for a custom-engineered system
2. Continuous production of variable mixtures of products Medium production rates
3. Flexibility to deal with product design variations.

The essential features that distinguish flexible automation from programmable au-tomation are

(1) The capacity to change part programs with no lost production time

(2) The capability to change over the physical setup, again with no lost production time.

These features allow the automated production system to continue production without the downtime between batches that is characteristic of programmable automation. Changing the part programs is generally accomplished by preparing the programs off-line on a computer system and electronically transmitting the programs to the automated production system. Therefore, the time required to do the programming for the next job does not interrupt production on the current job. Advances in computer systems technology are largely responsible for this programming capability in flexible automation. Changing the physical setup between parts is accomplished by making the changeover off-line and then moving it into place simultaneously as the next part comes into position for processing. The use of pallet fixtures that hold the parts and transfer into position at the workplace is one way of implementing this approach. For these approaches to be successful, the variety of parts that can be made on a flexible automated production system is usually more limited than a system controlled by programmable automation.

The relative positions of the three types of automation for different production volumes and product varieties are depicted in Figure 5

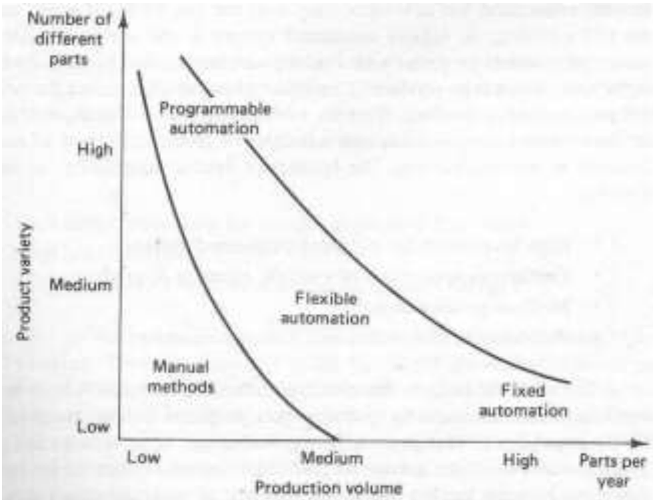


Figure 5 Three types of production automation as a function of volume of production verses product variety

1.8. REASONS FOR AUTOMATING

The important reasons for automating include the following:

1. ***Increased productivity***: Automation of manufacturing operations holds the promise of increasing the productivity of labor. This means greater output per hour of labor input. Higher production rates (output per hour) are achieved with automation than with the corresponding manual operations.

2. ***High cost of labor***: The trend in the industrialized societies of the world has been toward ever-increasing labor costs. As a result, higher investment in automated equipment has become economically justifiable to replace manual operations. The high cost of labor is forcing business leaders to substitute machines for human labor. Because machines can produce at higher rates of output, the use of automation results in a lower cost per unit of product.

3. ***Labor shortages:*** In many advanced nations there has been a general shortage of labor. Labor shortages also stimulate the development of automation as a substitute for labor.

4. ***Trend of labor toward the service sector:*** This trend has been especially prevalent in the advanced countries. First around 1986, the proportion of the work force employed in manufacturing stands at about 20%. In 1947, this percentage was 30%. By the year 2000, some estimates put the figure as low as 2%, certainly, automation of production jobs has caused some of this shift. The growth of

government employment at the federal, state, and local levels has consumed a certain share of the labor market which might otherwise have gone into manufacturing. Also, there has been a tendency for people to view factory work as tedious, demeaning, and dirty. This view has caused them to seek employment in the service sector of the economy.

5. ***Safe:*** By automating the operation and transferring the operator from an active participation to a supervisory role, work is made safer. The safety and physical well-being of the worker has become a national objective with the enactment of the Occupational. Safety and Health Act of 1970 (OSHA). It has also provided an impetus for automation.

6. ***High cost of raw materials:*** The high cost of raw materials in manufacturing results in the need for greater efficiency in using these materials. The reduction of scrap is one of the benefits of automation.

7. ***Improved product quality:*** Automated operations not only produce parts at faster rates than do their manual counterparts, but they produce parts with greater consistency and conformity to quality specifications.

8. ***Reduced manufacturing lead time:*** For reasons that we shall examine in sub sequent chapters, automation allows the manufacturer to reduce the time between customer order and product delivery. This gives the manufacturer a competitive advantage in promoting good customer service.

9. ***Reduction of in-process inventory:*** Holding large inventories of work-in-process represents a significant cost to the manufacturer because it ties up capital. In-process inventory is of no value. It serves none of the purposes of raw materials stock or finished product inventory. Accordingly, it is to the manufacturer's advantage to reduce work-in- progress to a minimum. Automation tends to accomplish this goal by reducing the time a workpart spends in the factory.

10. ***High cost of not automating:*** A significant competitive advantage is gained by

automating a manufacturing plant. The advantage cannot easily be demonstrated on a company's project authorization form. The benefits of automation often show up in intangible and unexpected ways, such as improved quality, higher sales, better labor relations, and better company image. Companies that do not automate are likely to find themselves at a competitive disadvantage with their customers, their employees, and the general public.

All of these factors act together to make production automation a feasible and attractive alternative to manual methods of manufacture.

1.9. TYPES OF PRODUCTION

Another way of classifying production activity is according to the quantity of product made. In this classification, there are three types of production:

1. Job shop production
2. Batch production
3. Mass production

1. Job shop production. The distinguishing feature of job shop production is low volume. The manufacturing lot sizes are small, often one of a kind. Job shop production is commonly used to meet specific customer orders, and there is a great variety in the type of work the plant must do. Therefore, the production equipment must be flexible and general-purpose to allow for this variety of work. Also, the skill level of job shop workers must be relatively high so that they can perform a range of different work assignments. Examples of products manufactured in a job shop include space vehicles, aircraft, machine tools, special tools and equipment, and prototypes of future products. Construction work and shipbuilding are not normally identified with the job shop category, even though the quantities are in the appropriate range. Although these two activities involve the transformation of raw materials into finished products, the work is not performed in a factory.

2. Batch production: This category involves the manufacture of medium-sized lots of the same item or product. The lots may be produced only once, or they may be produced at regular intervals. The purpose of batch production is often to satisfy continuous customer demand for an item. However, the plant is capable of a production rate that exceeds the demand rate. Therefore, the shop produces to build up an inventory of the item. Then it changes over to other orders. When the stock of the first item becomes depleted, production is repeated to build up the inventory again. The manufacturing equipment used in batch production is general-purpose but designed for higher rates of production. Examples of items made in batch-type shops include industrial equipment, furniture, textbooks, and component parts for many assembled consumer products (household appliances, lawn mowers, etc.). Batch production plants include machine shops, casting foundries, plastic molding factories, and press working shops. Some types of chemical plants are also in this general category.

3. Mass production: This is the continuous specialized manufacture of identical products. Mass production is characterized by very high production rates, equipment that is completely dedicated to the manufacture of a particular product, and very high demand rates for the product. Not only is the equipment dedicated to one product, but the entire plant is often designed for the exclusive purpose of producing the particular product. The equipment is special-purpose rather than general-purpose. The investment in machines and specialized tooling is high. In a sense, the production skill has been transferred from the operator to the machine. Consequently, the skill level of labor in a mass production plant tends to be lower than in a batch plant or job shop.

1.10. FUNCTIONS IN MANUFACTURING

For any of the three types of production, there are certain basic functions that must be carried out to convert raw materials into finished product. For a firm engaged in making discrete products, the functions are:

1. Processing

2. Assembly
3. Material handling and storage
4. Inspection and test
5. Control

The first four of these functions are the physical activities that "touch" the product as it is being made. Processing and assembly are operations that add value to the product. The third and fourth functions must be performed in a manufacturing plant, but they do not add value to the product. The Figure 6, shows the model of the functions of manufacturing in factory.

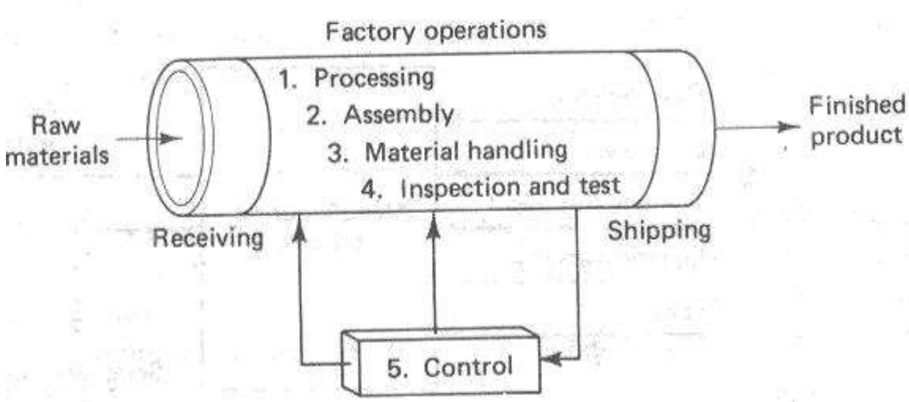


Figure 6 Model of the factory showing five functions of manufacturing

Processing operations

Processing operations transform the product from one state of completion into a more advanced state of completion. Processing operations can be classified into one of the following four categories:

1. Basic processes
2. Secondary processes
3. Operations to enhance physical properties
4. Finishing operations

Basic processes are those which give the work material its initial form. Metal casting and plastic molding are examples. In both cases, the raw materials are converted into the basic geometry of the desired product.

Secondary processes follow the basic process and are performed to give the work part its final desired geometry. Examples in this category include machining (turning, drilling, milling, etc.) and press working operations (blanking, forming, drawing, etc.).

Operations to enhance physical properties do not perceptibly change the physical geometry of the work part. Instead, the physical properties of the material are improved in some way. Heat-treating operations to strengthen metal pans and preshrinking used in the garment industry are examples in this category.

Finishing operations are the final processes performed on the work part. Their purpose is, for example, to improve the appearance, or to provide a protective coating on the part. Examples in this fourth category include polishing, painting, and chrome plating.

Figure 6 presents an input/output model of a typical processing operation in manufacturing. Most manufacturing processes require five inputs:

1. Raw materials
2. Equipment
3. Tooling, fixtures
4. Energy (electrical energy)
5. Labor

Assembly operations

Assembly and joining processes constitute the second major type of manufacturing operation. In assembly, the distinguishing feature is that two or more separate components are joined together. Included in this category are mechanical fastening operations, which make use of screws, nuts, rivets, and so on, and joining processes, such as welding, brazing, and soldering. In the fabrication of a product, the assembly operations follow the processing operations.

Material handling and storage

A means of moving and storing materials between the processing and assembly operations must be provided. In most manufacturing plants, materials spend more time being moved and stored than being processed. In some cases, the majority of the labor cost in the factory is consumed in handling, moving, and storing materials. It is important that this function be carried out as efficiently as possible.

Inspection and testing

Inspection and testing are generally considered part of quality control. The purpose of inspection is to determine whether the manufactured product meets the established design standards and specifications. For example, inspection examines whether the actual di-mensions of a mechanical part are within the tolerances indicated on the engineering drawing for the part and testing is generally concerned with the functional specifications of the final product rather than the individual parts that go into the product.

Control

The control function in manufacturing includes both the regulation of individual processing and assembly operations, and the management of plant-level activities. Control at the process level involves the achievement of certain performance objectives by proper ma-nipulation of the inputs to the process. Control at the plant level includes effective use of labor, maintenance of the equipment, moving materials in the factory, shipping products of good quality on schedule, and keeping plant operating costs at the minimum level possible. The manufacturing control function at the plant level represents the major point of intersection between the physical operations in the factory and the information-processing activities that occur in production.

1.11. ORGANIZATION-AMD INFORMATION PROCESSING IN MANUFACTURING

Manufacturing firms must organize themselves to accomplish the five functions described above. Figure 7 illustrates the cycle of information-processing activities that typically occur in a manufacturing firm which produces discrete parts and assembles them into final products for sale to its customers. The factory operations described in the preceding section are pictured in the center of the figure. The information-processing cycle, rep-resented by the outer ring, can be described as consisting of four functions:

1. Business functions
2. Product design
3. Manufacturing planning
4. Manufacturing control

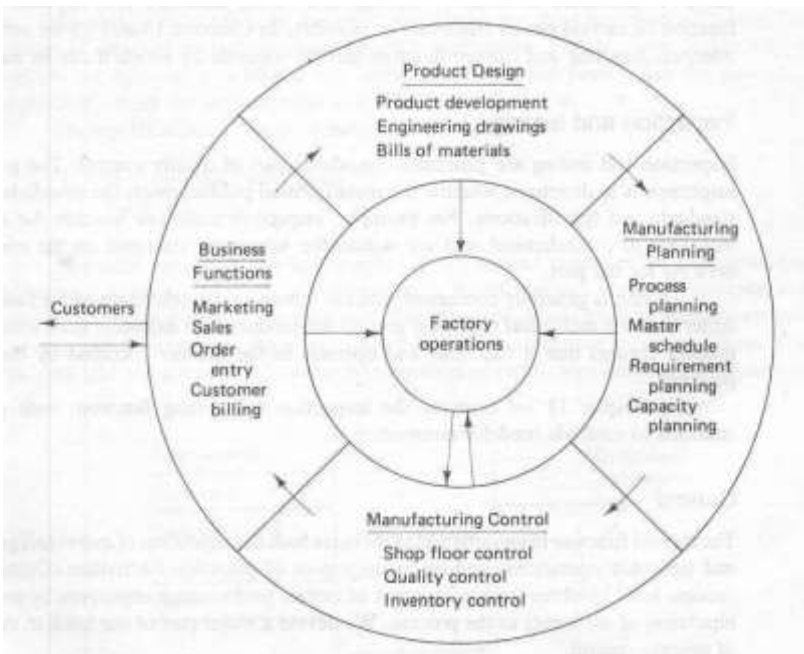


Figure 7 Information-processing cycle in a typical manufacturing firm

Business functions

The business functions are the principal means of communicating with the customer. They are the beginning and the end of the information-processing cycle. Included within this category are sales and marketing, sales forecasting, order entry, cost accounting, customer billing, and others.

An order to produce a product will typically originate from the sales and marketing department of the firm. The production order will be one of the following forms: (1) an order to manufacture an item to the customer's specifications, (2) a customer order to buy one or more of the manufacturer's, proprietary products, or (3) an order based on a forecast of future demand for a proprietary product.

Product design

If the product is to be manufactured to customer specifications, the design will have been provided by the customer. The manufacturer's product design department will not be involved.

If the product is proprietary, the manufacturing firm is responsible for its development and design. The product design is documented by means of component drawings, specifications, and a bill of materials that defines how many of each component goes into the product.

Manufacturing planning

The information and documentation that constitute the design of the product flow into the *manufacturing planning* function. The departments in the organization that perform manufacturing planning include manufacturing engineering, industrial engineering, and production planning and control.

As shown in Figure 7, the in formation-processing activities in manufacturing planning include process planning, master scheduling, requirements planning, and capacity planning. *Process planning* consists of determining the sequence of the individual processing and assembly operations needed to produce the part. The document used to specify the process sequence is called a *route sheet.* The route sheet lists the production operations and associated machine tools for each component (and subassembly) of the product. The manufacturing engineering and industrial engineering departments are responsible for planning the processes and related manufacturing details. The authorization to produce the product must be translated into the master schedule or master production schedule. The *master schedule* is a listing of the products to be made, when they are to be delivered, and in what quantities. Units of months are generally used to specify the deliveries on the master schedule. Based on this schedule, the individual components and subassemblies that make up each product must be planned. Raw materials must be requisitioned, purchased parts must be ordered from suppliers, and all of these items must be planned so that they are available when needed. This whole task is called *requirements planning* or *material requirements planning.* In addition, the master schedule must not list more quantities of products than the factory is capable of producing with its given number of machines and workers each month. The production quantity that the factory is capable of producing is referred to as the plant capacity. We will define and discuss this term later in the chapter. *Capacity planning* is concerned with planning the manpower and machine resources of the firm.

Manufacturing control

Manufacturing control is concerned with managing and controlling the physical operations in the factory to implement the manufacturing plans.

Shop floor control is concerned with the problem of monitoring the progress of the product as it is being processed, assembled, moved, and inspected in the factory. The sections of a traditional production planning and control department that are involved in shop floor control include scheduling, dispatching, and expediting. Production scheduling is concerned with assigning start dates and due dates to the various parts (and products) that are to be made in the factory. This requires that the parts be scheduled one by one through the various production machines listed on the route sheet for each part. Based on the production schedule, *dispatching* involves issuing the individual work orders to the machine operators to accomplish the processing of the parts. The dispatching function is performed in some plants by the shop foremen, in other plants by a person called the dispatcher. Even with the best plans and schedules, things sometimes go wrong (e.g., machine breakdowns, improper tooling, parts delayed at the vendor). The *expediter* compares the actual progress of a production order against the schedule. For orders that fall behind, the expediter attempts to take the necessary corrective action to complete the order on time.

Inventory control overlaps with shop floor control to some extent. *Inventory control* attempts to strike a proper balance between the danger of too little inventory (with possible stock-outs of materials) and the expense of having too much inventory. Shop floor control is also concerned with inventory in the sense that the materials being processed in the factory represent inventory (called work-in-process). The mission of quality *control* is to assure that the quality of the product and its components meet the standards specified by the product designer. To accomplish its mission, quality control depends on the inspection activities performed in the factory at various times throughout the manufacture of the product. Also, raw materials and components from outside sources must be inspected when they are received. Final inspection and testing of the finished product is performed to ensure functional quality and appearance.

1.12. PRODUCTION CONCEPTS AND MATHEMATICAL MODELS

A number of production concepts are quantitative, or require a quantitative approach to measure them.

Manufacturing lead time

Our description of production is that it consists of a series of individual steps: processing and assembly operations. Between the operations are material handling, storage, inspections, and other nonproductive activities. Let us therefore divide the activities in production into two main categories, operations and non operation elements. An operation on a product (or work part) takes place when it is at the production machine. The non operation elements

are the handling, storage, inspections, and other sources of delay. Let us use T_o *to* denote the lime per operation at a given machine or workstation, and T_{no} to represent the non operation

time associated with the same machine. Further, let us suppose that there are n_m separate machines or operations through which the product must be routed in order to be completely processed. If we assume a batch production situation, there are Q units of the product in the batch, A setup procedure is generally required to prepare each production machine for the particular product. The setup typically includes arranging the workplace and installing the

tooling and fixturing required for the product. Let this setup time be denoted as T_m.

Given these terms, we can define an important production concept, manufacturing lead time. The *manufacturing lead lime* (MLT) is the total time required to process a given product (or work part) through the plant. We can express it as follows:

$$MLT = \sum_{i=1} \left(T_{sui} + QT_{oi} + T_{noi} \right)$$

Where i indicates the operation sequence in the processing, i = 1,2, . .n The MLT equation does not include the time the raw work part spends in storage before its turn in the production schedule begins.

Let us assume that all operation times, setup times, and non operation times are equal, respectively then MLT is given by

$$MLT = n_m \left(T_{su} + QT_o + T_{no} \right)$$

For mass production, where a large number of units are made on a single machine, the MLT simply becomes the operation time for the machine after the setup has been completed and production begins.

For flow-type mass production, the entire production line is set up in advance. Also, the non operation time between processing steps consists simply of the time to transfer the product (or pan) from one machine or workstation to the next. If the workstations are integrated so that parts are being processed simultaneously at each station, the station with the longest operation time will determine the MLT value. Hence,

$$MLT = n_m \left(Transfer\ time + Longst\ T_o \right)$$

In this case, n_m represents the number of separate workstations on the production line.

The values of setup time, operation time, and non operation time are different for the different production situations. Setting up a flow line for high production requires much more time than setting up a general-purpose machine in a job shop. However, the concept of how time is spent in the factory for the various situations is valid.

1.13. Numerical Problems

Problem .1

A certain part is produced in a batch size of 50 units and requires a sequence of eight operations in the plant. The average setup time is 3 h, and the average operation time per machine is 6 min. The average non operation time due to handling, delays, inspections, and so on, is 7 h. compute how many days it will take to produce a batch, assuming that the plant operates on a 7-h shift per day.

Solution:

The manufacturing lead time is computed from

$$MLT = n_m \left(T_{su} + QT_o + T_{no} \right)$$

$$MLT = {}_m 8 \left(3 + 50 \times 0.1 + 7 \right) = 120\ Hr$$

Production Rate

The production rate for an individual manufacturing process or assembly operation is usually expressed as an hourly rate (e.g., units of product per hour). The rate will be symbolized as R_p

$$R_P = \frac{1}{T_P}$$

Where T_P is given by

$$T_P = \frac{\text{Batch time per Machine}}{Q}$$

$$T_P = \frac{(T_{su} + QT_o)}{Q}$$

Components of the operation time

The components of the operation time T_o, The operation time is the time an individual workpart spends on a machine, but not all of this time is productive. Let us try to relate the operation time to a specific process. To illustrate, we use a machining operation, as machining is common in discrete-parts manufacturing. Operation lime for a machining operation is composed of three elements: the actual machining time T_m, the workpiece handling time T_h, and any tool handling time per workpiece T_h. Hence,

$$T_o = T_m + T_h + T_{th}$$

The tool handling time represents all the time spent in changing tools when they wear out, changing from one tool to the next for successive operations performed on a turret lathe, changing between the drill bit and tap in a drill-and-tap sequence performed at one drill press, and so on. $T_{,h}$ is the average time per workpiece for any and all of these tool handling activities.

Each of the terms T_m,T_h, and $T_{,h}$ has its counterpart in many other types of discrete-item production operations. There is a portion of the operation cycle, when the material is actually being worked (T_m), and there is a portion of the cycle when either the work part is being handled (T_k) or the tooling is being adjusted or changed ($T_{,h}$). We can therefore generalize on Eq. (2.8) to cover many other manufacturing processes in addition to machining.

Capacity

The term *capacity,* or *plant capacity,* is used to define the maximum rate of output that a plant is able to produce under a given set of assumed operating conditions. The assumed operating conditions refer to the number of shifts per day (one, two, or three), number of days in the week (or month) that the plant operates, employment levels, whether or not overtime is included, and so on. For continuous chemical production, the plant may be operated 24 h per day, 7 days per week.

Let *PC* be the production capacity (plant capacity) of a given work center or group of work centers under consideration. Capacity will be measured as the number of good units produced per week. Let *W* represent the number of work centers under consideration. A work center is a production system in the plant typically consisting of one worker and one machine. It might also be one automated machine with no worker, or several workers acting together on a production line. It is capable of producing at a rate R_p units per hour. Each work center operates for *H* hours per shift. *H* is an average that excludes time for machine breakdowns and repairs, maintenance, operator delays, and so on. Provision for setup time is also included.

Problem 2

The turret lathe section has six machines, all devoted to production of the same pad. The section operates 10 shifts per week. The number of hours per shift averages 6.4 because of operator delays and machine breakdowns. The average production rate is 17 units/h. Determine the production capacity of the turret lathe section.

Solution:

$$PC = 6(10)(6.4)(17) = 6528 \text{ units/week}$$

If we include the possibility that in a batch production plant, each product is routed through n_m machines, the plant capacity equation must be amended as follows:

$$PC = \frac{(WS_w HR_p)}{n_m}$$

Another way of using the production capacity equation is for determining how resources might be allocated to meet a certain weekly demand rate requirement. Let D_w be the demand rate for the week in terms of number of units required. Replacing *PC* and rearranging, we get

$$WS_w H = \frac{(D_w n_m)}{R_p}$$

Given a certain hourly production rate for the manufacturing process, indicates three possible ways of adjusting the capacity up or down to meet changing weekly demand requirements:

1. Change the number of work centers, *W*, in the shop. This might be done by using equipment that was formerly not in use and by hiring new workers. Over the long term, new machines might be acquired.

2. Change the number of shifts per week, 5_W. For example, Saturday shifts might be authorized.

3. Change the number of hours worked per shift, W. For example, overtime might be authorized.

In cases where production rates differ, the capacity equations can be revised, summing the requirements for the different products.

$$WS_W H = \sum (D_W n_m)$$

Problem 3

Three products are to be processed through a certain type of work center. Pertinent data are given in the following table.

Product	*Weekly demand*	*Production rale (units/hi*
1	600	10
2	1000	20
3	2200	40

Determine the number of work centers required to satisfy this demand, given that the plant works 10 shifts per week and there are 6.5 h available for production on each work center for each shift. The value of n_m = 1.

Solution:

Product	*Weekly demand*	*ProductionHrs*
1	600	600/10
2	1000	1000/20

3	2200	2200/40
Total production hours required		165

Since each work center can operate (10 shifts/week)(6.5 h) or 65 h/week, the total number of work centers is

W = 165/65 = 2.54 work centers ≈3

Utilization

Utilization refers to the amount of output of a production facility relative to its capacity. Letting *U* represent utilization, we have

$$U = \frac{\text{Output}}{\text{Capacity}}$$

Problem 4

A production machine is operated 65 h/week at full capacity. Its production rate is 20 units/hr. During a certain week, the machine produced 1000 good parts and was idle the remaining time.

(a) Determine the production capacity of the machine.

(b) What was the utilization of the machine during the week under consideration?

Solution:

(a) The capacity of the machine can be determined using the assumed 65-h week as follows:

PC = 65(20) = 1300 units/week

(b) The utilization can be determined as the ratio of the number of parts made during productive use of the machine relative to its capacity.

$$U = \frac{Output}{Capacity} = \frac{1000}{1300} = 76.92\%$$

Availability

The availability is sometimes used as a measure of-reliability for equipment. It is especially germane for automated production equipment. Availability is defined using two other reliability terms, the *mean lime between failures* (MTBF) and the *mean time to repair* (MTTR). The MTBF indicates the average length of time between breakdowns of the piece of equipment. The MTTR indicates the average time required to service the equipment and place it back into operation when a breakdown does occur:

$$Availability = \frac{MTBF - MTTR}{MTBF}$$

Work-in-process

Work-in-process (WIP) is the amount of product currently located in the factory that is either being processed or is between processing operations. WIP is inventory that is in the state of being transformed from raw material to finished product. A rough measure of work-in-process can be obtained from the equation

$$WIP = \frac{PC\,U}{S_W\,H}(MLT)$$

Where WIP represents the number of units in-process.

Eugene Merchant, an advocate and spokesman for the manufacturing industry for many years, has observed that materials in a typical metal machining batch factory spend more time waiting or being moved than in processing. His observation is illustrated in Figure 8 About 95% of the time of a workpart is spent either moving or waiting; only 5% of its time is spent on the machine tool. Of this 5%, less than 30% of the time at the machine (1.5% of the total time of the pan) is time during which actual cutting is taking place. The remaining 70% (3.5% of the total) is required for loading and unloading, positioning, gaging, and other causes of nonprocessing time. These time proportions are evidence of the inefficiencies with which work-in-process is managed in the factory.

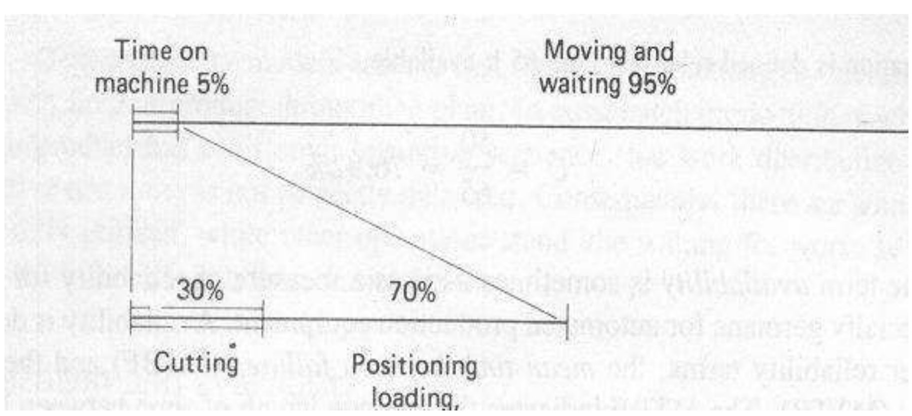


Figure 8 Time spent a part in batch production shop

Two measures that can be used to assess the magnitude of the work-in-process problem in a given factory are the WIP ratio and the TIP ratio. The WIP *ratio* provides an indication of the amount of inventory-in-process relative to the work actually being processed. It is the total quantity of a given part (or assembly) in the plant or section of the plant divided by the quantity of the same part that is being processed (or assembled).

The WIP ratio is therefore determined as

$$WIP\ ratio = \frac{WIP}{Number\ of\ machine\ processing}$$

$$Number\ of\ processing\ machine = WU \frac{QT_0}{T_{su} + QT_0}$$

The ideal WIP ratio is 1: 1, which implies that all parts in the plant are being processed. In a high-volume flow line operation, we would expect the WIP ratio to be relatively close to I: I if we ignore the raw product that is waiting to be launched onto the line and the finished product that has been completed. In a batch production shop, the WIP ratio is significantly higher, perhaps 50: 1 or higher, depending on the average batch size, nonproductive time, and other factors in the plant.

The *TIP* ratio measures the time that the product spends in the plant relative to its actual processing time. It is computed as the total manufacturing lead time for a pan divided by the sum of the individual operation times for the part.

$$TIP\ ratio = \frac{MLT}{n_m T_0}$$

Again, the ideal TIP ratio is 1: 1, and again it is very difficult to achieve such a low ratio in practice. In the Merchant observation of Figure 2.6, the TIP ratio = 20: 1.

It should be noted that the WIP and TIP ratios reduce to the same value in our simplified model of manufacturing presented in this section. This can be demonstrated mathematically. In an actual factory situation, the WIP and TIP ratios would not nec- essarily be equal, owing to the complexities and realities encountered in the real world. For example, assembled products create complications in evaluating the ratio values because of the combination of parts into one assembly.

AUTOMATION STRATEGIES

There are certain fundamental strategies that tan be employed to improve productivity in manufacturing operations. Since these strategies are often implemented by means of automation technology,

1. ***Specialization of operations:*** The first strategy involves the use special-purpose equipment designed to perform one operation with the greatest possible

   efficiency. This is analogous to the concept of labor specialization, which has been employed to improve labor productivity. $\text{Re}\ duce\ T_o$
2. ***Combined operations:*** Production occurs as a sequence of operations. Com-plex pans may require dozens, or even hundreds, of processing steps. The strategy of

combined operations involves reducing the number of distinct production machines on workstations through which the part must be routed.

$\text{Re}\,duce\; n_m, T_h, T_{no}, T_{su}$

3. ***Simultaneous operations:*** A logical extension of the combined operations strategy is to perform at the same time the operations that are combined at one workstation. In effect, two or more processing (or assembly) operations are being performed simultaneously on the same workpart, thus reducing total processing time.

$\text{Re}\,duce\; n_m, T_h, T_{no}, T_{su}, T_o$

4. **Integration *of operations.*** Another strategy is to link several workstations into a single integrated mechanism using automated work handling devices to transfer parts between stations. In effect, this reduces the number of separate machines through which the product must be scheduled. With more than one workstation, several parts can be processed simultaneously, thereby increasing the overall output of the system.

$\text{Re}\,duce\; n_m, T_h, T_{no}, T_{su}$

5. ***Increased flexibility.*** This strategy attempts to achieve maximum utilization of equipment for job shop and medium-volume situations by using the same equipment for a variety of products. This normally translates into lower manufacturing lead time and lower work-in-process.

$\text{Re}\,duce\; T_{su}, MLT, WIP, \; increase\; U$

6. **Improved *material* handling *and storage.*** A great opportunity for reducing nonproductive time exists in the use of automated material handling and storage systems. Typical benefits included reduced work-in-process and shorter manufacturing lead times.

$\text{Re}\,duce\; T_{no}, MLT, WIP$

7. ***On*-line inspection.** Inspection for quality of work is traditionally performed after the process. This means that any poor-quality product has already been produced by the time it is inspected. Incorporating inspection into the manufacturing process permits corrections to the process as product is being made. This reduces scrap and brings the overall quality of product closer to the nominal specifications intended by the designer.

$\text{Re}\,duce\; T_{no}, MLT, q$

8. ***Process* control *and optimization*.** This includes a wide range of control schemes

intended to operate the individual processes and associated equipment more efficiently. By this strategy, the individual process times can be reduced and product quality improved.

$$\text{Re}\,duce\ T_o\ ,q\ ,\ improved\ quality\ control$$

9. ***Plant* operations *control.*** Whereas the previous strategy was concerned with the control of the individual manufacturing process, this strategy is concerned with control at the plant level. It attempts to manage and coordinate the aggregate operations in the plant more efficiently. Its implementation usually involves a high level of computer networking within the factory,

$$\text{Re}\,duce\ T_{no}\ ,MLT\ ,\ increase\ U$$

10. ***Computer* integrated *manufacturing (CIM).*** Taking the previous strategy one step further, we have the integration of factory operations with engineering design and many of the other business functions of the firm. CIM involves extensive use of computer applications, computer data bases, and computer networking in the company.

$$\text{Re}\,duce\ MLT\ ,\ increase\ U\ ,\ design\ time\ production\ planning\ time$$

<u>OUTCOMES:</u>

Students will be able to

1. Use mathematical models to analyze production parameters.
2. Distinguish different automations with its features.
3. Understand different types of production systems.

<u>QUESTIONAIRE</u>

1. Define automation. Explain its types.
2. List and explain types of production systems.
3. List and mathematical models. Represent them mathematically.
4. Write a note on WIP , Availability, TIP.

<u>FURTHER READING</u>

1. http://productlifecyclestages.com/
2. http://papers.sae.org/2002-01-2120/
3. http://www.yourarticlelibrary.com/products/product-life-cycle-definition-assumption-and-stages/48626/

UNIT 2
AUTOMATED FLOW LINES

CONTENTS:

OBJECTIVES:

1. To understand different configurations involved in automated flow lines.
2. To understand different transfer mechanisms used for workpart transportation.
3. To understand concepts like buffer storage and control functions.

2.1. Introduction

An automated flow line consists of several machines or workstations which are linked together by work handling devices that transfer parts between the stations. The transfer of workparts occurs automatically and the workstations carry out their specialized functions automatically. The flow line can be symbolized as shown in Figure1 using the symbols presented in Table1. A raw workpart enters one end of the line and the processing steps are performed sequentially as the part moves from one station to the next. It is possible to incorporate buffer storage zones into the flow line, either al a single location or between every workstation. It is also possible to include inspection stations in the line to automatically perform intermediate checks on the quality of the workparts. Manual stations might also be located along the flow line to perform certain operations which are difficult or uneconomical to automate.

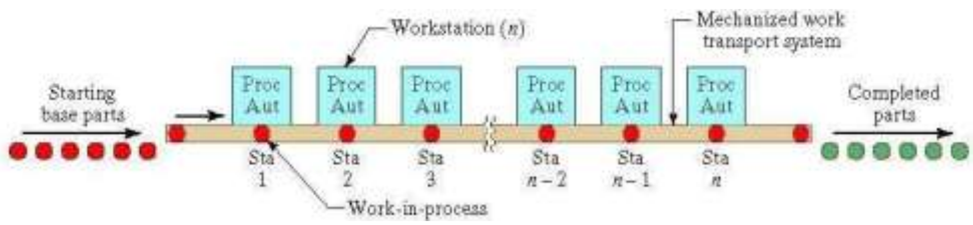


Figure 1 In-line configuration

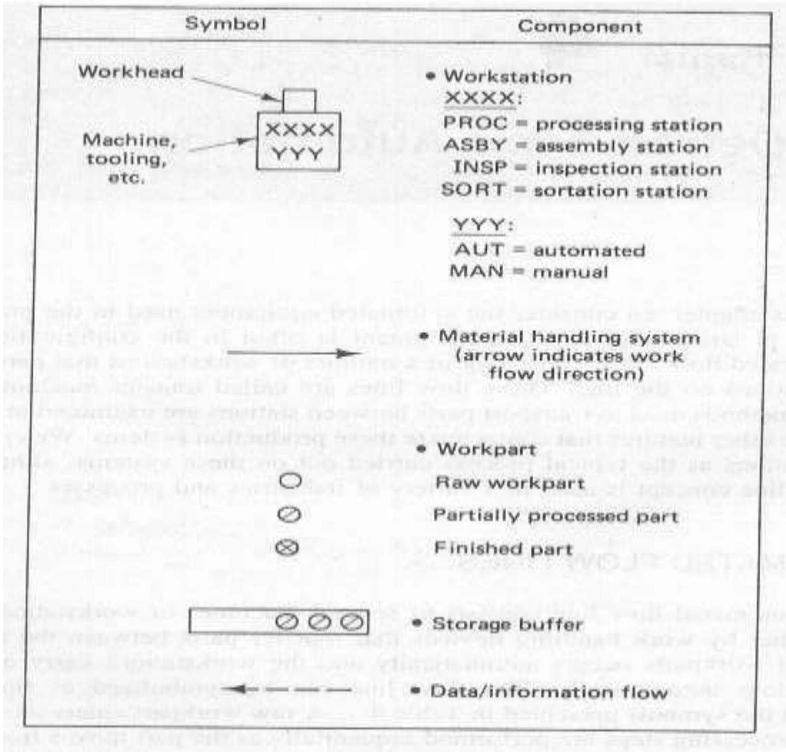


Figure 2 symbols used in production systems diagrams

The objectives of the use of flow line automation are, therefore:

To reduce labor costs

To increase production rates

To reduce work-in-process

To minimize distances moved between operations

To achieve specialization of operations

To achieve integration of operations

2.2. Configurations of automated flow line.

1) In-line type

The *in-line* configuration consists of a sequence of workstations in a more-or-straight-line arrangement as shown in figure 1. An example of an less in-line machine used for metal-cutting operations is illustrated in Figure 4 and transfer 5.

Figure 4 Example of 20 stations In-line

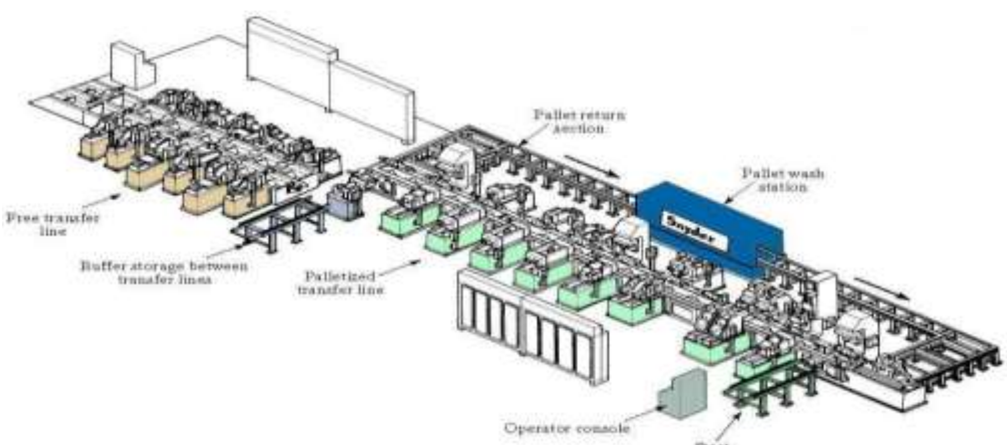


Figure 5 Example of 20 stations In-line configuration

2) Segmented In-Line Type

The segmented *in-line* configuration consists of two or more straight-line arrangement which are usually perpendicular to each other with L-Shaped or U-shaped or Rectangular shaped as shown in figure 5-7. The flow of work can take a few 90° turns, either for workpieces reorientation, factory layout limitations, or other reasons, and still qualify as a straight-line configuration.

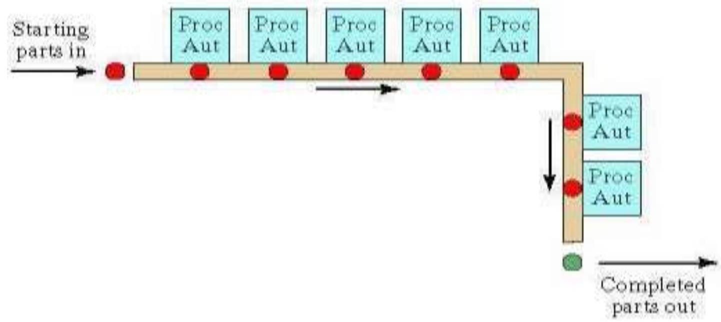


Figure 5 L-shaped configuration

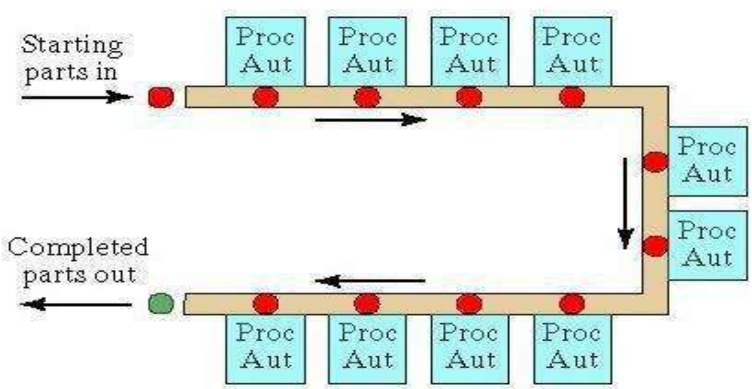


Figure 6 U-shaped configuration

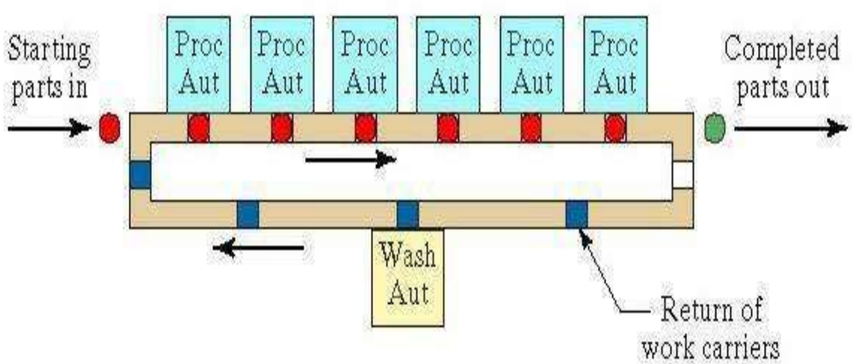


Figure 7 Rectangular-shaped configuration

3) Rotary type

In the *rotary* configuration, the workparts are indexed around a circular table or dial. The workstations are stationary and usually located around the outside periphery of the dial. The parts ride on the rotating table and arc registered or positioned, in turn, at each station for its processing or assembly operation. This type of equipment is often referred to as an *indexing machine* or *dial index machine* and the configuration is shown in Figure 8 and example of six station rotary shown in figure 9.

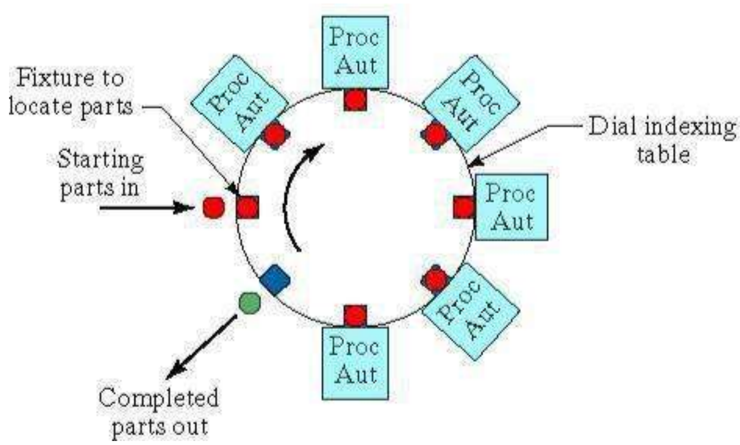


Figure 8 Rotary configuration

Figure 9 Example of 6 station rotary configuration

2.3. METHODS OF WORKPART TRANSPORT

The transfer mechanism of the automated flow line must not only move the partially completed workparts or assemblies between adjacent stations, it must also orient and locate the parts in the correct position for processing at each station. The general methods of transporting workpieces on flow lines can be classified into the following three categories:

1. Continuous transfer
2. Intermittent or synchronous transfer
3. Asynchronous or power-and-free transfer

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

The types of operation to be performed
The number of stations on the line
The weight and size of the work parts
Whether manual stations are included on the line
Production rate requirements
Balancing the various process times on the line

1) Continuous transfer

With the continuous method of transfer, the workparts are moved continuously at Constant speed. This requires the workheads to move during processing in order to maintain continuous registration with the workpart. For some types of operations, this movement of the workheads during processing is not feasible. It would be difficult, for example, to use this type of system on a machining transfer line because of inertia problems due to the size and weight of the workheads. In other cases, continuous transfer would be very practical. Examples of its use are in beverage bottling operations, packaging, manual assembly operations where the human operator can move with the moving flow line, and relatively simple automatic assembly tasks. In some bottling operations, for instance, the bottles are transported around a continuously rotating drum. Beverage is discharged into the moving bottles by spouts located at the drum's periphery. The advantage of this application is that the liquid beverage is kept moving at a steady speed and hence there are no inertia problems. Continuous transfer systems are relatively easy to design and fabricate and can achieve a high rate of production.

2) Intermittent transfer

As the name suggests, 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. All workparts are transported at the same time and, for this reason, the term "synchronous transfer system" is also used to describe this method of workpart transport.

3) Asynchronous transfer

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 sta-tions.

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 systems can also compensate for line balancing problems where there are significant differences in process times between stations. Parallel stations or several series stations can be used for the longer operations, and single stations can be used for the shorter operations. Therefore, the average production rates can be approximately equalized. Asynchronous lines are often used where there are one or more manually operated stations and cycle-time variations would be a problem on either the continuous or synchronous transport systems. Larger workparts can be handled on the asynchronous systems. A disadvantage of the power- and-free systems is that the cycle rates are generally slower than for the other types.

2.4. TRANSFER MECHANISMS

There are various types of transfer mechanisms used to move parts between stations. These mechanisms can be grouped into two types: those used to provide linear travel for in-line machines, and those used to provide rotary motion for dial indexing machines.

Linear transfer mechanisms

We will explain the operation of three of the typical mechanisms; the walking beam transfer bar system, the powered roller conveyor system, and the chain-drive conveyor system. This is not a complete listing of all types, but it is a representative sample.

Walking beam systems

With the walking beam transfer mechanism, the work-parts are lifted up from their workstation locations by a transfer bar and moved one position ahead, to the next station. The transfer bar then lowers the pans into nests which position them more accurately for processing. This type of transfer device is illustrated in Figure10 and 11. For speed and accuracy, the motion of the beam is most often generated by a rotating camshaft powered by an electric motor or a roller movement in a profile powered by hydraulic cylinder. Figure 12 shows the working of the beam mechanish.

Figure 10 Almac Industrial Systems, the Ontario-based manufacturer of material handling equipment- Walking Beam'.

Figure 11 SIKAMA INTERNATIONAL has developed a Walking beam mechanism for FALCON 1200 and 8500

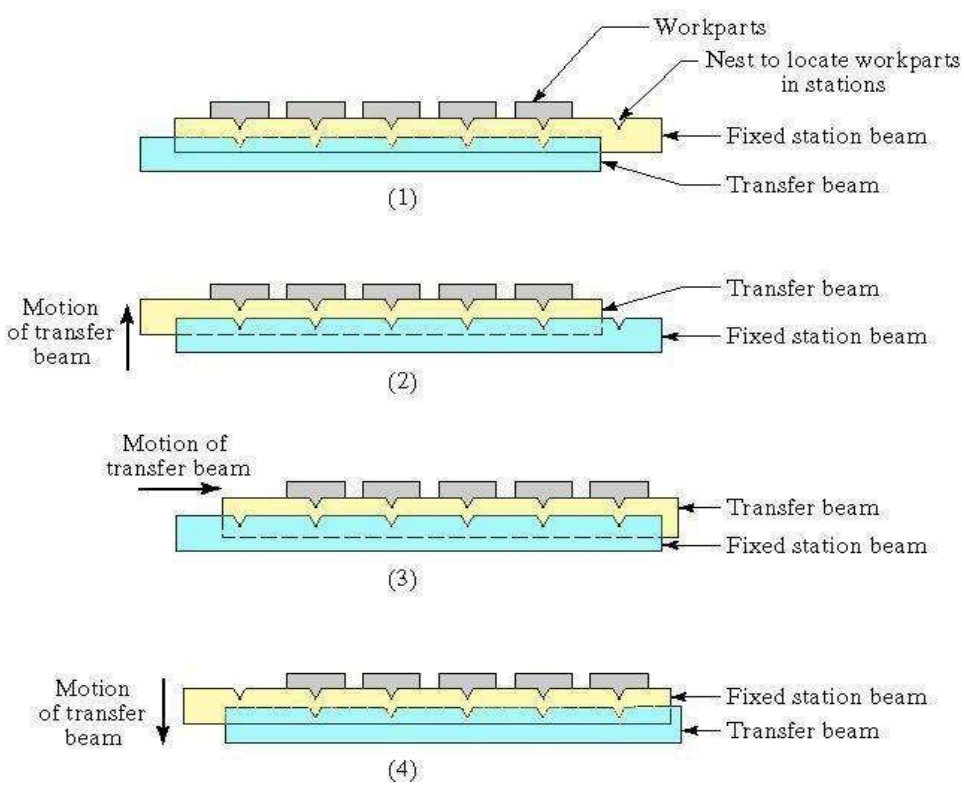


Figure 12 walking beam transfer system, showing various stage during transfer stage

Powered roller conveyor system

This type of system is used in general stock handling systems as well as in automated flow lines. The conveyor can be used to move pans or pallets possessing flat riding surfaces. The rollers can be powered by either of two mechanisms. The first is a belt drive, in which a flat moving belt beneath the rollers provides the rotation of the rollers by friction. A chain drive is the second common mechanism used to power the rollers. Powered roller conveyors are versatile transfer systems because they can be used to divert work pallets into workstations or alternate tracks.

(13 a)

(13 b)

Figure 13 a, b and c Power Conveyor

Chain-drive conveyor system

In chain-drive conveyor system either a chain or a flexible steel belt is used to transport the work carriers. The chain is driven by pulleys in either an "over-and- under" configuration, in which the pulleys turn about a horizontal axis, or an "around-the-corner" configuration, in which the pulleys rotate about a vertical axis. Figure 14 shows the chain conveyor transfer system.

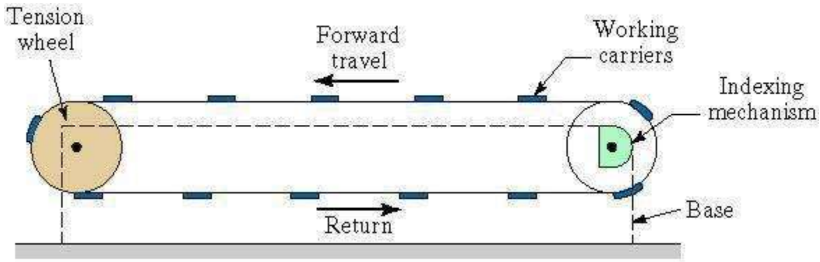


Figure 14 Chain drive conveyor

This general type of transfer system can be used for continuous, intermittent, or nonsynchronous movement of workparts. In the nonsynchronous motion, the workparts are pulled by friction or ride on an oil film along a track with the chain or belt providing the movement. It is necessary to provide some sort of final location for the workparts when they arrive at their respective stations.

Rotary transfer mechanisms

There are several methods used to index a circular table or dial at various equal angular positions corresponding to workstation locations.

Rack and pinion

This mechanism is simple but is not considered especially suited to the high- speed operation often associated with indexing machines. The device is pictured in Figure 4.6 and uses a piston to drive the rack, which causes the pinion gear and attached indexing table to rotate, A clutch or other device is used to provide rotation in the desired direction.

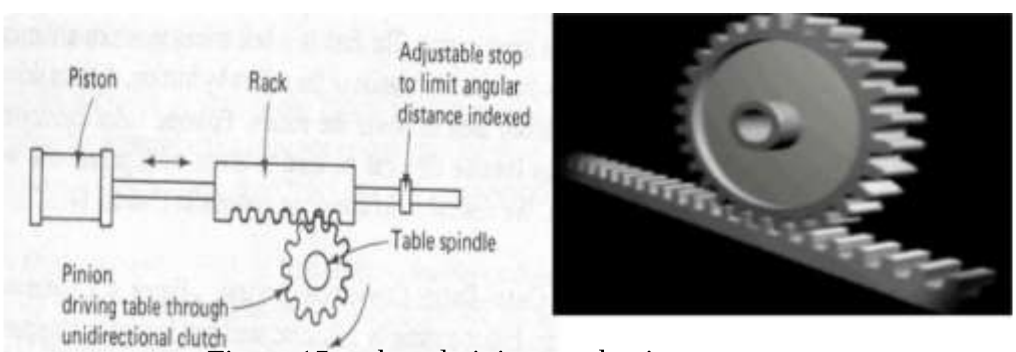


Figure 15 rack and pinion mechanisms

Ratchet and pawl:

A ratchet is a device that allows linear or rotary motion in only one direction, while preventing motion in the opposite direction.

Ratchets consist of a gearwheel and a pivoting spring loaded finger called a pawl that engages the teeth. Either the teeth, or the pawl, are slanted at an angle, so that when the teeth are moving in one direction, the pawl slides up and over each tooth in turn, with the spring forcing it back with a 'click' into the depression before the next tooth. When the teeth are moving in the other direction, the angle of the pawl causes it to catch against a tooth and stop further motion in that direction. This drive mechanism is shown in Figure 16.

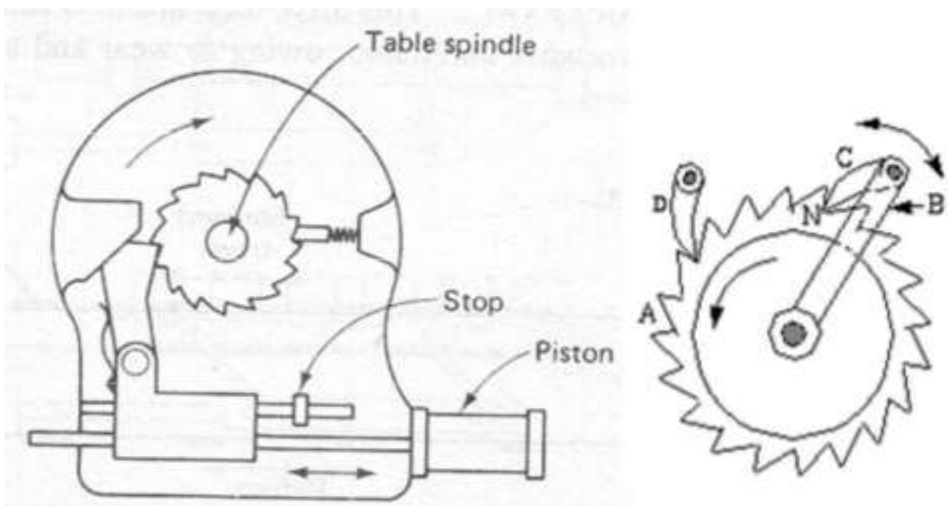


Figure 16 Rachet and pawl mechanism

Geneva mechanism:

The two previous mechanisms convert a linear motion into a rotational motion. The Geneva mechanism uses a continuously rotating driver to index the table, as pictured in Figure 17. If the driven member has six slots for a six-station dial indexing machine, each turn of the driver will cause the table to advance one- sixth of a turn. The driver only causes movement of the table through a portion of its rotation. For a six-slotted driven member, 120° of a complete rotation of the driver is used to index the table. The other 240° is dwell. For a four-slotted driven member, the ratio would be 90° for index and 270° for dwell. The usual number of indexings per revolution of the table is four, five, six, and eight.

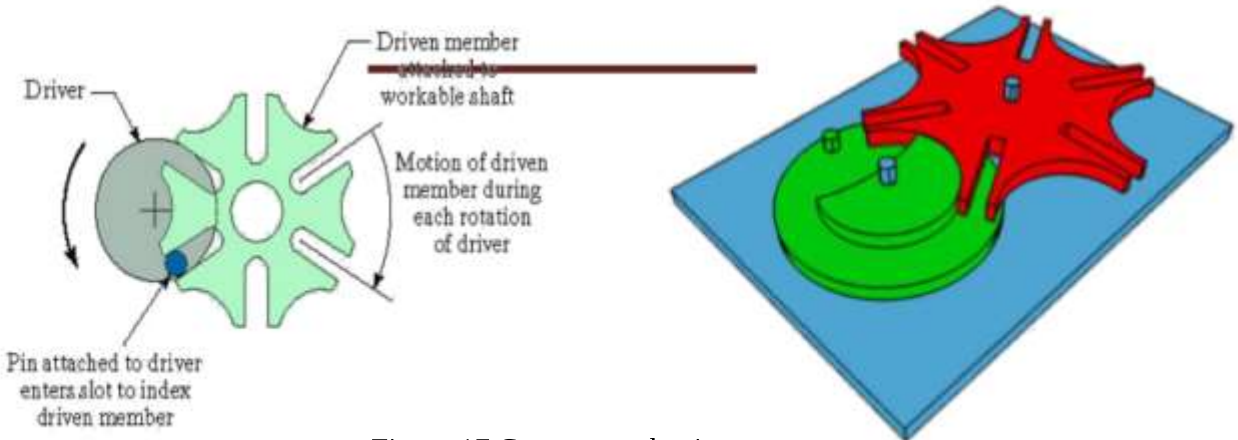


Figure 17 Geneva mechanism

CAM Mechanisms:

Various forms of cam mechanism, an example of which is illustrated in Figure 18, provide probably the most accurate and reliable method of indexing the dial. They are in widespread use in industry despite the fact that the cost is relatively high compared to alternative mechanisms. The cam can be designed to give a variety of velocity and dwell characteristics.

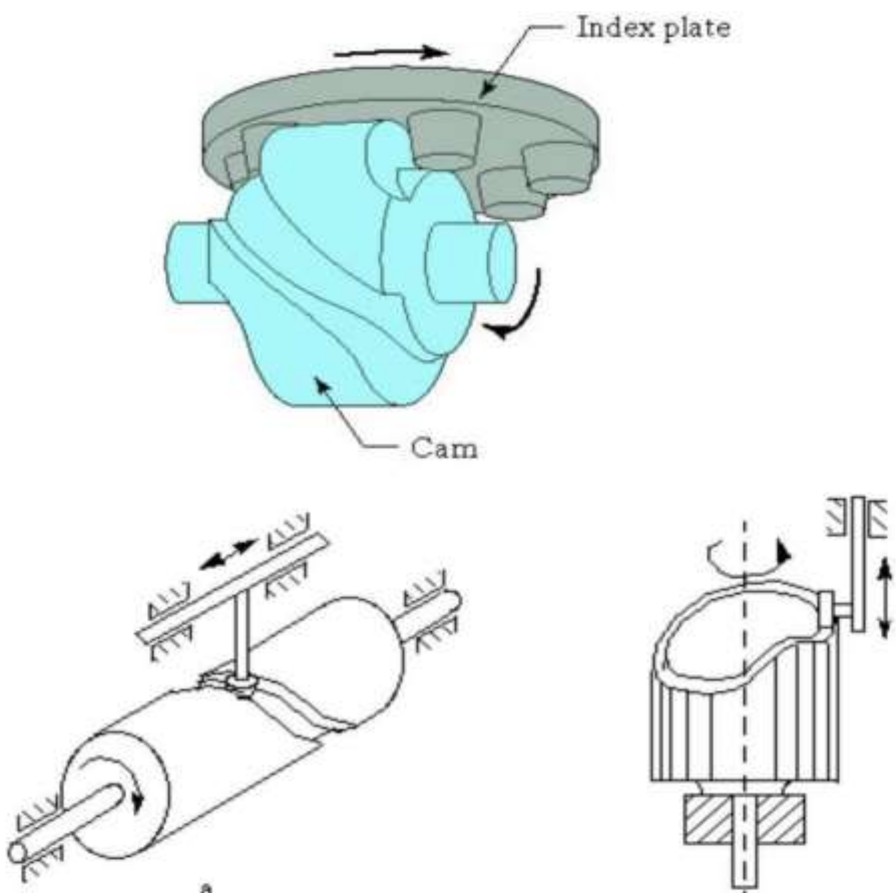


Figure 18 CAM mechanisms

2.5. CONTROL FUNCTIONS

Controlling an automated flow line is a complex problem, owing to the sheer number of sequential steps that must be carried out. There are three main functions that are utilized to control the operation of an automatic transfer system. The first of these is an operational requirement, the second is a safety requirement, and the third is dedicated to improving quality.

1. Sequence control.

The purpose of this function is to coordinate the sequence of actions of the transfer system and its workstations. The various activities of the automated flow line must be carried out with split-second timing and accuracy.

Sequence control is basic to the operation of the flow line.

2. Safety monitoring:

This function ensures that the transfer system does not operate in an unsafe or hazardous condition. Sensing devices may be added to make certain that the cutting tool status is satisfactory to continue to process the workpart in the case of a machining-type transfer line. Other checks might include monitoring certain critical steps in the sequence control function to make sure that these steps have all been performed and in the correct order. Hydraulic or air pressures might also be checked if these are crucial to the operation of automated flow lines.

3. Quality monitoring:

The third control function is to monitor certain quality attributes of the workpart. Its purpose is to identify and possibly reject defective workparts and assemblies. The inspection devices required to perform quality monitoring are sometimes incorporated into existing processing stations. In other cases, separate stations are included in the line for the sole purpose of inspecting the workpart as shown in figure 19.

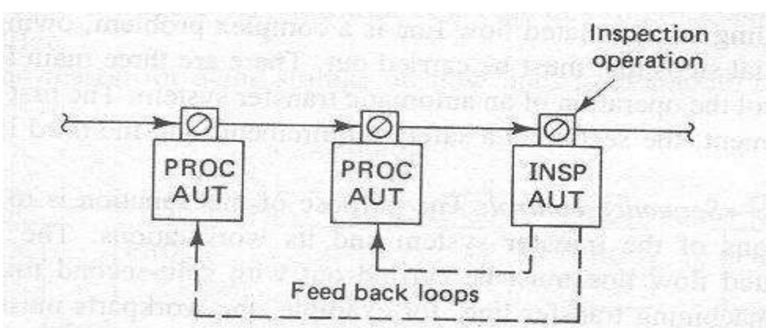


Figure 19 Inspection station with feedback

Conventional thinking on the control of the line has been to stop operation when a malfunction occurred. While there are certain malfunctions representing unsafe con-ditions that demand shutdown of the line, there are other situations where stoppage of the line is not required and perhaps not even desirable. There are alternative control strategies 1.Instantaneous control and 2. Memory control.

Instantaneous control:

This mode of control stops the operation of the flow line immediately when a malfunction is detected. It is relatively simple, inexpensive, and trouble-free. Diagnostic features are often added to the system to aid in identifying the location and cause of the trouble to the operator so that repairs can be quickly made. However, stopping the machine results in loss of production from the entire line, and this is the system's biggest drawback.

Memory control:

In contrast to instantaneous control, the memory system is designed to keep the machine operating. It works to control quality and/or protect the machine by preventing subsequent stations from processing the particular workpart and by segregating the part as defective at the end of the line. The premise upon which memory-type control is based is that the failures which occur at the stations will be random and infrequent. If, however, the station failures result from cause and tend to repeat, the memory system will not improve production but, rather, degrade it. The flow line will continue to operate, with the consequence that bad parts will continue to be produced. For this reason, a counter is sometimes used so that if a failure occurs at the same station for two or three consecutive cycles, the memory logic will cause the machine to stop for repairs.

2.6. BUFFER STORAGE

Automated flow lines are often equipped with additional features beyond the basic transfer mechanisms and workstations. It is not uncommon for production flow lines to include storage zones for collecting banks of workparts along the line. One example of the use of storage zones would be two intermittent transfer systems, each without any storage capacity, linked together with a workpart inventory area. It is possible to connect three, four, or even more lines in this manner. Another example of workpart storage on flow lines is the asynchronous transfer line. With this system, it is possible to provide a bank of workparts for every station on the line.

There are two principal reasons for the use of buffer storage zones. The first is to reduce the effect of individual station breakdowns on the line operation. The continuous or intermittent transfer system acts as a single integrated machine. When breakdowns occur at the individual stations or when preventive maintenance is applied to the machine, production must be halted. In many cases, the proportion of time the line spends out of operation can be significant, perhaps reaching 50% or more. Some of the common reasons for line stoppages are:

Tool failures or tool adjustments at individual processing stations Scheduled tool changes Defective workparts or components at assembly stations, which require that the Feed mechanism be cleared Feed hopper needs to be replenished at an assembly station Limit switch or other electrical malfunction Mechanical failure of transfer system or workstation

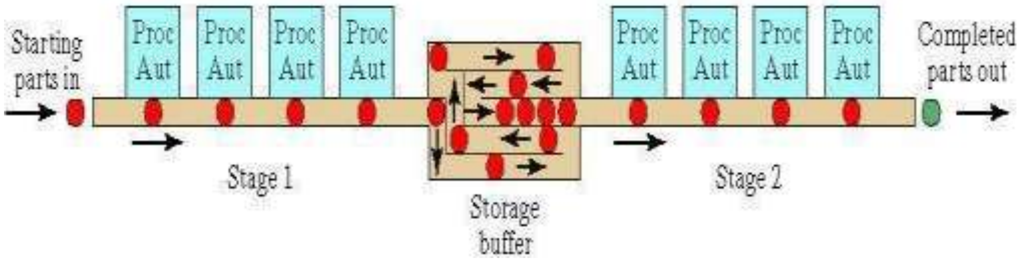


Figure 20 Storage buffer between two stages of a production

When a breakdown occurs on an automated flow line, the purpose of the buffer storage zone is to allow a portion of the line to continue operating while the remaining portion is stopped and under repair. For example, assume that a 20- station line is divided into two sections and connected by a parts storage zone which automatically collects parts from the first section and feeds them to the second section. If a station jam were to cause the first section of the line to stop, the second section could continue to operate as long as the supply of parts in the buffer zone lasts. Similarly, if the second section were to shut down, the first section could continue to operate as long as there is room in the buffer zone to store parts. Hopefully, the average production rate on the first section would be about equal to that of the second section. By dividing the line and using the storage area, the average production rate would be improved over the original 20-station Mow line. Figure 20 shows the Storage buffer between two stages of a production line

Reasons for using storage buffers:

– To reduce effect of station breakdowns
– To provide a bank of parts to supply the line
– To provide a place to put the output of the line
– To allow curing time or other required delay
– To smooth cycle time variations
– To store parts between stages with different production rates

The disadvantages of buffer storage on flow lines are increased factory floor space, higher in-process inventory, more material handling equipment, and greater complexity of the overall flow line system. The benefits of buffer storage are often great enough to more than compensate for these disadvantages.

2.7. AUTOMATION FOR MACHINING OPERATIONS

Transfer systems have been designed to perform a great variety of different metal-cutting processes. In fact, it is difficult to think of machining operations that must be excluded from the list. Typical applications include operations such as milling, boring, drilling, reaming, and tapping. However, it is also feasible to carry out operations such as turning and grinding on transfer-type systems.

There are various types of mechanized and automated machines that perform a sequence of operations simultaneously on different work parts. These include dial indexing machines, trunnion machines, and transfer lines. To consider these machines in approximately the order of increasing complexity, we begin with one that really does not belong in the list at all, the single-station machine.

Single-station machine

These mechanized production machines perform several operations on a single workpart which is fixtured in one position throughout the cycle. The operations are performed on several different surfaces by work heads located around the piece. The available space surrounding a stationary workpiece limits the number of machining heads that can be used. This limit on the number of operations is the principal disadvantage of the single-station machine. Production rates are usually low to medium. The single station machine is as shown in figure 21.

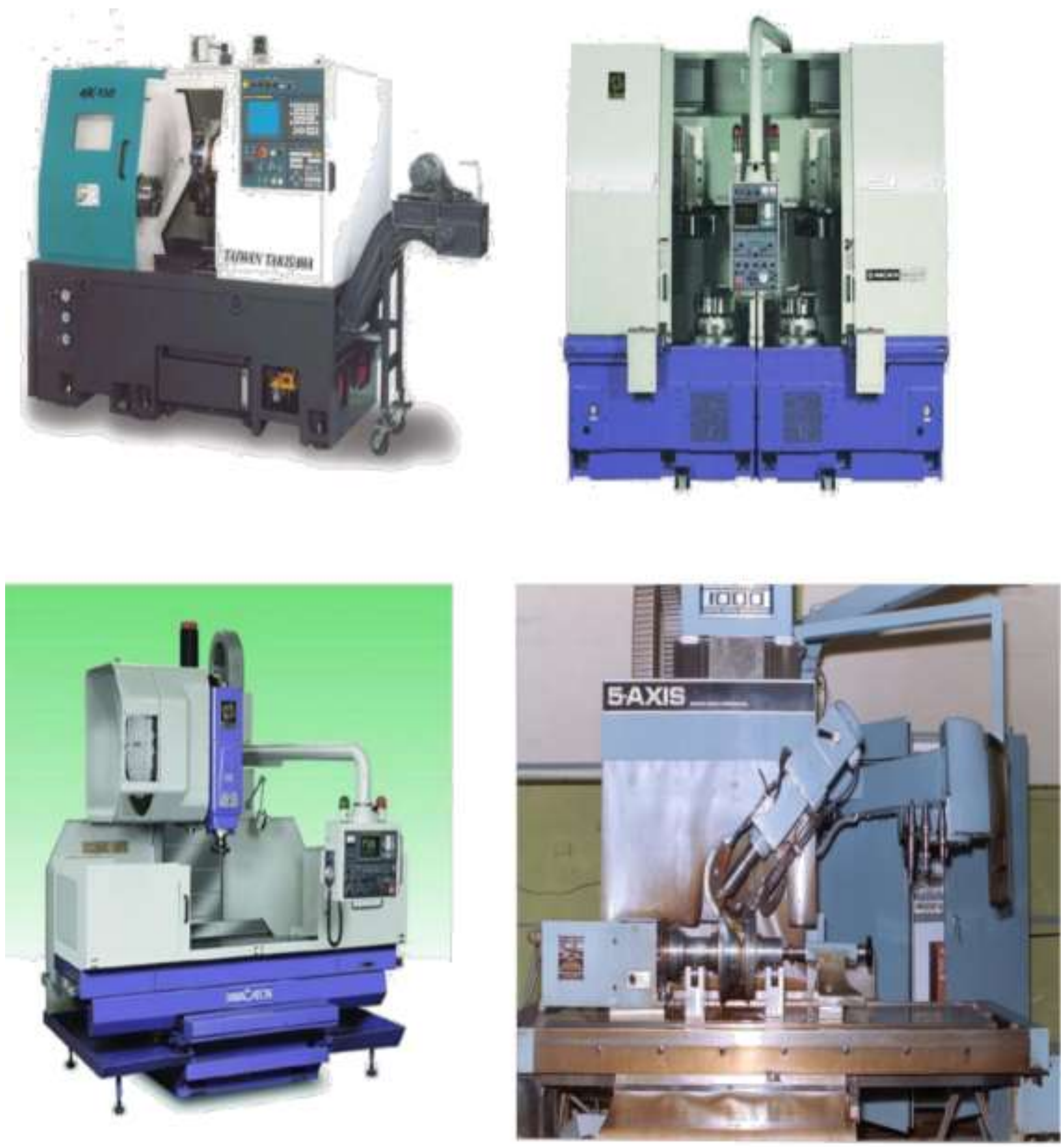


Figure 21 single-station machines

Rotary indexing machine

To achieve higher rates of production, the rotary indexing machine performs a sequence of machining operations on several work parts simultaneously. Parts are fixtured on a horizontal circular table or dial, and indexed between successive stations. An example of a dial indexing machine is shown in Figure 22 and 23.

Figure 22 Example of 6 station rotary configuration

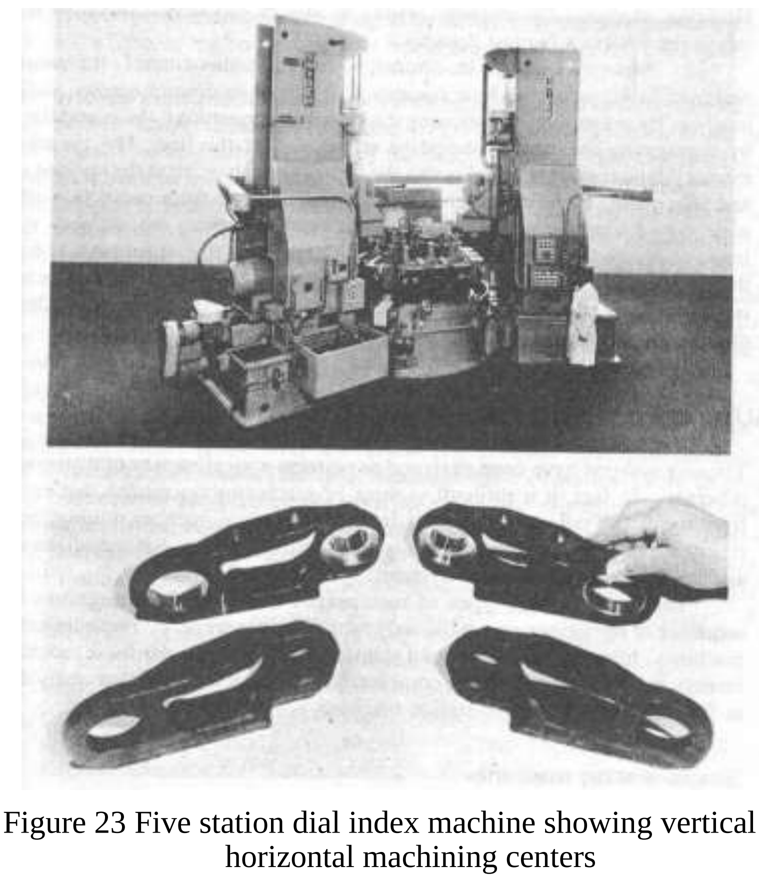
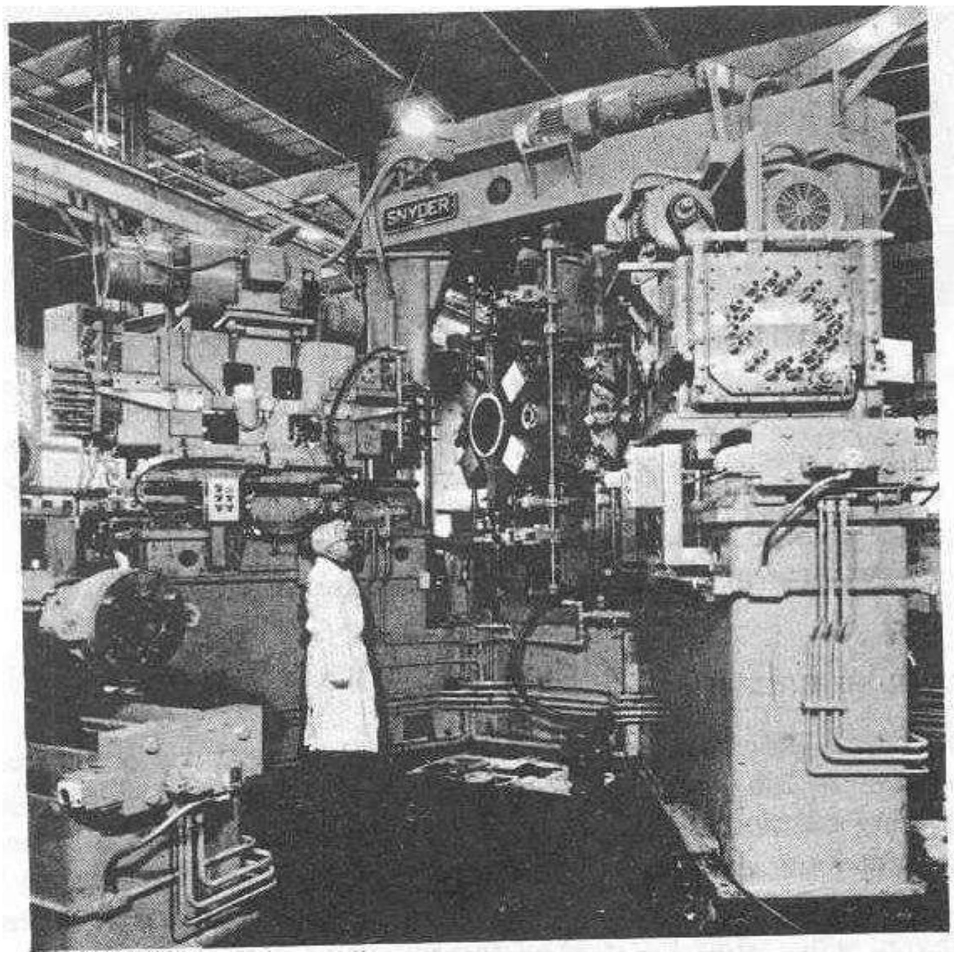


Figure 23 Five station dial index machine showing vertical and horizontal machining centers

Trunnion machine

Trunnion machine is a vertical drum mounted on a horizontal axis, so it is a variation of the dial indexing machine as shown in figure 24. The vertical drum is called a trunnion. Mounted on it are several fixtures which hold the work parts during processing. Trunnion machines are most suitable for small workpieces. The configuration of the machine, with a vertical rather than a horizontal indexing dial, provides the opportunity to perform operations on opposite sides of the workpart. Additional stations can be located on the outside periphery of the trunnion if it is required. The trunnion-type machine is appropriate for work parts in the medium production range.



Center column machine

Another version of the dial indexing arrangement is the center column type, pictured in Figure 25. In addition to the radial machining heads located around the periphery of the horizontal table, vertical units are mounted on the center column of the machine. This increases the number of machining operations that can be performed as compared to the regular dial indexing type. The center column machine is considered to be a high-production machine which makes efficient use of floor space.

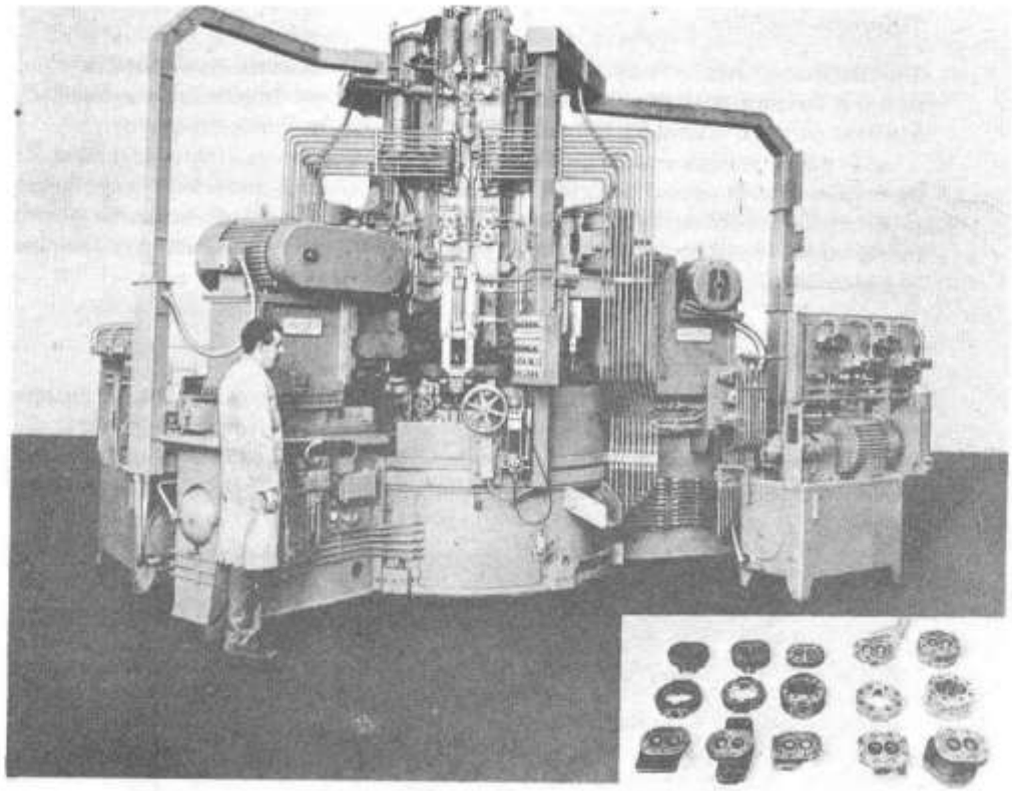


Figure 25 Ten-station center column machine

Transfer machine

The most highly automated and versatile of the machines is the transfer line, as explained earlier the workstations are arranged in a straight-line flow pattern and parts are transferred automatically from station to station. The transfer system can be synchronous or asynchronous, work parts can be transported with or without pallel fixtures, buffer storage can be incorporated into the line operation if desired, and a variety of different monitoring and control features can be used to manage the line. Hence, the transfer machine offers the greatest flexibility of any of the machines discussed. The transfer line can accommodate larger workpieces than the rotary-type indexing systems. Also, the number of stations, and therefore the number of operations, which can be included on the line is greater than for the circular arrangement. The transfer line has traditionally been used for machining a single product in high quantities over long production runs. More recently, transfer machines have been designed for ease of changeover to allow several different but similar workparts to be produced on the same line. These attempts to introduce flexibility into transfer line design add to the appeal of these high-production systems.

Figure 26 Example of 20 stations Transfer line

Figure 27 Example of Transfer line

OUTCOMES:

Students will be able to

1. Use the knowledge of buffer storage to have optimized manufacturing system.
2. Construct prototypes of workpart transfer mechanisms.
3. Classify different configurations of automated flow lines.

QUESTIONAIRE:

1. Give the detailed classification of automated flow line systems.
2. Write a note on workpart transfer mechanisms.
3. With neat sketch , explain Geneva mechanism.
4. Write a note on Buffer storage.
5. Explain control functions.

FURTHER READING:

1. https://www.wisdomjobs.com/e-university/production-and-operations-management-tutorial-295/automated-flow-lines-9685.html
2. https://rekadayaupaya.wordpress.com/2013/05/03/5-4-automated-flow-lines-with-storage-buffers/

MINIMUM RATIONAL WORK ELEMENT

CONTENTS:

OBJECTIVES:

1. To understand concepts like Total worl content, cycle time and workstation process time.
2. To understand precedence constraints and diagrams.
3. To use different methods to analyze balance delay in work part movement.

4.1. Introduction

In order to spread the job to be done on the line among its stations, the job must be divided into its component tasks. The minimum rational work elements are the smallest practical indivisible tasks into which the job can be divided. These work elements cannot be subdivided further. For example, the drilling of a hole would normally be considered as a minimum rational work element. In manual assembly, when two components are fastened together with a screw & nut, it would be reasonable for these activities to be taken together. Hence, this assembly task would constitute a minimum rational work element. We can symbolize the time required to carry out this minimum rational work element *Tej*, where *j* is used to identify the element out of the *ne* elements that make up the total work or job. For instance, the element time *Tej*, for element 1 in the table above is 0.2 min.

The time *Tej* of a work element is considered a constant rather than a variable. An automatic work head most closely fits this assumption, although the processing time could probably be altered by making adjustments in the station. In a manual operation, the time required to perform a work element will, in fact, vary from cycle to cycle.

Another assumption implicit in the use of *Te* values is that they are additive. The time to perform two work elements is the sum of the times of the individual elements. In practice, this might not be true. It might be that some economy of motion could be achieved by combining two work elements at one station, thus violating the additivity assumption

Problem:

A new small electrical appliance is to be assembled on a production flow line. The total job of assembling the product has been divided into minimum rational work elements. The industrial engineering department has developed time standards based on previous similar jobs. This information is given in the table below. In the right hand column are the immediate predecessors for each element as determined by precedence requirements. Production demand will be 120,000 units/yr. At 50 weeks/yr & 40 h/week, this reduces to an output from the line of 60 units/h or 1 unit/min.

No.	Element description	T_{ej}	Must be preceded by:
1	Place frame on work holder & clamp	0.2	--------
2	Assemble plug, grommet to power cord	0.4	--------
3	Assemble brackets to frame	0.7	1
4	Wire power cord to motor	0.1	1.2
5	Wire power to switch	0.3	2
6	Assemble mechanism plate to bracket	0.11	3
7	Assemble blade to bracket	0.32	3
8	Assemble motor to brackets	0.6	3, 4
9	Align blade & attach to motor	0.27	6,7,8
10	Assemble switch to motor bracket	0.38	5, 8
11	Attach cover, inspect, & test	0.5	9, 10
12	Place in tote pan for packing	0.12	11

4.2. Total Work Content:

This is the aggregate of all the work elements to be done on the line. Let Twc be the time required for the total work content. Hence,

$$Twc = \sum_{j=1}^{nc} Tej \text{ ------------------- } 3$$

For the example, Twc = 4.00 min.

4.3. Workstation Process Time:

A workstation is a location along the flow line where work is performed, either manually or by some automatic device. The work performed at the station consists of one or more of the individual work elements & the time required is the sum of the times of the work elements done at the station. We use Tsi to indicate the process time at station i of an n-station line. It should be clear that the sum of the station process times should equal the sum of the work element times.

$$\sum_{i=1}^{n} Tsi = \sum_{j=1}^{ne} Tej \text{ -------------- } 4$$

4.4. Cycle Time:

This is the ideal or theoretical cycle time of the flow line, which is the time interval between parts coming off the line. The design value of T_c would be specified according to the required production rate to be achieved by the flow line. Allowing for downtime on the line, the value of T_c must meet the following requirement:

$$T_c \leq \frac{E}{R_p} \text{ --------------- } 5$$

Where E is the line efficiency & R_p the required production rate.

The line efficiency of an automated line will be somewhat less than 100%. For a manual line, where mechanical malfunctions are less likely the efficiency will be closer to 100%.

In the above example, the required production rate is 60 units/h or 1 unit/min. at a line efficiency of 100%, the value T_c of would be 1.0 min. At efficiencies less than 100%, the ideal cycle time must be reduced (or what is the same thing, the ideal production rate R_c must be increased) to compensate for the downtime.

The minimum possible value T_c of is established by the bottleneck station, the one with the largest of T_s. That is

$$T_c \geq \max T_{si} \text{ --------------- } 6$$

If $T_c = \max T_{si}$, there will be idle time at all stations whose T_s values are less than T_c.

Finally, since the station times are comprised of element times,

$$T_c \geq T_{ej} \text{ (for all } j = 1, 2, \ldots\ldots n_e) \text{ ---------- } 7$$

This equation states the obvious: that the cycle time must be greater than or equal to any of the element times.

4.5. Precedence Constraints:

These are also referred to as “technological sequencing requirements”. The order in which the work elements can be accomplished is limited at least to some extent. In the problem above, the switch must be mounted onto the motor bracket before the cover of the appliance can be attached. The right hand column in the table above gives a complete listing of the precedence constraints for assembling the hypothetical electrical appliance. In nearly every processing or assembly job, there are precedence requirements that restrict the sequence in which the job can be accomplished.

In addition to the precedence constraints described above, there may be other types of constraints on the line balancing solution. These concern the restrictions on the arrangement of the stations rather than the sequence of work elements. The first is called a *zoning constraint*. A zoning constraint may be either a positive constraint or a negative constraint. A *positive* zoning constraint means that certain work elements should be placed near each other, preferably at the same workstation. For example, all the spray-painting elements should be performed together since a special semienclosed workstation has to be utilized. A *negative* zoning constraint indicates that work elements might interfere with one another & should therefore not be located in close proximity. As an illustration, a work element requiring fine adjustments or delicate coordination should not be located near a station characterized by loud noises & heavy vibrations.

Another constraint on the arrangement of workstations is called a *position constraint*. This would be encountered in the assembly of large products such as automobiles or major appliances. The product is too large for one worker to perform work on both sides. Therefore, for the sake of facilitating the work, operators are located on both sides of the flow line. This type of situation is referred to as a position constraint.

In the example there are no zoning constraints or position constraints given. The line balancing methods are not equipped to deal with these constraints conveniently. However, in real-life situations, they may constitute a significant consideration in the design of the flow line.

4.6. Precedence Diagram:

This is a graphical representation of the sequence of work elements as defined by the precedence constraints. It is customary to use nodes to symbolize the work elements, with arrows connecting the nodes to indicate the order in which the elements must be performed. Elements that must be done first appear as nodes at the left of the diagram. Then the sequence of processing and/or assembly progresses to the right. The element times are recorded above each node for convenience.

4.7. Balance Delay:

Sometimes also called balancing loss, this is a measure of the line inefficiency which results from idle time due to imperfect allocation of work among stations. It is symbolized as d & can be computed for the flow line as follows:

$$d = \frac{nT_c - T_{wc}}{nT_c} \quad \text{---------------} \; 8$$

The balance delay is often expressed as a percent rather than as a decimal fraction in Eq. 8.

The balance delay should not be confused with the proportion downtime, D, of an automated flow line. D is a measure of the inefficiency that results from line stops. The balance delay measures the inefficiency from imperfect line balancing.

Considering the data given in the previous problem, the total work content T_{wc} = 4.00

min.

We shall assume that T_c = 1.0 min. If it were possible to achieve perfect balance with n = 4 workstations, the balance delay would be

$$d = \frac{4(1.0) - 4.0}{4(1.0)} = 0$$

If the line could only be balanced with n = 5 stations for the 1.0 min cycle, the balance delay would be

$$d = \frac{5(1.0) - 4.0}{5(1.0)} = 0.20 \text{ or } 20\%$$

Both of these solutions provide the same theoretical production rate. However, the second solution is less efficient because an additional workstation, & therefore an additional assembly operator, is required. One possible way to improve the efficiency of the five station line is to decrease the cycle time T_c. To illustrate, suppose that the line could be balanced at a cycle time of T_c = 0.80 min. The corresponding measure of inefficiency would be

$$d = \frac{5(0.80) - 4.0}{5(0.80)} = 0$$

This solution (if it were possible) would yield a perfect balance. Although five workstations are required, the theoretical production rate would be R_c = 1.25 units/min, an increase over the production rate capability of the four-station line. The reader can readily

perceive that there are many combinations of n & T_c that will produce a theoretically perfect balance. Each combination will give a different production rate. In general, the balance delay d will be zero for any values n & T_c that satisfy the relationship

$$nT_c = T_{wc} \text{ ----------------- } 9$$

Unfortunately, because of precedence constraints & because the particular values of T_c usually do not permit it, perfect balance might not be achievable for every nT_c combinations that equals the total work content time. In other words, the satisfaction of Eq. 9 is a necessary condition for perfect balance, but not a sufficient condition.

As indicated by Eq 5, the desired maximum value of T_c is specified by the production rate required of the flow line. Therefore Eq 9 can be cast in a different form to determine the theoretical minimum number of workstations required to optimize the balance delay for a specified T_c. Since n must be an integer, we can state:

$$\text{minimum } n \text{ is the smallest integer } \geq \frac{T_{wc}}{T_c} \quad 10$$

Applying this rule to our example with

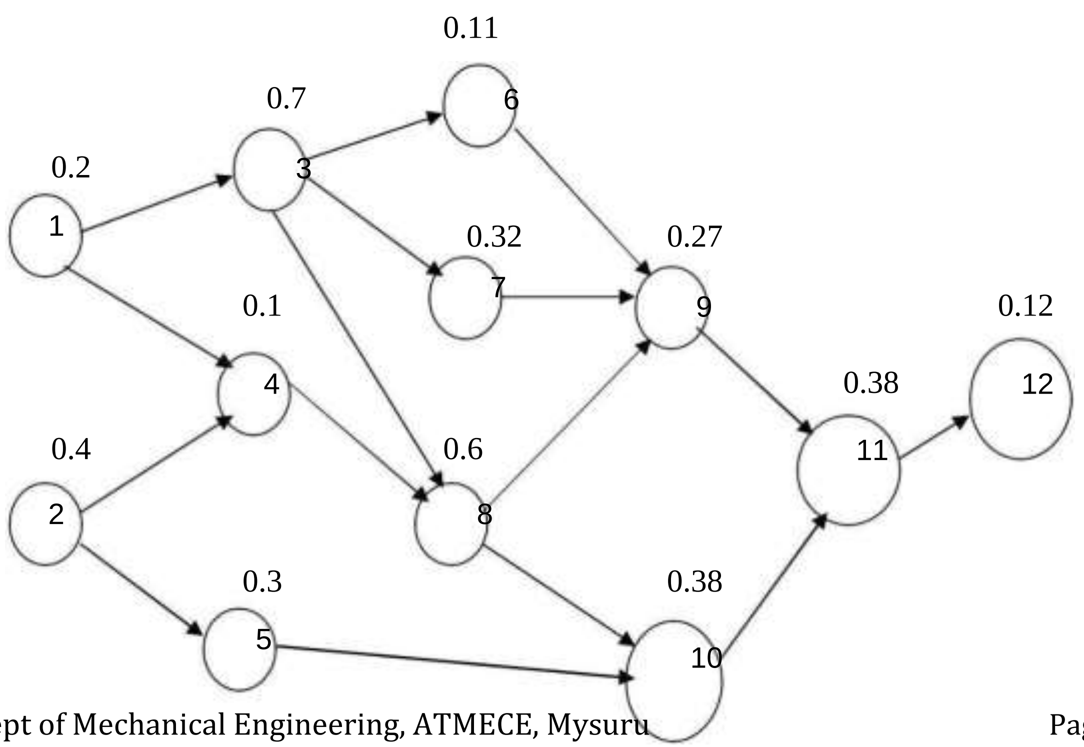
T_{wc} = 4.0 min & T_c = 1.0 min, the minimum n = 4 stations.

Problem:1

A new small electrical appliance is to be assembled on a production flow line. The total job of assembling the product has been divided into minimum rational work elements. The industrial engineering department has developed time standards based on previous similar jobs. This information is given in the table below. In the right hand column are the immediate predecessors for each element as determined by precedence requirements. Production demand will be 120,000 units/yr. At 50 weeks/yr & 40 h/week, this reduces to an output from the line of 60 units/h or 1 unit/min.

No	Element Description	Tek (mins)	Must be preceded by
1	Place frame on work holder & clamp	0.2	----------------
2	Assemble plug, grommet to power cord	0.4	--------------------
3	Assemble brackets to frame	0.7	1
4	Wire power cord to motor	0.1	1 ,2
5	Wire power to switch	0.3	2
6	Assemble mechanism plate to bracket	0.11	3
7	Assemble blade to bracket	0.32	3
8	Assemble motor to brackets	0.6	3 , 4
9	Align blade & attach to motor	0.27	6,7,8
10	Assemble switch to motor bracket	0.38	5 , 8
11	Attach cover, inspect, & test	0.5	9,10
12	Place in tote pan for packing	0.12	11

Step 1:



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4.8. Largest Candidate Rule

Step 2:

The Table below is according to the descending order of the Element Times.

Work Element	T_{ek} (min)	Preceded By
3	0.7	1
8	0.6	3, 4
11	0.5	9, 10
2	0.4	----
10	0.38	5 ,8
7	0.32	3
5	0.3	2
9	0.27	6,7,8
1	0.2	----
12	0.12	11
6	0.11	3
4	0.1	1 ,2

Step 3:

Station	Work Element	Tek (min)	Station time (min)
1	2	0.4	
	5	0.3	
	1	0.2	
	4	0.1	0.1
2	3	0.7	
	6	0.11	0.81
3	8	0.6	
	10	0.38	0.98
4	7	0.32	
	9	0.27	0.59
5	11	0.5	
	12	0.12	0.62

$$Eb = \frac{4.0}{5\,(0.98)} = 0.816$$

Cycle Time $(T_c) = T_s + T_r = 0.98 + 0.08 = 1.06$ min

$$R_c = \frac{60}{1.06} = 56.66 \text{ cycles/hr}$$

$R_p = 57 \times 0.96 = 54.72$ units/hr

4.9. KILBRIDGE & WESTER METHOD

Problem 2:

The following list defines the precedence relationships & element times for a new model toy:

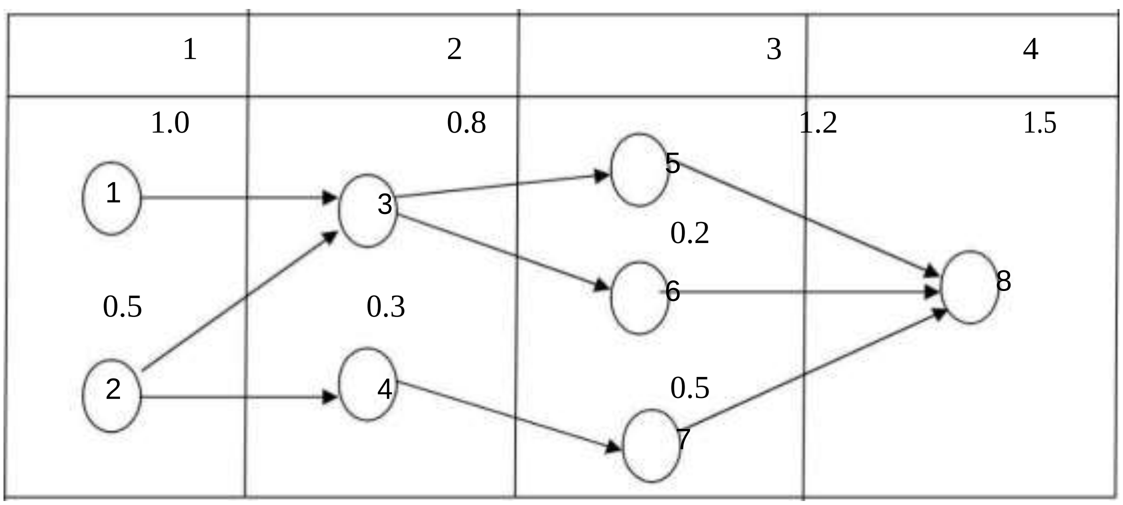
Element	1	2	3	4	5	6	7	8
Tc min	1.0	0.5	0.8	0.3	1.2	0.2	0.5	1.5
Immediate Predecessor	---	---	1, 2	2	3	3, 4	4	5,6,7

I. Construct the precedence diagram.

II. If the ideal cycle is 1.5 mins, what is the theoretical minimum number of stations required to minimize the balance delay?

III. Compute the balance delay.

Step 1:



Step 2:

Work Element	Column	T (mins)	Preceded by
1	i	1.0	-
2	i	0.5	-
3	ii	0.8	1,2
4	ii	0.3	2
5	Iii	0.2	3
6	Iii	0.2	3
7	iii, iv	0.5	4
8	iv	1.5	6,7,8

Step 3:

Station	Work Element	Column	Tc (min)	Station Time
1	1	i	1.0	1.5
	2	i	0.5	
2	3	ii	0.8	1.3
	4	ii	0.3	
3	5	iii	0.2	1.2
	6	iii	1.2	
4	7	iii, iv	0.5	0.5
5	8	iv	1.5	1.5

$$E_b = \frac{6}{5\,(1.5)} = 0.80$$

$$R_c = \frac{60}{1.5} = 40 \text{ cycles/hr}$$

R_p = 40 x 0.96 = 38.4 pieces/hr

4.10. Ranked Positional Weight Method:

Step 1:

The Ranked positional weights method is applied to the second problem in the following steps

RPW1 = 0.8 + 1.2 + 0.2 + 1.5 = 4.7 mins

RPW2 = 0.5 + 0.8 + 0.3 + 1.2 + 0.2 + 0.5 + 1.5 = 5 mins

RPW3 = 0.8 + 0.2 + 1.2 + 1.5 = 3.7 mins

RPW4 = 0.3 + 0.2 + 0.5 + 1.5 = 2.5 mins

RPW5 = 1.2 + 1.5 = 2.7 mins

RPW6 = 0.2 + 1.5 = 1.7 mins

RPW7 = 0.5 + 1.5 = 2 mins

RPW8 = 1.5 mins

Step 2

Work Element	RPW	T (mins)	Preceded by
2	5	0.5	-
1	4.7	1.0	-
3	3.7	0.8	1,2
5	2.5	1.2	3
4	2.7	0.3	2
6	1.7	0.2	3, 4
7	2	0.5	4
8	1.5	1.5	5,6,7

Step 3:

Station	Work Element	Tc (min)	Station Time
1	2	0.5	1.5
	1	1.0	
2	3	0.8	1.3
	4	0.3	
	6	0.2	1.2
3	5	1.2	
4	7	0.5	0.5
5	8	1.5	1.5

$$Eb = \frac{6}{5\ (1.5)} = 0.80$$

Cycle Time = Tc + Tv = 1.5 + 0.8 = 1.58 mins

$$Rc = \frac{60}{1.58} = 38 \text{ cycles / hr}$$

Rp = 38 x 0.96 = 36.48pieces/hr

OUTCOMES:

Students will be able to

1. Use different production concepts in analyzing work part transport.
2. Explain the importance of precedence constraints and diagrams.
3. Use different methods to analyze work part transport.

QUESSIONAIRE:

1. Explain the fallowing terms in line balancing.
   a. Minimum rational work element.
   b. Total work content.
   c. Cycle time.
   d. Balance delay
2. Write a note on computerized line balancing.
3. Write a note on balance delay and precedence diagram.
4. Explain assembly line balance and line balance.

FURTHER READING

1. **http://nptel.ac.in/courses/110106045/25**

2. **http://nptel.ac.in/courses/112102106/33**

COMPUTERIZED MANUFACTURING PLANNING SYSTEM:

CONTENTS:

OBJECTIVES:

1. To understand the meaning of process planning and its importance.
2. To distinguish and understand types of process planning systems.
3. To understand the concepts like material requirement planning and capacity planning.

6.1. Traditional Process Planning:

There are variations in the level of detail found in route sheets among different companies & industries. In the one extreme, process planning is accomplished by releasing the part print to the production shop with the instructions “make to drawing.” Most firms provide a more detailed list of steps describing each operation and identifying each work center. In any case, it is traditionally the task of the manufacturing engineers or industrial engineers in an organization to write these process plans for new part designs to be produced by the shop. The process planning procedure is very much dependent on the experience and judgement of the planner. It is the manufacturing engineer’s responsibility to determine an optimal routing for each new part design. However, the individual engineers each have their own opinions about what constitutes the best routing. Accordingly, there are differences among the operation sequences developed by various planners. We can illustrate rather dramatically these differences by means of an example.

In one case, a total of 42 different routings were developed for various sizes of a relatively simple part called an “expander sleeve.” There were a total of 64 different sizes & styles, each with its own part number. The 42 routings included 20 different machine tools in the shop. The reason for this absence of process standardization was that many different individuals had worked on the parts: 8 or 9 manufacturing engineers, 2 planners and 25 NC part programmers. Upon analysis, it was determined that only two different routings through 4 machines were needed to process the 64 part numbers. It is clear that there were potentially great differences in the perceptions among process planners as to what constitutes the “optimal” method of production.

In addition to this problem of variability among planners, there are often difficulties in the conventional process planning procedure. New machine tools in the factory render old routings less than optimal. Machine breakdowns force shop personnel to use temporary routings, & these become the documented routings even after the machine is repaired. For these reasons and others, a significant proportion of the total number of process plans used in manufacturing are not optimal.

6.2. Automated Process Planning:

Because of the problems encountered with manual process planning, attempts have been made in recent years to capture the logic, judgement, and experience required for this important function and incorporate them into computer programs. Based on the characteristics of a given part, the program automatically generates the manufacturing operation sequence. A computer-aided process planning (CAPP) system offers the potential for reducing the routine clerical work of manufacturing engineers. At the same time, it provides the opportunity to generate production routings which are rational, consistent, and perhaps even optimal. Two alternative approaches to computer-aided process planning have been developed. These are:

1. Retrieval-type CAPP systems (also called variant systems)

2. Generative CAPP systems

The two types are described as below:

6.3. Retrieval-type Process Planning systems:

Retrieval-type CAPP systems use parts classification & coding & group technology as a foundation. In this approach, the parts produced in the plant are grouped into part families, distinguished according to their manufacturing characteristics. For each part family, a standard process plan is established. The standard process plan is stored in computer files & then retrieved for new workparts which belong to that family. Some form of parts classification & coding system is required to organize the computer files & to permit efficient retrieval of the appropriate process plan for a new workpart. For some new parts, editing of the existing process plan may be required. This is done when the manufacturing requirements of the new part are slightly different from the standard. The machine routing may be the same for the new part, but the specific operations required at each machine may be different. The complete process plan must document the operations as well as the sequence of machines through which the part must be routed. Because of the alterations that are made in the retrieved process plan, these CAPP systems are sometimes also called by the name “variant system”.

The figure illustrated further will help to explain the procedure used in a retrieval process planning system. The user would initiate the procedure by entering the part code number at a computer terminal. The CAPP program then searches the part family matrix file to determine if a match exists. If the file contains an identical code number, the standard machine routing & operation sequence are retrieved from the respective computer files for display to the user. The standard process plan is examined by the user to permit any necessary editing of the plan to make it compatible with the new part design. After editing, the process plan formatter prepares the paper document in the proper form.

If an exact match cannot be found between the code numbers in the computer file & the code number for the new part, the user may search the machine routing file & the operation sequence file for similar parts that could be used to develop the plan for the new part. Once the process plan for a new part code number has been entered, it becomes the standard process for future parts of the same classification.

In the figure illustrated in the previous slide, the machine routing file is distinguished from the operation sequence file to emphasize that the machine routing may apply to a range of different part families & code numbers. It would be easier to find a match in the machine routing file than in the operation sequence file. Some CAPP retrieval systems would use only one such file which would be a combination of operation sequence file & machine routing file.

The process plan formatter may use other application programs. These could include programs to compute machining conditions, work standards, & standard costs. Standard cost programs can be used to determine total product costs for pricing purposes.

A number of retrieval-type computer-aided process planning systems have been developed. These include MIPLAN, one of the MICLASS modules, the CAPP system developed by Computer-Aided Manufacturing --- International,

COMCAPP V by MDSI, & systems by individual companies. We will use MIPLAN as an example to illustrate these industrial systems.

MIPLAN is a computer-aided process planning package available from the Organization for Industrial Research, Inc., of Waltham, Massachusetts. It is basically a retrieval-type CAPP system with some additional features. The MIPLAN system consists of several modules which are used in an interactive, conversational mode.

To operate the system, the user can select any of the four different options to create the process plan for a new part:

1. The first option is a retrieval approach in which the user inputs a part code number & a standard process plan is retrieved from the computer file for possible editing. To generate the part code number, the planner may elect to use the MICLASS interactive parts classification & coding system.

2. In the second option, a process play is retrieved from the computer files by entering an existing part number (rather than a part code number). Again, the existing process plan can be edited by the user if required.

3. A process plan can be created from scratch, using standard text material stored in computer files. This option is basically a specialized word-processing system in which the planner selects from a menu of text related to machines & processes. The process plan is assembled from text passages subject to editing for the particular requirements of the new part.

4. The user can call up an incomplete process plan from the computer file. This may occur when the user is unable to complete the process plan for a new part at one sitting. For example, the planner may interrupted in the middle of the procedure

to solve some emergency problem. When the procedure is resumed, the incomplete plan can be retrieved & finished.

After the process plan has been completed using one of the four MIPLAN options, the user can have a paper document printed out by the computer. A typical MIPLAN output is shown in the figure in the next slide. It is also possible for the user to store the completed process plan (or the partially completed plan as with the option 3) in the computer files, or to purge an existing plan from the files. This might be done, for example, when an old machine tool is replaced by a more productive machine, & this necessitates changes in some of the standard process plans.

Computer graphics can be utilized to enhance the MIPLAN output. This possibility is illustrated in the next slide, which shows a tooling setup for the machining operation described. With this kind of pictorial process planning, drawings of workpart details, tool paths, & other information can be presented visually to facilitate communication to the manufacturing shops.

6.4. Generative Process Planning Systems:

Generative Process Planning involves the use of computer to create an individual process plan from scratch, automatically & without human assistance. The computer would employ a set of algorithms to progress through the various technical & logical decisions toward a final plan for manufacturing. Inputs to the system would include a comprehensive description of the workpart. This may involve the use of some form of part code number to summarise the workpart data, but it does not involve the retrieval of existing standard plans. Instead, the generative CAPP system synthesizes the design of the optimum process sequence, based on an analysis of part geometry, material & other factors which would influence manufacturing decisions.

In the ideal generative process planning package, any part design could be presented to the system for creation of the optimal plan. In practice, current generative-type systems are far from universal in their applicability. They tend fall short of a truly generative capability, and they are developed for a somewhat limited range of manufacturing processes.

We will illustrate the generative process planning by means of a system called GENPLAN developed at Lockheed-Georgia Company.

GENPLAN is close to a generative process planning system, but it requires a human planner to assist with some of the manufacturing decisions. Also there are several versions GENPLAN (one for parts fabrication, and another for assembly), which means that it is not a system of universal applicability.

To operate the system, the planner enters a part classification code using a coding scheme developed at Lockheed. GENPLAN then analyses the characteristics of the part based on the code number (e.g., part geometry, work piece material, & other manufacturing-related features) to synthesize an optimum process plan. It does not store standard manufacturing plans. Rather, it stores machine tool capabilities & it employs the logic & technological science of manufacturing. The output is a document specifying the sequence of operations, machine tools, & calculated process times. An example of a computer-generated route sheet produced by GENPLAN is shown in the figure in the next slide. Process plans that previously required several hours to accomplish manually are now done typically by GENPLAN in 15 minutes.

Benefits of CAPP:

Whether it is retrieval system or a generative system, computer-aided process planning offers a number of potential advantages over manually oriented process planning.

1. *Process rationalization*. Computer-automated preparation of operation routings is more likely to be consistent, logical, & optimal than its manual counterpart. The process plans will be consistent because the same computer software is being used by all planners. We avoid the tendency for drastically different process plans from different planners. The process plans tend to be more logical & optimal because the company has presumably incorporated the experience & judgement of its best manufacturing people into the process planning computer software.

2. *Increased productivity of process planners.* With computer-aided process planning, there is reduced clerical effort, fewer errors are made, & the planners have immediate access to the process planning data base. These benefits translate into higher productivity of the process planners. One system was reported to increase productivity by 600% in the process planning function.

3. *Reduced turnaround time.* Working with the CAPP system, the process planner is able to prepare a route sheet for a new part in less time compared to manual preparation. This leads to an overall reduction in manufacturing lead time.

4. *Improved legibility*. The computer prepared document is neater & easier to read than manually written route sheets. CAPP systems employ standard text, which facilitates interpretation of the process plan in the factory.

5. *Incorporation of other application programs.* The process planning system can be designed to operate in conjunction with other software packages to automate many of the time-consuming manufacturing support functions.

Aggregate Production Planning & The Master Production Schedule:

Aggregate planning is a high-level corporate planning activity. The *aggregate production plan* indicates production output levels for the major product lines of the company. The aggregate plan must be coordinated with the plans of the sales & marketing departments. Because the *aggregate production plan* includes products that are currently in production, it must also consider the present & future inventory levels of those products & their component parts. Because new products currently being developed will also be included in the aggregate plan, the marketing plans & promotions for current products & new products must be reconciled against the total capacity resources available to the company.

The production quantities of the major product lines listed in the aggregate plan must be converted into a very specific schedule of individual products, known as the *master production schedule* (MPS). It is a list of products to be manufactured, when they should be completed & delivered, & it what quantities. A hypothetical MPS for a narrow product set is presented in the table, showing how it is derived from the corresponding aggregate plan in the 2nd table. The master schedule must be based on an accurate estimate of demand & a realistic assessment of the company's production capacity.

	Week									
Product Line	1	2	3	4	5	6	7	8	9	10
M model line	200	200	200	150	150	120	120	100	100	100
N model line	80	60	50	40	30	20	10			
P model line							70	130	25	100

(a) Aggregate Production Plan

	Week									
Product Line models	1	2	3	4	5	6	7	8	9	10
Model M3	120	120	120	100	100	80	80	70	70	70
Model M4	80	80	80	50	50	40	40	30	30	30
Model N8	80	60	50	40	30	20	10			
Model P1								50		100
Model P2							70	80	25	

(b) Master Production Schedule

Products included in the MPS divide into 3 categories: (1) firm customer orders, (2) forecasted demand, & (3) spare parts. Proportions in each category vary for different companies, & in some cases one or more categories are omitted. Companies producing assembled products will generally have to handle all three types. In the case of customer orders for specific products, the company is usually obligated to deliver the item by a particular date that has been promised by the sales department. In the second category, production output quantities are based on statistical forecasting techniques applied to previous demand patterns, estimates by the sales staff, & other sources. For many companies forecasted demand constitutes the largest portion of the master schedule. The third category consists of repair parts that either will be stocked in the company's service department or sent directly to the customer. Some companies exclude this third category from the master schedule since it does not represent end products.

The MPS is generally considered to be a medium-range plan since it must take into account the lead times to order raw materials & components, produce parts in the factory, & then assemble the end products. Depending on the product, the lead times can range from several weeks to many months; in some cases, more than a year. The MPS is usually considered to be fixed in the near term. This means that changes are not allowed within about a six week horizon because of the difficulty in adjusting production schedules within such a short period. However, schedule adjustments are allowed beyond six weeks to cope with changing demand patterns or the introduction of new products. Accordingly, we should note that the aggregate production plan is not the only input to the master schedule. Other inputs that may cause the master schedule to depart from the aggregate plan include new customer orders & changes in sales forecast over the near term.

6.5. Material Requirements Planning:

Material Requirements Planning (MRP) is a computational technique that converts the master schedule for end products into a detailed schedule for the raw materials & components used in the end products. The detailed schedule identifies the quantities of each raw material & component item. It also indicates when each item must be ordered & delivered to meet the master schedule for final products. MRP is often thought of as a method of inventory control. It is both an effective tool for minimizing unnecessary inventory investment & a useful method in production scheduling & purchasing of materials.

The distinction between independent demand & dependent demand is important in MRP. *Independent demand* means that demand for a product is unrelated to demand for other items. Final products & spare parts are examples of items whose demand is independent. Independent demand patterns must usually be forecasted. *Dependent demand* means that demand for the item is directly related to the demand for some other item, usually a final product. The dependency usually derives from the fact that the item is a component of the other product. Component parts, raw materials, & subassemblies are examples of items subject to dependent demand.

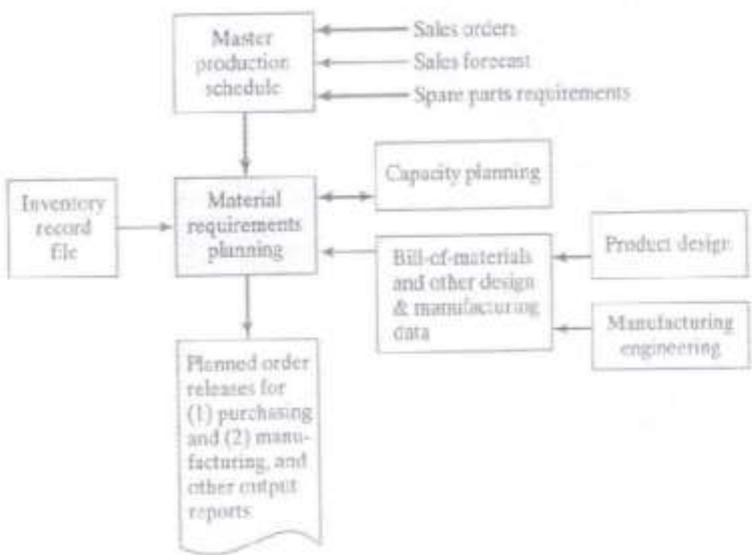
Whereas demand for the firm’s end products must often be forecasted, the raw materials & component parts used in the end products should not be forecasted. Once the delivery schedule for the end products is established, the requirements for components & raw materials can be directly calculated. For example, even though demand for automobiles in a given month can only be forecasted, once the quantity is established & production is scheduled, we know that five tires will be needed to deliver the car (don’t forget the spare). MRP is the appropriate technique for determining quantities of dependent demand items. These items constitute the inventory of manufacturing: raw materials, work-in-process (WIP), component parts & subassemblies. That is why MRP is such a powerful technique in planning & control of manufacturing inventories. For independent demand items, inventory control is often accomplished using order point systems.

The concept of MRP is relatively straightforward. Its implementation is complicated by the sheer magnitude of the data to be processed. The master schedule provides the overall production plan for the final products in terms of month-by-month deliveries. Each product may contain hundreds of individual components. These components are produced from raw materials, some of which are common among the components. For example, several components may be made out of the same gauge sheet steel. The components are assembled into simple subassemblies, & these subassemblies are put together into more complex subassemblies, & so on, until the final products are assembled. Each step in the manufacturing & assembly sequence takes time. All of these factors must be incorporated into the MRP calculations. Although each calculation is uncomplicated, the magnitude of the date is so large that the application of MRP is practically impossible except by computer processing.

6.6. Inputs to the MRP system :

To function, the MRP program needs data contained in several files. These files server as inputs to the MRP processor. They are (1) the master production schedule, (2) the bill of materials file and other engineering and manufacturing data, and (3) the inventory record file. Figure 1 illustrates the flow of data into the MRP processor and its conversation into useful output report. In a properly implemented MRP system, capacity planning also provides input to ensure that the MRP schedule does not exceed the production capacity of the firm. This concept is elaborated further.

The MPS lists what end products and how many of each are to be produced and when they are to be ready for shipment. Manufacturing firms generally work on monthly delivery schedules, but the master schedule in our figure uses weeks as the time periods. Whatever the duration, these time periods are called *time buckets* in MRP. Instead of treating time as a continuous variable (which of course , it is), MRP makes its computations of materials and parts requirements in terms of the buckets.



The bill of material (BOM) file provides information the product structure by listing the components parts and subassemblies that make up each product, It is use to computer the raw material and components requirement for end products listed in the master schedule. The structure of an assembled product can be illustrated as in Figure 2. This is much simpler than most commercial products, but its simplicity will server for illustration purposes. Product PI is composed of two subassemblies, SI and S@, each of which is made up of components C1,C2 and C3, and C3, and C4,C5 and C6, respectively. Finally, at the the bottom level are the raw materials that go into each component. The items at each successively higher level are called the parents of the items feeding into it form below. For example. SI is the parent of C1 ,C2 and C3. The product structure must also specify the number of each subassembly , component, and raw material that go into respective parent. These numbers are shown in parentheses in our figure.

Period		1	2	3	4	5	6	7
Item : Raw Material M4								
Gross Requirement								
Scheduled receipt				40				
On hand	50	50	50	90				
Net requirement								
Planned order releases								

The inventory record file is referred to as the item master file in a computerize inventory system. The types of data contained in the inventory record are divided into three segments.

1. Item master data : This provides the item's identification (part number) and other data about the part such as order quantity and lead times.

2. Inventory status : This gives a time-phased record of inventory status. In MRP, its is import to know not only the current level of inventory but also any future changes that will occur against the inventory. Therefore , the inventory status segment lists the gross requirements for the item, schedules receipts, on-hand status, and planned order releases, as shown in figure 25.5.

3. Subsidiary data. The third file segment provided subsidiary data such purchase orders, scrap or rejects and engineering changes.

How MRP Works

The MRP processor operates on data contained in the MPS, the BOM file, and the inventory record file. The master schedule specifies the period-by period list of final products required. The BOM define what material and components are needed for each

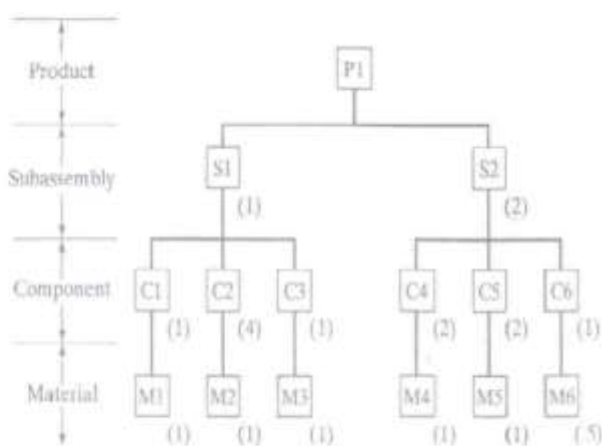


Figure 25.4 Product structure for product P1.

Figure 25.5 Initial inventory status of material M4 in Example 25.2

Product and inventory record files gives the current and future inventory status of each product, component, and material. The MRP processor computers how many of each component and raw material are needed each period by " exploding " the end product requirements into successively lower levels in the product structure.

Example 25.1 MRP Gross Quantity Computations

In the master schedule of Figure 25.2, 50 units of product PI are to be completed in week 8. Explode this product requirement into the corresponding number of subassemblies and components required.

Solution : Referring to the product structure in Figure 25.4, 50 units of P1 explode into 50 units of S1 and 100 units of S2. Similarly, the requirements for these subassemblies explode into 50 units of C1, 200 of C2, 50 of C3, 200 of C5 and 100 of C6. Quantities of raw materials are determined in a similar manner.

Several complicating factors must be considered during the MRP computations. First the quantities of component and subassemblies listed in the solution of Example 25.1 do not account for any of those items that may already be stocked in inventory or are expected to be received as future order. Accordingly, the computed quantities must be adjusted for any inventories on hand or on order, a procedure called netting. For each time bucket, net requirements = gross requirements less on hand inventories and less quantities on order.

Second, quantities of common use items must be combined during parts explosion to determine the total quantities required for each component and raw material in the schedule. Common use items are raw materials and components that are used on more than one product. MRP collects these common use items from different products to achieve economics in ordering the raw materials and producing the components.

Third, lead times for each item must be taken into account, The lead time for a job is the time that must be allowed to complete the job from start to finish. There are two kinds of lead times in MRP: ordering lead timed and manufacturing lead times. Ordering lead time for an item is the time required from initiation of the purchase requisition to receipt of the item from the vendor. If the item is raw material that is stocked by the vendor, the ordering lead time should be relatively short, perhaps a few days or a few weeks. If the items is fabricated, the lead time may be substantial, perhaps several months. Manufacturing lead time is the time required to produce the item in the company's own plant, form order release to completion, once the raw material for the item are available. The scheduled delivery of end product must be translated into time-phased requirements for components and materials by factoring in the ordering and manufacturing lead time.

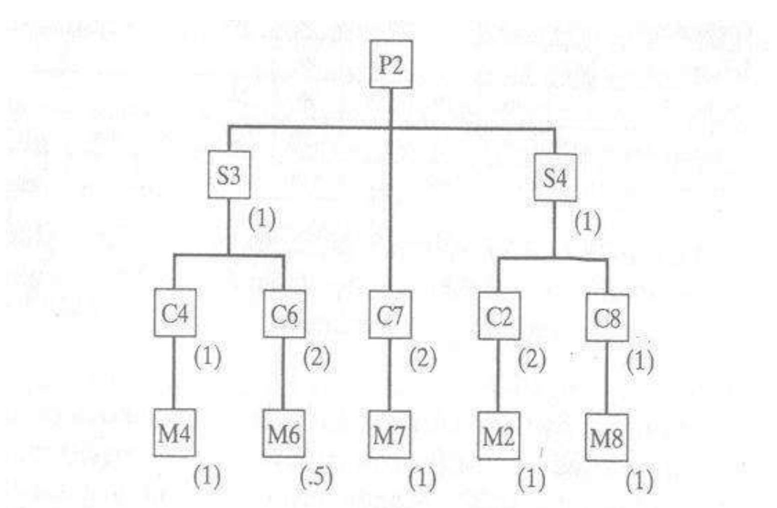
EXAMPLE 25.2 MRP Time Phased Quantity Requirements :

To illustrate these various complicating factors, let use consider the MRP procedure for component C4, which is used in product P1. This part also happens to be used on product P2 of the master schedule in Figure 25.2. The product structure for P2 is shown in figure 5.6. Component C4 is made out of material M4, one unit of M4 for each unit of C4, and the inventory status of M4 is given in figure 25.5. the lead time and inventory status for each of the other items needed in the MRP calculations are shown in the table below. Complete the

MRP calculations to determine the time phased requirements for items S2,S3,C4 and M4, based on the requirements for P1 and P2 given in the MPS of Figure 25.2. we assume that the inventory on hand or on order for P1 , P2,S2,S3 and C4 is zero for all future periods except for the calculated valves in this problem solution.

Item	Lead Time	Inventory
P1	Assembly lead time = 1 wk	No inventory of hand or on order
P2	Assembly lead time = 1 wk	No inventory of hand or on order
S2	Assembly lead time = 1 wk	No inventory of hand or on order
S3	Assembly lead time = 1 wk	No inventory of hand or on order
C4	Manufacturing lead time = 2 wk	No inventory of hand or on order
M4	Ordering lead time = 3 wk	See Figure 25.6

Solution : The result of the MRP calculations are given in figure 25.7. the delivery requirements for P1 and P2 must be offset by their 1 wk assembly lead time to obtain the planned order released. These quantities are then exploded into requirements for subassemblies S2 (for P1) and S3 (for P1) and S3 (for P2). These requirements are offer by their 1 wk assembly lead time and combined in week 6 to obtain gross requirements for component C4. Net requirements equal gross requirements for P1, P2,S2 and C4 because of no inventory on hand and no planned orders. We see the effect of current inventory and planned orders in the time-phased inventory status of M4. The on-hand stock of 50 units plus scheduled receipts of 40 are used to meet gross requirements of 70 units of M4 in week 3, with 20 units remaining that can be applied to the gross requirements of 280 units in week 4. Net requirements in week 4 are therefore 260 units. With an ordering lead time of 3 wk, the order release for 260 units must be planned for week 1.



Period		1	2	3	4	5	6	7	8	9	10
Item: Product P1									50		100
Gross Requirements											
Scheduled receipts											
On Hand	0										
Net requirement									50		100
Planned order releases								50		100	
Item: Product P2								70	80	25	
Gross Requirements											
Scheduled receipts											
On Hand	0	0									
Net requirement								70	80	25	
Planned order releases							70	80	25		
Item: Subassembly S2								100		200	
Gross Requirements											
Scheduled receipts											
On Hand		0									
Net requirement								100		200	
Planned order releases							100		200		
Item: Subassembly S3							70	80	25		
Gross Requirements											
Scheduled receipts											
On Hand	0	0									
Net requirement							70	80	25		
Planned order releases						70	80	25			
Item: Component						70	280	25	400		

C4											
Gross Requirements											
Scheduled receipts											
On Hand		0									
Net requirement						70	280	25	400		
Planned order releases				70	280	25	400				
Item: Raw Material M4											
Gross Requirements				70	280	25	400				
Scheduled receipts				40							
On Hand	50	50	50	90	20						
Net requirement				-20	260	25	400				
Planned order releases		260	25	400							

Figure 25.7 MRP solution to Example 25.2. Time –phased requirements for P1 and P2 are taken from Figure 25.2. Requirements for S2,S3,C4 and M4 are calculated..

6.7. MRP Output and Benefits :

The MRP program generates a variety of outputs that can be used in planning and managing plant operations. The ouput include (1) planned order releases, which provide the authority to place orders that have been planned by the MRP system: (2) report of planned order releases in future periods ; (3) rescheduling notices, indicating changes in due dates for open orders; (4) cancellation notices, indicating that certain open orders have been canceled because in the MPS;(5) reports on inventory status; (6) performance reports of various types , indicating costs, item usage, actual versus planned lead times, and so on;

(7) exception report , showing deviations from the schedule from the schedule, orders that are overdue, scrap, and so on; and (8) inventory forecasts, indicating projected inventory levels in future periods.

Of the MRP output listed above, the planned order releases are the most important because they drive the production system. Planned order of two kinds, purchase orders and work orders. Purchase orders provide the authority to purchase raw materials or parts from outside vendors, with quantities and delivery dates specified. Work orders generate the authority to produce parts or assembly subassemblies or products in the company's own factory. Again , quantities to be completed and completion dates are specified.

Benefits reported by users of MRP systems include the following: (1) reduction in inventory, (2) quicker response to changes in demand than is possible with a manual requirements planning systems, (3) reduced setup and product changeover costs, (4) better machine utilization, (5) improved capacity to respond to changes in the master schedule, and (6) aid in developing the master schedule.

Notwithstanding these claimed benefits, the success rate in implementing MRP systems throughout industry has been less than perfect. Some MRP systems have not been successful because (1) the application was not appropriate, usually because the product structure did not fit the data requirements of MRP; (2) the MRP computations were based on inaccurate data; and (3) the MPS was not coupled with a capacity planning system, so the MRP program generated an unrealistic schedule of work orders that overloaded the factory.

6.8. CAPACITY PLANNING :

The original MRP system that were developed in the 1970s created schedules that were not necessarily consists with the production capabilities and limitations of the plants that were to produce the products. In many instances, the MRP system developed the detailed schedule based on a master production schedule that was unrealistic. A successful production schedule must consider production capacity. In cases where current capacity is inadequate, the firm must make plans for changes in capacity to meet the changing production requirements specified in the schedule. In chapter 3, we defined production capacity and formulated equations to determine the capacity of a plant. Capacity planning consists of determining what labor and equipment resources are required to meet the current MPS as well as long term future production needs of the firm (see Advanced Manufacturing Planning, Section 24.4). Capacity planni9ng also identifies the limitations of the available production resources to prevent the MRP program from planning an un realistic master schedule.

Capacity planning is typically accomplished in two stages, as indicated in Figure 25.8: first, when the MPS is established; and second , when the MRP computations are done. In the MPS stage, a rough-cut capacity planning (RCCP) calculations is made to assess the feasibility of the master schedule . Such a calculation indicates whether there is a significant violation of production capacity in the MPS. On the other hand, if the calculation shows no capacity violation, neither does is guarantee that the production schedule can be met. This depends on the allocation of word orders to specific work cells in the plant.. Accordingly, a second capacity calculation is made at the time the MRP schedule is prepared.. Called capacity requirements planning (CRP) , this detailed calculation determined whether there is sufficient production capacity in the individual departments and in the work cells to complete the specific parts and assemblies that have been scheduled by MRP. If the schedule is not compatible with capacity, then either the plant capacity or the master schedule must be adjusted.

Capacity adjustments can be divided into short-term adjustment and long-term adjustments. Capacity adjustments for the short term include the following.

- Employment levels : Employment in the plant can be increase or decrease in response to changes in capacity requirements.

- Number of temporary workers. Increase in employment level can also be achieved by using workers from temporary agency. When the busy period is passed, these workers move to positions at other companies where their services are needed

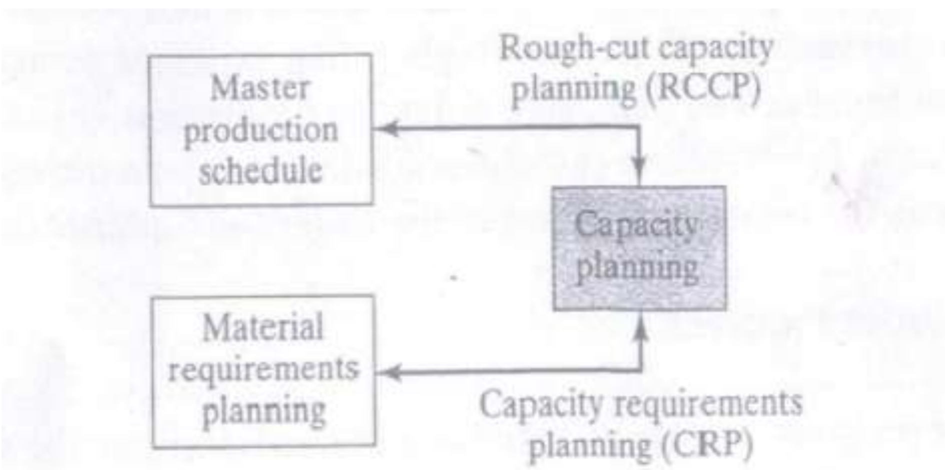
- Number of work shifts. The numbers of shifts worked per production period can be increased or decreased.

- Number of labor hours. The numbers of labor hours per shift can be increased or decreased, through the use of overtime or reduce hours.

- Inventory stockpiling. This tactic might be used to maintain steady employment level during slow demand periods.

- Order backlogs. : Deliveries of the product to the customer could be delayed during busy period when production resources are insufficient to keep up with demand.

- Workload through subcontracting. This involves the letting of the jobs to other shops during busy periods , or the taking in of extra work during slack periods.



Capacity planning adjustments for the long term include changes in production capacity that generally require long times. These adjustments include the following actions:

- Investing in new equipment. This involves investing in more machines or more

  productive machines to meet increased future production requirements, ore investing in new types of machines to match changes in product design.

- Constructing new plants. Building a new factory represents a major investment for the company. However, it also represents a significant increase in production capacity for the firm.

- Purchasing existing plants from other companies.

- Acquiring existing companies . This may be done to increase productive capacity. However , there are usually more important reasons for taking over an existing company, such as to achieve economies of scale that result from increase market share and reducing staff.

- Closing Plants. This involves the closing of plants that will not be needed in the future.

OUTCOMES:

Students will be able to

1. Explain the meaning and importance of process plans
2. Classify types of process planning systems to generate process plans.
3. Explain the concepts like MRP and capacity planning.

QUESSIONAIRE:

1. With a neat sketch, explain retrieval type CAPP system.
2. With a neat block diagram, explain generative type of CAPP system.
3. Discuss the need for CAPP systems.
4. Write a note on
    a. MRP
    b. Capacity planning
    c. Route sheet
    d. Bill of Material
    e. Group[technology

FURTHER READING:

1. http://nptel.ac.in/courses/112102103/Module%20G/Module%20G(5)/p3.htm

2. http://nptel.ac.in/courses/112102103/Module%20G/Module%20G(5)/p4.htm

3. http://nptel.ac.in/courses/Webcourse-contents/IIT-ROORKEE/INDUSTRIAL-ENGINERRING/part3/mrp/lecture1.htm

CNC MACHINING CENTERS

CONTENTS:

OBJECTIVES:

1. To understand history and evolution of numerical control systems.
2. To understand and classify different machining centers.
3. To prepare a part program for a given turning or milling model.

7.1. INTRODUCTION TO COMPUTER NUMERICAL CONTROL

The variety being demanded in view of the varying tastes of the consumer calls for a very small batch sizes. Small batch sizes will not be able to take advantage of the mass production techniques such as special purpose machines or transfer lines. Hence, the need for flexible automation is felt , where you not only get the benefits of rigid automation but are also able to vary the products manufactured thus bringing in the flexibility. Numerical control fits the bill perfectly and we would see that manufacturing would increasingly be dependent on numerical control in future.

Numerical control

Numerical control of machine tools may be defined as a method of automation in which various functions of machine tools are controlled by letters, numbers and symbols. Basically a NC machine runs on a program fed to it. The program consists of precise instructions about the methodology of manufacture as well as movements. For example, what tool is to be used, at what speed, at what feed and to move from which point to which point in what path. Since the program is the controlling point for product manufacture, the machine becomes versatile and can be used for any part. All the functions of a NC machine tool are therefore controlled electronically, hydraulically or pneumatically. In NC machine tools, one or more of the following functions may be automatic.

a. Starting and stopping of machine tool spindle.

b. Controlling the spindle speed.

c. Positioning the tool tip at desired locations and guiding it along desired paths by automatic control of motion of slides.

d. Controlling the rate of movement of tool tip (feed rate)

e. Changing of tools in the spindle.

Functions of a machine tool

The purpose of a machine tool is to cut away surplus material, usually metal from the material supplied to leave a work piece of the required shape and size, produced to an acceptable degree of accuracy and surface finish. The machine tool should possess certain capabilities in order to fulfill these requirements. It must be

a. Able to hold the work piece and cutting tool securely.
b. Endowed the sufficient power to enable the tool to cut the work piece material at economical rates.
c. Capable of displacing the tool and work piece relative to one another to produce the required work piece shape. The displacements must be controlled with a degree of precision which will ensure the desired accuracy of surface finish and size.

Concept of numerical control

Formerly, the machine tool operator guided a cutting tool around a work piece by manipulating hand wheels and dials to get a finished or somewhat finished part. In his procedure many judgments of speeds, feeds, mathematics and sometimes even tool configuration were his responsibility. The number of judgments the machinist had to make usually depended on the type of stock he worked in and the kind of organization that prevailed. If his judgment was an error, it resulted in rejects or at best parts to be reworked or repaired in some fashion.

Decisions concerning the efficient and correct use of the machine tool then depended on the craftsmanship, knowledge and skill of the machinist himself. It is rare that two expert operators produced identical parts using identical procedure and identical judgment of speeds, feeds and tooling. In fact even one craftsman may not proceed in same manner the second time around.. Process planners and programmers have now the responsibilities for these matters.

It must be understood that NC does not alter the capabilities of the machine tool. The With NC the correct and most efficient use of a machine no longer rests with the operator.Actual machine tool with a capable operator can do nothing more than it was capable of doing before a MCU was joined to it. New metal removing principles are not involved. Cutting speeds, feeds and tooling principles must still be adhered to. The advantage is idle time is reduced and the actual utilization rate is mush higher (compresses into one or two years that a conventional machine receives in ten years).

Historical Development

1947 was the year in which Numerical control was born. It began because of an urgent need. John C Parsons of the parson’s corporation, Michigan, a manufacturer of helicopter rotor blades could not make his templates fast enough. so he invented a way of coupling computer equipment with a jig borer.

The US air force realized in 1949 that parts for its planes and missiles were becoming more complex. Also the designs were constantly being improved; changes in drawings were frequently made. Thus in their search for methods of speeding up production, an air force study contract was awarded to the Parson's Corporation. The servomechanisms lab of MIT was the subcontractor.

In 1951, the MIT took over the complete job and in 1952; a prototype of NC machine was successfully demonstrated. The term "Numerical Control" was coined at MIT. In 1955 seven companies had tape controlled machines. In 1960, there were 100 NC machines at the machine tool shown in Chicago and a majority of them were relatively simple point to point application.

During these years the electronics industry was busy. First miniature electronic tubes were developed, then solid state circuitry and then modular or integrated circuits. Thus the reliability of the controls has been greatly increased and they have become most compact and less expensive.

Today there are several hundred sizes and varieties of machines, many options and many varieties of control system available.

Definition:

The simplest definition is as the name implies, "a process a controlled by numbers ". Numerical Control is a system in which the direct insertions of programmed numerical value, stored on some form of input medium are automatically read and decoded to cause a corresponding function on the machine tool which it is controlling.

Advantages of NC machine tools:

1. **Reduced lead time:**

   Lead time includes the time needed for planning, design and manufacture of jigs, etc. This time may amount to several months. Since the need for special jigs and fixtures is often entirely eliminated, the whole time needed for their design and manufacture is saved.

2. **Elimination of operator errors:**

   The machine is controlled by instructions registered on the tape provided the tape is correct and machine and tool operate correctly, no errors will occur in the job. Fatigue, boredom, or inattention by operator will not affect the quality or duration of the machining. Responsibility is transferred from the operator to the tape, machine settings are achieved without the operator reading the dial.

3. **Operator activity:**

The operator is relieved of tasks performed by the machine and is free to attend to matters for which his skills and ability are essential. Presetting of tools, setting of components and preparation and planning of future jobs fall into this category. It is possible for two work stations to be prepared on a single machine table, even with small batches. Two setting positions are used, and the operator can be setting one station while machining takes place at the other.

4. Lower labor cost

More time is actually spent on cutting the metal. Machine manipulation time ex.:. Gear changing and often setting time are less with NC machines and help reduce the labor cost per job considerably.

5. Smaller batches

By the use of preset tooling and presetting techniques downtime between batches is kept at a minimum. Large storage facilities for work in progress are not required. Machining centers eliminate some of the setups needed for a succession of operation on one job; time spent in waiting until each of a succession of machine is free is also cut. The components circulate round the machine shop in a shorter period, inter department costs are saved and 'program chasing' is reduced.

6. Longer tool life

Tools can be used at optimum speeds and feeds because these functions are controlled by the program.

7. Elimination of special jigs and fixtures

Because standard locating fixtures are often sufficient of work on machines. the cost of special jigs and fixture is frequently eliminated. The capital cost of storage facilities is greatly reduced. The storage of a tape in a simple matter, it may be kept for many years and manufacturing of spare parts, repeat orders or replacements is made much more convenient.

8. Flexibility in changes of component design

The modification of component design can be readily accommodated by reprogramming and altering the tape. Savings are affected in time and cost.

9. Reduced inspection.

The time spent on inspection and in waiting for inspection to begin is greatly reduced. Normally it is necessary to inspect the first component only once the tape is proved; the repetitive accuracy of the machine maintains a consistent product.

10. Reduced scrap

Operator error is eliminated and a proven tape results in accurate component.

11. Accurate costing and scheduling

The time taken in machining is predictable, consistent and results in a greater accuracy in estimating and more consistency in costing.

Evolution of CNC:

With the availability of microprocessors in mid 70's the controller technology has made a tremendous progress. The new control systems are termed as computer numerical control (CNC) which are characterized by the availability of a dedicated computer and enhanced memory in the controller. These may also be termed "soft wired numerical control".

There are many advantages which are derived from the use of CNC as compared to NC.

- Part program storage memory.
- Part program editing.
- Part program downloading and uploading.
- Part program simulation using tool path.
- Tool offset data and tool life management.
- Additional part programming facilities.
- Macros and subroutines.
- Background tape preparation, etc.

The controls with the machine tools these days are all CNC and the old NC control do not exist any more.

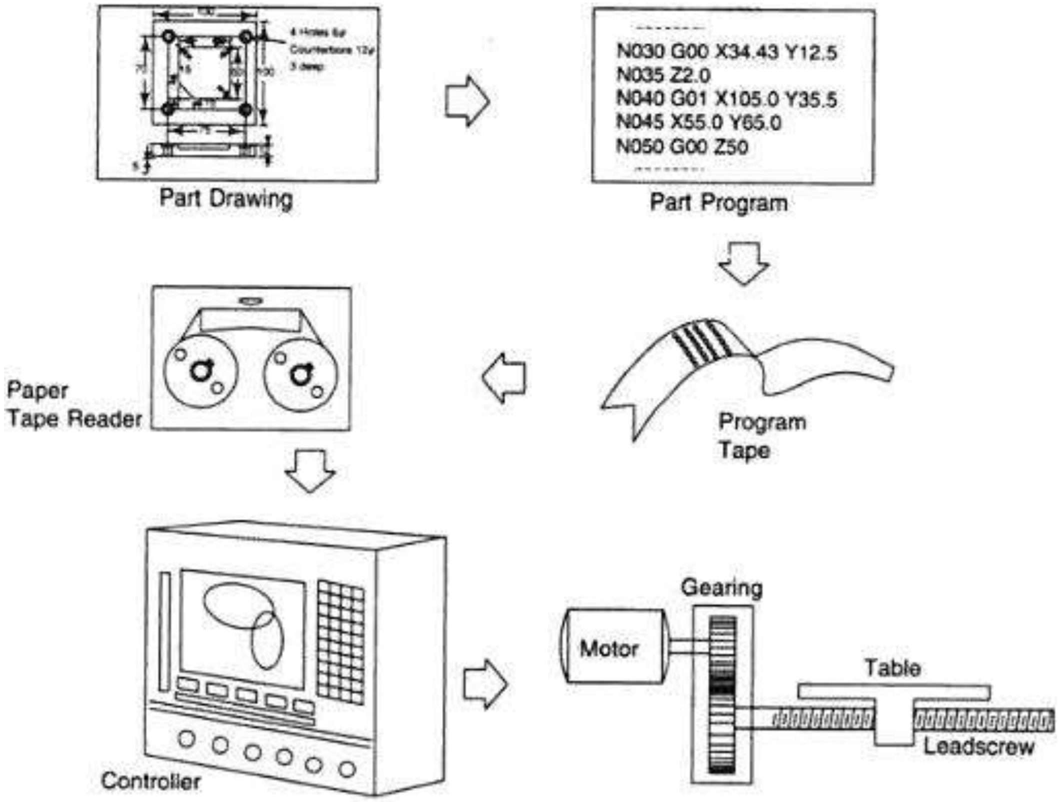


Fig. *Elements of NC Machine Tool Operation*

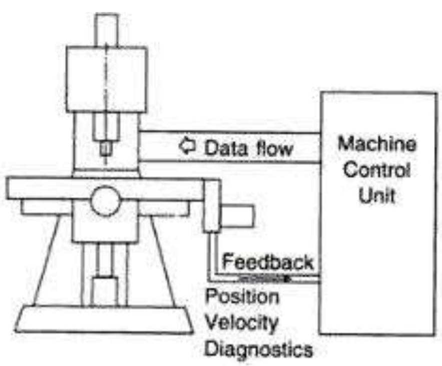


Fig. *The Data Processing in a CNC Machine Tool in Closed Loop Control*

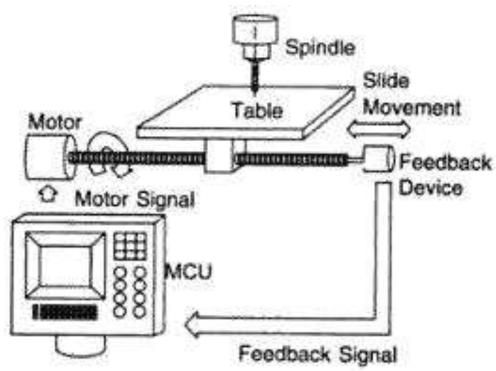


Fig. *The Data Processing in a CNC Machine Tool in Closed Loop Control*

7.2. DEFINITION AND FEATURES OF CNC

Computer Numerical Control (CNC)

CNC refers to a computer that is joined to the NC machine to make the machine versatile. Information can be stored in a memory bank. The programme is read from a storage medium such as the punched tape and retrieved to the memory of the CNC computer. Some CNC machines have a magnetic medium (tape or disk) for storing programs. This gives more flexibility for editing or saving CNC programs. Figure 1 illustrates the general configuration of CNC.

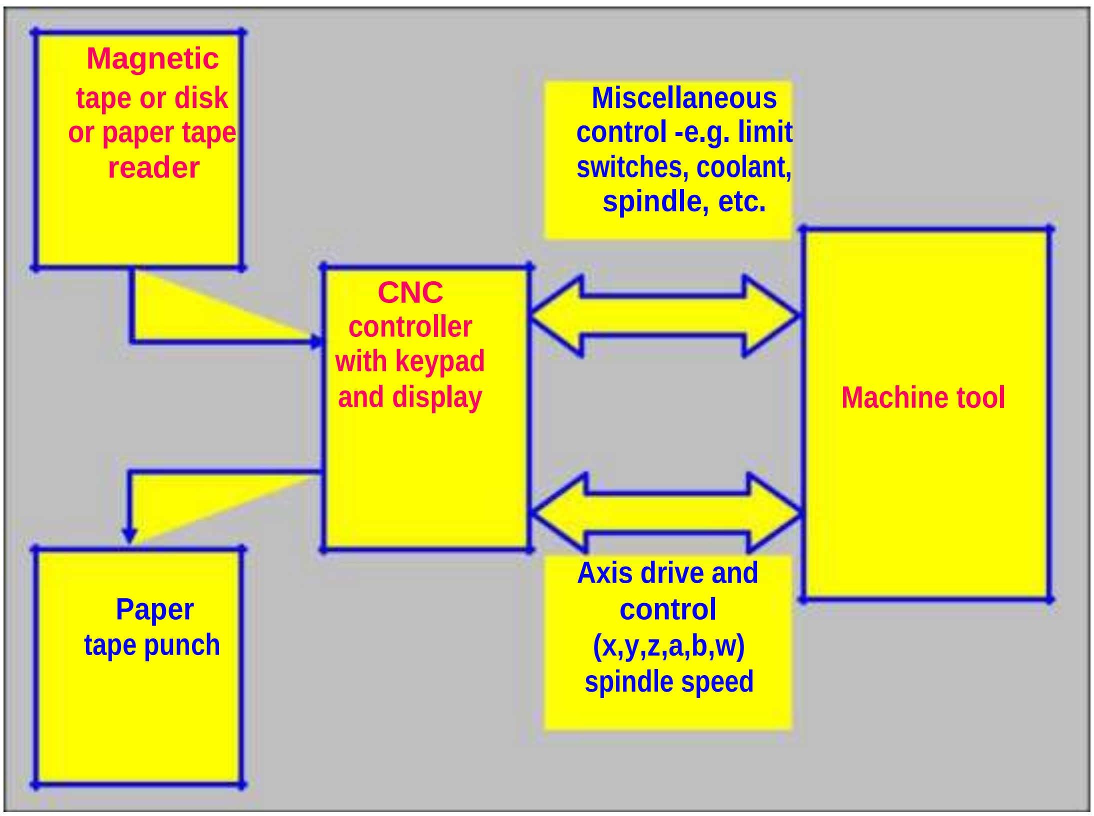


Figure 1 The general configuration of CNC.

Advantages of CNC

1. Increased productivity.
2. High accuracy and repeatability.
3. Reduced production costs.
4. Reduced indirect operating costs.
5. Facilitation of complex machining operations.

6. Greater flexibility.
7. Improved production planning and control.
8. Lower operator skill requirement.
9. Facilitation of flexible automation.

Limitations of CNC:

1. High initial investment.
2. High maintenance requirement.
3. Not cost-effective for low production cost.

Features of CNC

- **Storage of more than one part program :** With improvements in computer storage technology, newer CNC controllers have sufficient capacity to store multiple programs. Controller manufacturers generally offer one or more memory expansions as options to the MCU

- **Various forms of program input :** Whereas conventional (hard-wired) MCUs are limited to punched tape as the input medium for entering part programs, CNC controllers generally possess multiple data entry capabilities, such as punched tape, magnetic tape, floppy diskettes, RS-232 communications with external computers, and manual data input (operator entry of program).

- **Program editing at the machine tool :** CNC permits a part program to be edited while it resides in the MCU computer memory. Hence, a part program can be tested and corrected entirely at the machine site, rather than being returned to the programming office for corrections. In addition to part program corrections, editing also permits cutting conditions in the machining cycle to be optimized. After the program has been corrected and optimized, the revised version can be stored on punched tape or other media for future use.

- **Fixed cycles and programming subroutines :** The increased memory capacity and the ability to program the control computer provide the opportunity to store frequently used machining cycles as macros, that can be called by the part program. Instead of writing the full instructions for the particular cycle into every program, a programmer includes a call statement in the part program to indicate that the macro cycle should be executed. These cycles often require that certain parameters be defined, for example, a bolt hole circle, in which the diameter of the bolt circle, the spacing of the bolt holes, and other parameters must be specified.

- **Interpolation :** Some of the interpolation schemes are normally executed only on a CNC system because of computational requirements. Linear and circular interpolation are sometimes hard-wired into the control unit, but helical, parabolic, and cubic interpolations are usually executed by a stored program algorithm.

- **Positioning features for setup :** Setting up the machine tool for a given workpart involves installing and aligning a fixture on the machine tool table. This must be accomplished so that the machine axes are established with respect to the workpart. The alignment task can be facilitated using certain features made possible by software options in the CNC system. Position set is one of the features. With position set, the operator is not required to locate the fixture on the machine table with extreme accuracy. Instead, the machine tool axes are referenced to the location of the fixture using a target point or set of target points on the work or fixture.

- **Cutter length and size compensation :** In older style controls, cutter dimensions hade to be set precisely to agree with the tool path defined in the part program. Alternative methods for ensuring accurate tool path definition have been incorporated into the CNC controls. One method involves manually entering the actual tool dimensions into the MCU. These actual dimensions may differ from those originally programmed. Compensations are then automatically made in the computed tool path. Another method involves use of a tool length sensor built into the machine. In this technique, the cutter is mounted in the spindle and the sensor measures its length. This measured value is then used to correct the programmed tool path.

- **Acceleration and deceleration calculations :** This feature is applicable when the cutter moves at high feed rates. It is designed to avoid tool marks on the work surface that would be generated due to machine tool dynamics when the cutter path changes abruptly. Instead, the feed rate is smoothly decelerated in anticipation of a tool path change and then accelerated back up to the programmed feed rate after the direction change.

- **Communications interface :** With the trend toward interfacing and networking in plants today, most modern CNC controllers are equipped with a standard RS-232 or other communications interface to link the machine to other computers and computer-driven devices. This is useful for various applications, such as (1)downloading part programs from a central data file; (2)collecting operational data such as workpiece counts, cycle times, and machine utilization; and (3)interfacing with peripheral equipment, such as robots that unload and load parts.

- **Diagnostics :** Many modern CNC systems possess a diagnostics capability that monitors certain aspects of the machine tool to detect malfunctions or signs of impending malfunctions or to diagnose system breakdowns.

The Machine Control Unit (MCU) for CNC

The MCU is the hardware that distinguishes CNC from conventional NC. The general configuration of the MCU in a CNC system is illustrated in Figure 2. The MCU consists of the following components and subsystems: (1) Central Processing Unit, (2) Memory, (3) Input/Output Interface, (4) Controls for Machine Tool Axes and Spindle Speed, and (5) Sequence Controls for Other Machine Tool Functions. These subsystems are interconnected by means of a system bus, which communicates data and signals among the components of a network.

- **Central Processing Unit :** The central processing unit (CPU) is the brain of the MCU. It manages the other components in the MCU based on software contained in main memory. The CPU can be divided into three sections: (1) control section, (2) arithmetic-logic unit, and (3) immediate access memory. The control section retrieves commands and data from memory and generates signals to activate other components in the MCU. In short, it sequences, coordinates, and regulates all the activities of the MCU computer. The arithmetic-logic unit (ALU) consists of the circuitry to perform various calculations (addition, subtraction, multiplication), counting, and logical functions required by software residing in memory. The immediate access memory provides a temporary storage of data being processed by the CPU. It is connected to main memory of the system data bus.

- **Memory :** The immediate access memory in the CPU is not intended for storing CNC software. A much greater storage capacity is required for the various programs and data needed to operate the CNC system. As with most other computer systems, CNC memory can be divided into two categories: (1) primary memory, and (2) secondary memory. Main memory (also known as primary storage) consists of ROM (read-only memory) and RAM (random access memory) devices. Operating system software and machine interface programs are generally stored in ROM. These programs are usually installed by the manufacturer of the MCU. Numerical control part programs are stored in RAM devices. Current programs in RAM can be erased and replaced by new programs as jobs are changed.

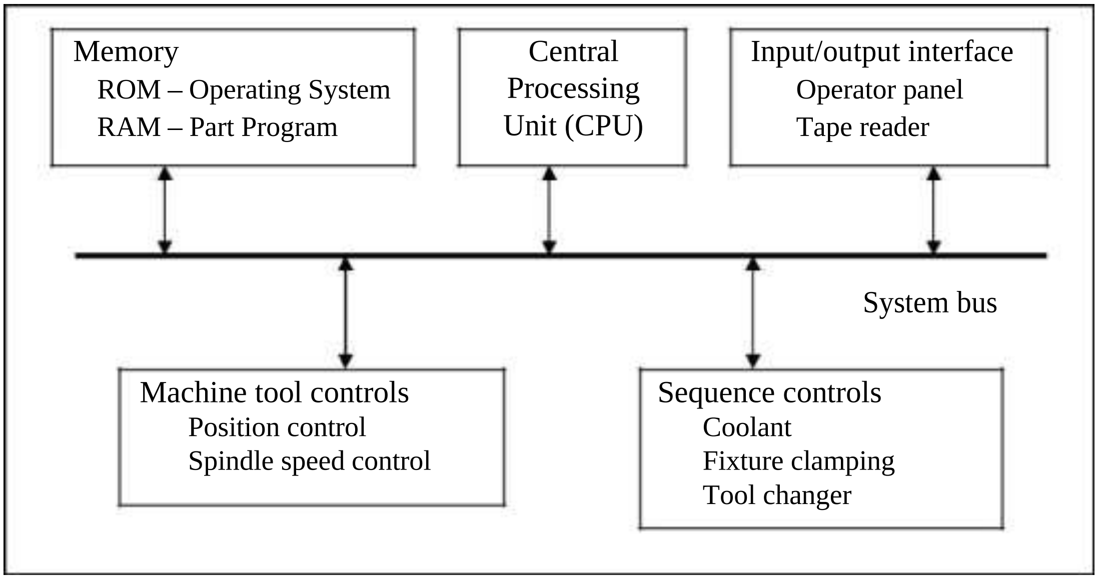


Figure 2 Configuration of CNC machine control unit

High-capacity secondary memory (also called auxiliary storage or secondary storage) devices are used to store large programs and data files, which are transferred to main memory as needed. Common among the secondary memory devices are hard disks and portable devices that have replaced most of the punched paper tape traditionally used to store part programs. Hard disks are high-capacity storage devices that are permanently installed in the CNC machine control unit. CNC secondary memory is used to store part programs, macros, and other software.

- **Input/Output Interface :** The I/O interface provides communication software between the various components of the CNC system, other computer systems, and the machine operator. As its name suggests, The I/O interface transmits and receives data and signals to and from external devices, several of which are illustrated in Figure 2. The operator control panel is the basic interface by which the machine operator communicates to the CNC system. This is used to enter commands related to part program editing, MCU operating mode (e.g., program control vs. manual control), speeds and feeds, cutting fluid pump on/off, and similar functions. Either an alphanumeric keypad or keyboard is usually included in the operator control panel. The I/O interface also includes a display (CRT or LED) for communication of data and information from the MCU to the machine operator. The display is used to indicate current status of the program as it is being executed and to warn the operator of any malfunctions in the CNC system.

Also included in the I/O interface are one or more means of entering the part program into storage. As indicated previously, NC part programs are stored in a variety of ways. Programs can also be entered manually by the machine operator or stored at a central computer site and transmitted via local area network (LAN) to the CNC system. Whichever means is employed by the plant, a suitable device must be included in the I/O interface to allow input of the program into MCU memory.

- **Controls for Machine Tool Axes and Spindle Speed :** These are hardware components that control the position and velocity (feed rate) of each machine axis as well as the rotational speed of the machine tool spindle. The control signals generated by MCU must be converted to a form and power level suited to the particular position control systems used to drive the machine axes. Positioning systems can be classified as open loop or closed loop, and different hardware components are required in each case.

Depending on the type of machine tool, the spindle is used to drive either (1) workpiece or (2) a rotating cutter. Turning exemplifies the first case, whereas milling and drilling exemplify the second. Spindle speed is a programmed parameter for most CNC machine tools. Spindle speed components in the MCU usually consist of s drive control circuit and a feedback sensor interface. The particular hardware components depend on the type of spindle drive.

- **Sequence Controls for Other Machine Tool Functions :**

In addition to control of table position, feed rate, and spindle speed, several additional functions are accomplished under part program control. These auxiliary functions are generally on/off (binary) actuations, interlocks, and discrete numerical data. To avoid overloading the CPU, a programmable logic controller is sometimes used to manage the I/O interface for these auxiliary functions.

7.3. Classification Of CNC Machine Tools

(1) Based on the motion type 'Point-to-point & Contouring systems'

There are two main types of machine tools and the control systems required for use with them differ because of the basic differences in the functions of the machines to be controlled. They are known as point-to-point and contouring controls.

(1.1)Point-to-point systems

Some machine tools for example drilling, boring and tapping machines etc, require the cutter and the work piece to be placed at a certain fixed relative positions at which they must remain while the cutter does its work. These machines are known as point-to-point machines as shown in figure 3 (a) and the control equipment for use with them are known as point-to-point control equipment. Feed rates need not to be programmed. In these machine tools, each axis is driven separately. In a point-to-point control system, the dimensional information that must be given to the machine tool will be a series of required position of the two slides. Servo systems can be used to move the slides and no attempt is made to move the slide until the cutter has been retracted back.

(1.2) Contouring systems (Continuous path systems)

Other type of machine tools involves motion of work piece with respect to the cutter while cutting operation is taking place. These machine tools include milling, routing machines etc. and are known as contouring machines as shown in figure 3 (b), 3 (a) and the controls required for their control are known as contouring control. Contouring machines can also be used as point-to-point machines, but it will be uneconomical to use them unless the work piece also requires having a contouring operation to be performed on it. These machines require simultaneous control of axes. In contouring machines, relative positions of the work piece and the tool should be continuously controlled. The control system must be able to accept information regarding velocities and positions of the machines slides. Feed rates should be programmed.

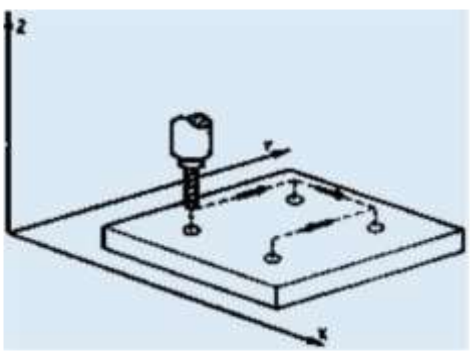


Figure 3 (a) Point-to-point system

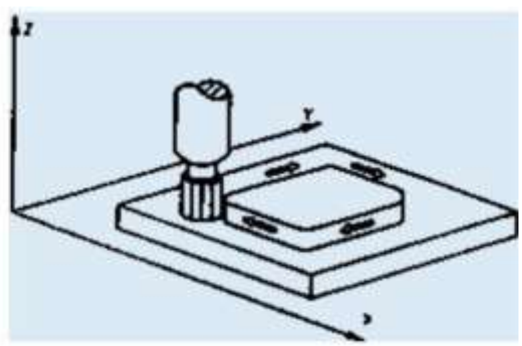


Figure 3 (b) Contouring system

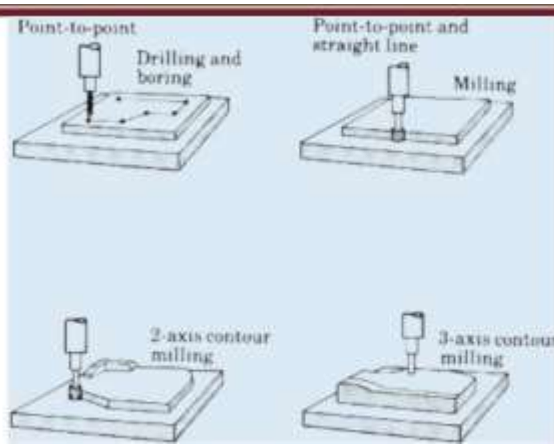


Figure 3 (c) Contouring systems

(2) Based on the control loops 'Open loop & Closed loop systems'

(2.1) Open loop systems (Fig 4(a)):

Programmed instructions are fed into the controller through an input device. These instructions are then converted to electrical pulses (signals) by the controller and sent to the servo amplifier to energize the servo motors. The primary drawback of the open-loop system is that there is no feedback system to check whether the program position and velocity has been achieved. If the system performance is affected by load, temperature, humidity, or lubrication then the actual output could deviate from the desired output. For these reasons the open -loop system is generally used in point-to-point systems where the accuracy requirements are not critical. Very few continuous-path systems utilize open-loop control.

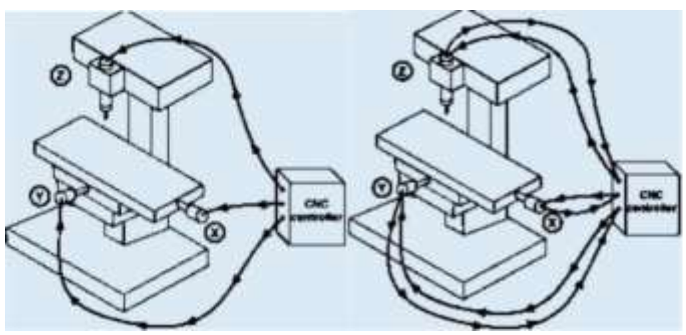


Figure 4(a) Open loop control system Figure 4(b) Closed loop control system

(2.2) Closed loop systems (Fig 4(b)):

The closed-loop system has a feedback subsystem to monitor the actual output and correct any discrepancy from the programmed input. These systems use position and velocity feed back. The feedback system could be either analog or digital. The analog systems measure the variation of physical variables such as position and velocity in terms of voltage levels. Digital systems monitor output variations by means of electrical pulses. To control the dynamic behavior and the final position of the machine slides, a variety of position transducers are employed. Majority of CNC systems operate on servo mechanism, a closed loop principle. If a discrepancy is revealed between where the machine element should be and where it actually is, the sensing device signals the driving unit to make an adjustment, bringing the movable component to the required location. Closed-loop systems are very powerful and accurate because they are capable of monitoring operating conditions through feedback subsystems and automatically compensating for any variations in real-time.

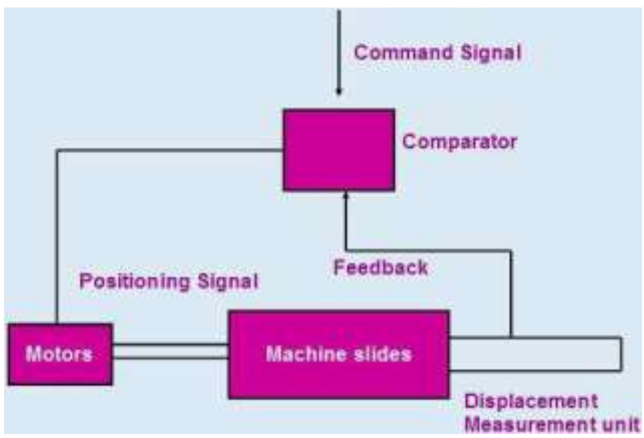


Figure 4 (c) Closed loop system

7.4. CNC MACHINING CENTERS

The machining centre, developed in the late 50's is a machine tool capable of multiple machining operations on a work part in one setup under NC program control.

Classification

Machining centres are classified as vertical, horizontal, or universal. The designation refers to the orientation of the machine spindle.

1. A vertical machining centre has its spindle on a vertical axis relative to the work table. A vertical machining centre (VMC) is typically used for flat work that requires tool access from top. E.g. mould and die cavities, Large components of aircraft

2. A horizontal machining centre (HMC) is used for cube shaped parts where tool access can be best achieved on the sides of the cube.

3. A universal machining centre (UMC) has a work head that swivels its spindle axis to any angle between horizontal and vertical making this a very flexible machine tool. E.g.: Aerofoil shapes, Curvilinear geometries.

The term "Multi tasking machine" is used to include all of these machine tools that accomplish multiple and often quite different types of operations. The processes that might be available on a single multi tasking machine include milling, drilling, tapping, grinding and welding. Advantage of this new class of highly versatile machine compared to more conventional CNC machine tolls include:

- Fewer steps,
- Reduced part handling,
- Increased accuracy and repeatability because the parts utilize the same fixture through out their processing
- Faster delivery of parts in small lot sizes.

Features of CNC machining centers:

CNC machining centers are usually designed with features to reduce non productive time. The features are:

- **Automatic tool changer :**

  The tools are contained in a storage unit that is integrated with the machine tool. When a cutter needs to be changed, the tool drum rotates to the proper position and an automatic tool changer (ATC) operating under program control, exchanges the tool in the spindle for the tool in the tool storage unit. Capacities of tool storage unit commonly range from 16 to 80 cutting tools.

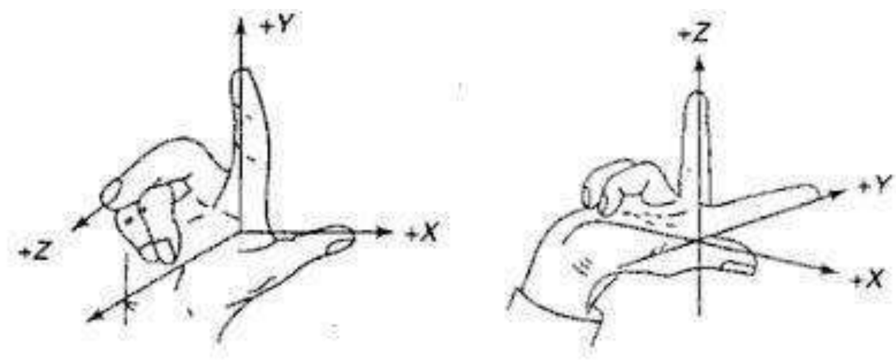
- **Automatic work part positioner:**

  Many horizontal and vertical machining centers have the capability to orient the work part relative to the spindle. This is accomplished by means of a rotary table on which work part is fixtured. The table can be oriented at any angle about a vertical axis to permit the cutting tool to access almost the entire surface of the part in a single setup.

- **Automatic pallet changer:**

  Machining centers are often equipped with two (or more) separate pallets that can be presented to the cutting tool using an automatic pallet changer. While machining is performed with one pallet in position at the machine, the other pallet is in a safe location away from the spindle. In this location, the operator can unload the finished part and then fixture the raw work part for next cycle.

Axes Designation in horizontal and vertical machining centres (Fig 1) :



(a) Axis Designation for Horizontal Z

(b) Axis Designation for Vertical Z

Fig 1: Axes Designation in horizontal and vertical machining centres

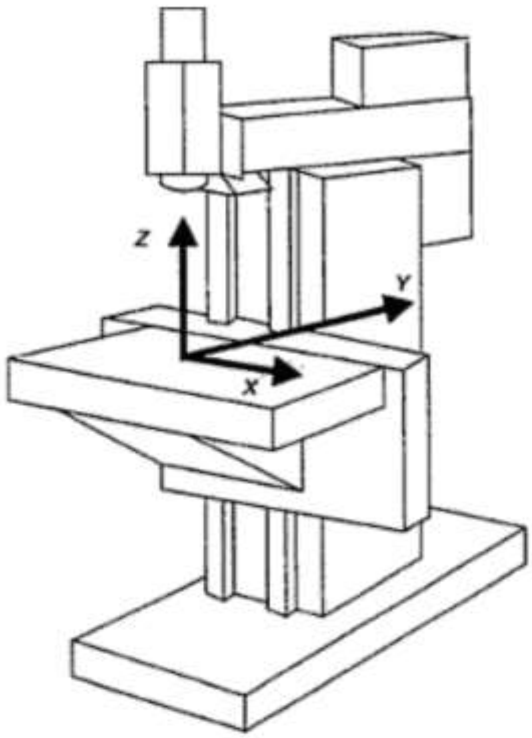


Fig 2 : Vertical Machining Centre

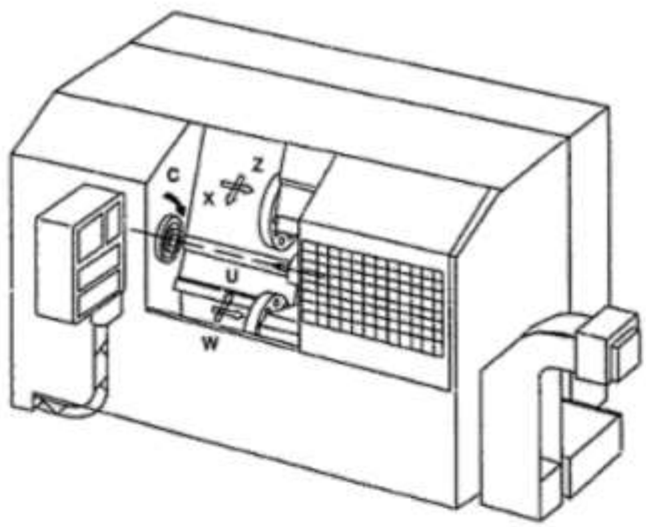


Fig. 3 : Horizontal Machining Centre

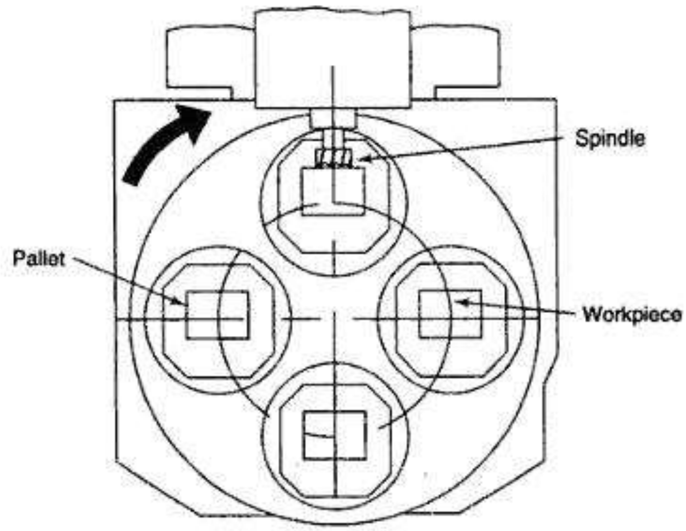


Fig 7 : Typical Rotary Type Pallet Changer

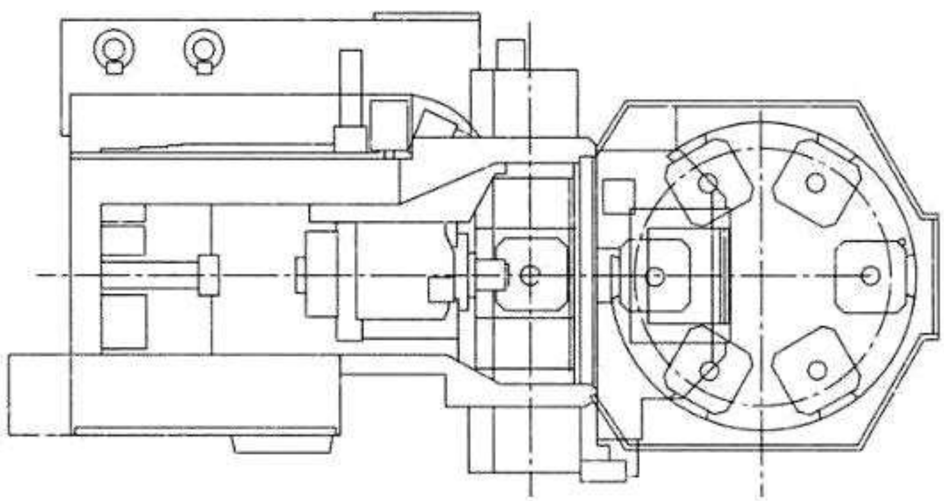


Fig 8 : Typical Shuttle Pallet Changer with Six Pallet Carousel

7.5. CNC PART PROGRAMMING

(1) Programming fundamentals

Machining involves an important aspect of relative movement between cutting tool and workpiece. In machine tools this is accomplished by either moving the tool with respect to workpiece or vice versa. In order to define relative motion of two objects, reference directions are required to be defined. These reference directions depend on type of machine tool and are defined by considering an imaginary coordinate system on the machine tool. A program defining motion of tool / workpiece in this coordinate system is known as a part program. Lathe and Milling machines are taken for case study but other machine tools like CNC grinding, CNC hobbing, CNC filament winding machine, etc. can also be dealt with in the same manner.

(1.1) Reference Point

Part programming requires establishment of some reference points. Three reference points are either set by manufacturer or user.

a) Machine Origin

The machine origin is a fixed point set by the machine tool builder. Usually it cannot be changed. Any tool movement is measured from this point. The controller always remembers tool distance from the machine origin.

b) Program Origin

It is also called home position of the tool. Program origin is point from where the tool starts for its motion while executing a program and returns back at the end of the cycle. This can be any point within the workspace of the tool which is sufficiently away from the part. In case of CNC lathe it is a point where tool change is carried out.

c) Part Origin

The part origin can be set at any point inside the machine's electronic grid system. Establishing the part origin is also known as zero shift, work shift, floating zero or datum. Usually part origin needs to be defined for each new setup. Zero shifting allows the relocation of the part. Sometimes the part accuracy is affected by the location of the part origin. Figure 1 and 2 shows the reference points on a lathe and milling machine.

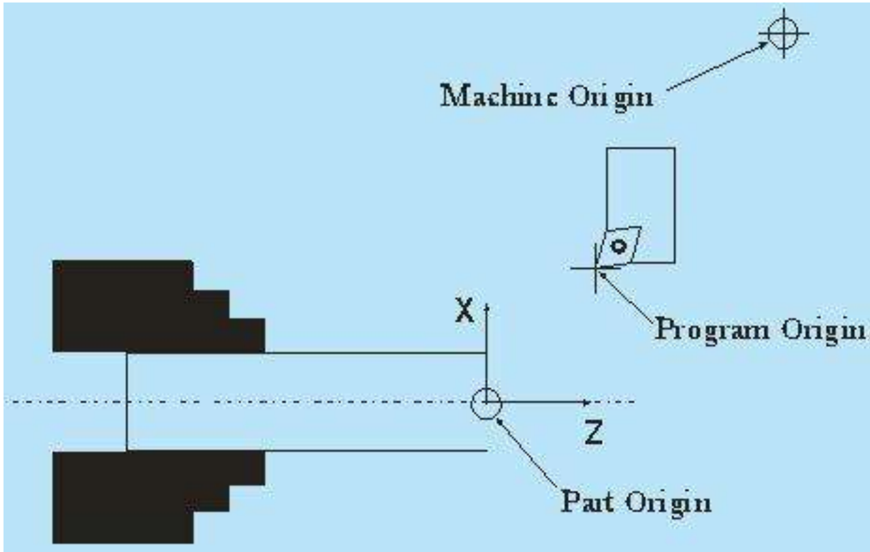


Figure 1 - Reference points and axis on a lathe

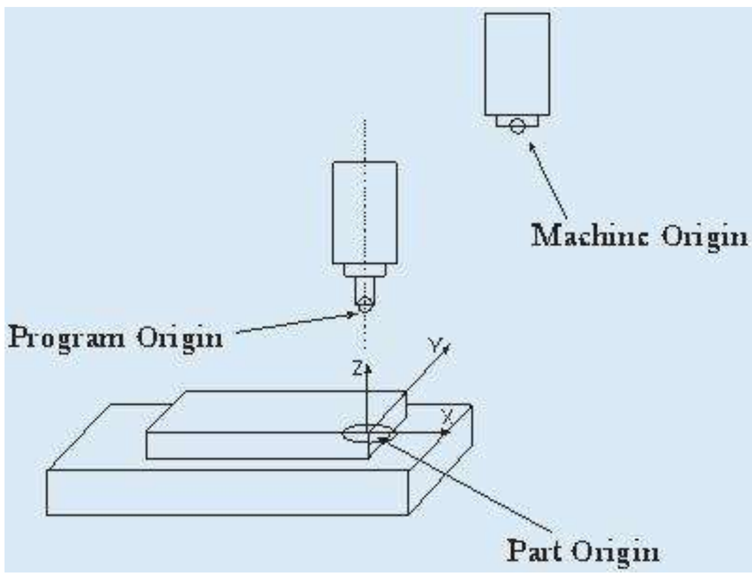


Figure 2 - Reference points and axis on a Milling Machine

1.2)Axis Designation

An object in space can have six degrees of freedom with respect to an imaginary Cartesian coordinate system. Three of them are liner movements and other three are rotary. Machining of simple part does not require all degrees of freedom. With the increase in degrees of freedom, complexity of hardware and programming increases. Number of degree of freedom defines axis of machine.

Axes interpolation means simultaneous movement of two or more different axes generate required contour.

For typical lathe machine degree of freedom is 2 and so it called 2 axis machines. For typical milling machine degree of freedom is $2^1/_2$, which means that two axes can be interpolated at a time and third remains independent. Typical direction for the lathe and milling machine is as shown in figure 1 and figure 2.

1.3) Setting up of Origin

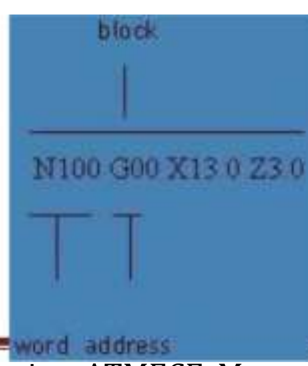
In case of CNC machine tool rotation of the reference axis is not possible. Origin can set by selecting three reference planes X, Y and Z. Planes can be set by touching tool on the surfaces of the workpiece and setting that surfaces as X=x, Y=y and Z=z.

(1.4) Coding Systems

The programmer and the operator must use a coding system to represent information, which the controller can interpret and execute. A frequently used coding system is the Binary-Coded Decimal or BCD system. This system is also known as the EIA Code set because it was developed by Electronics Industries Association. The newer coding system is ASCII and it has become the ISO code set because of its wide acceptance.

(2) CNC Code Syntax

The CNC machine uses a set of rules to enter, edit, receive and output data. These rules are known as CNC Syntax, Programming format, or tape format. The format specifies the order and arrangement of information entered. This is an area where controls differ widely. There are rules for the maximum and minimum numerical values and word lengths and can be entered, and the arrangement of the characters and word is important. The most common CNC format is the word address format and the other two formats are fixed sequential block address format and tab sequential format, which are obsolete. The instruction block consists of one or more words. A word consists of an address followed by numerals. For the address, one of the letters from A to Z is used. The address defines the meaning of the number that follows. In other words, the address determines what the number stands for. For example it may be an instruction to move the tool along the X axis, or to select a particular tool.



Most controllers allow suppressing the leading zeros when entering data. This is known as leading zero suppression. When this method is used, the machine control reads the numbers from right to left, allowing the zeros to the left of the significant digit to be omitted. Some controls allow entering data without using the trailing zeros. Consequently it is called trailing zero suppression. The machine control reads from left to right, and zeros to the right of the significant digit may be omitted.

3) Types of CNC codes

(3.1) Preparatory codes

The term "preparatory" in NC means that it "prepares" the control system to be ready for implementing the information that follows in the next block of instructions. A **preparatory function** is designated in a program by the word address G followed by two digits. Preparatory functions are also called **G-codes** and they specify the control mode of the operation.

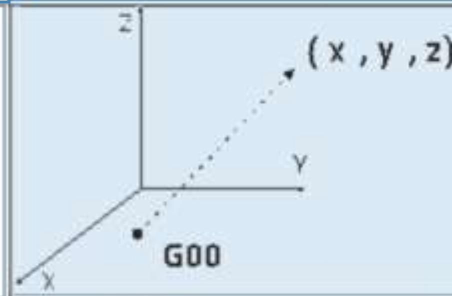
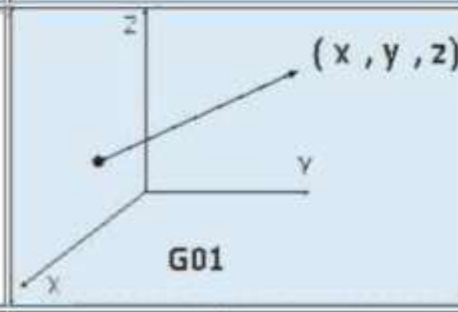
(3.2) Miscellaneous codes

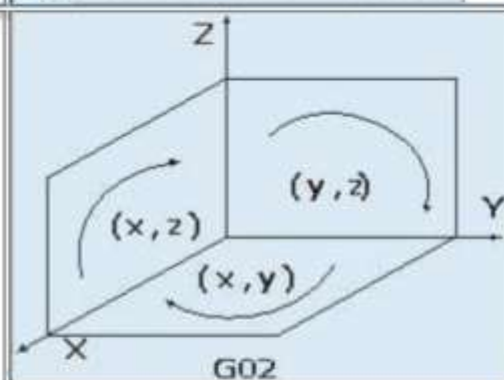
Miscellaneous functions use the address letter M followed by two digits. They perform a group of instructions such as coolant on/off, spindle on/off, tool change, program stop, or program end. They are often referred to as machine functions or **M-functions**. Some of the M codes are given below.

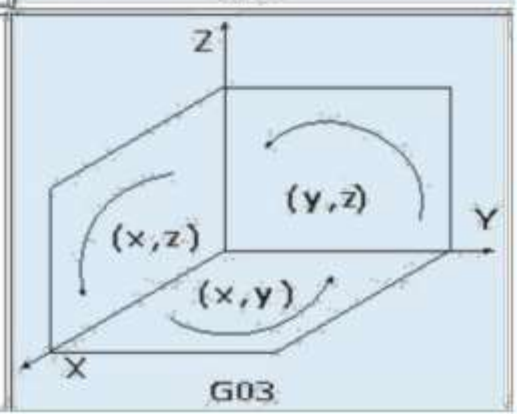
M00 Unconditional stop
M02 End of program
M03 Spindle clockwise
M04 Spindle counterclockwise
M05 Spindle stop
M06 Tool change (see Note below)
M30 End of program

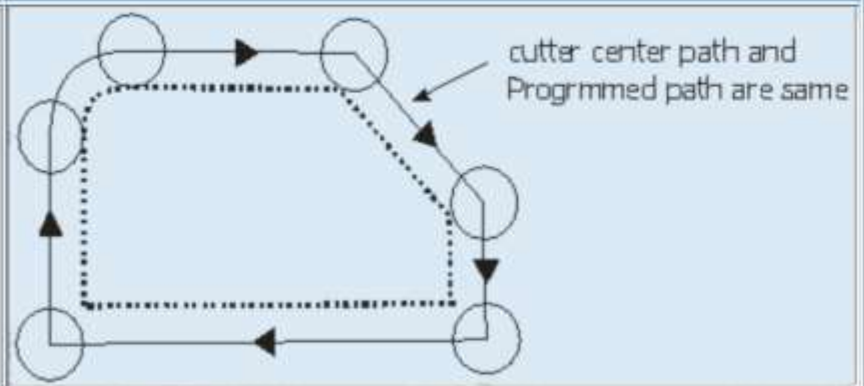
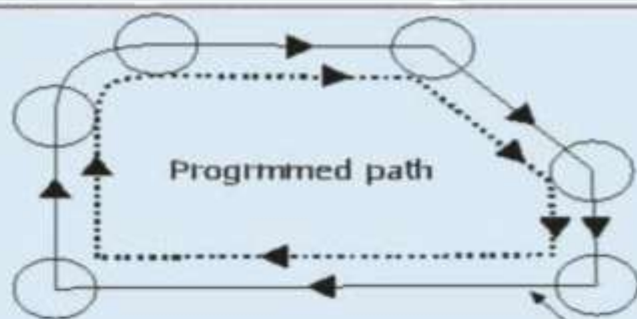
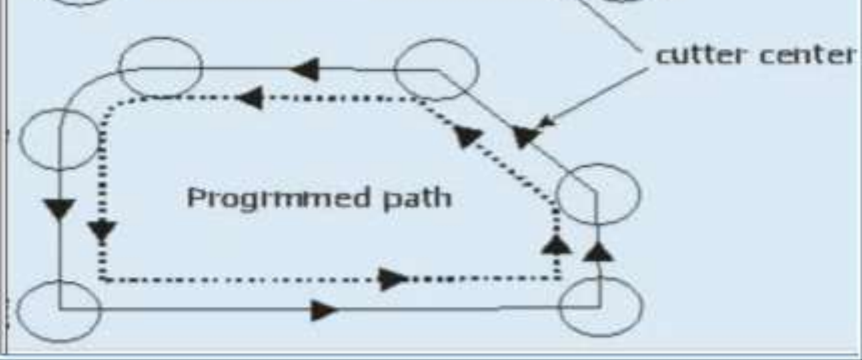
In principle, all codes are either modal or non-modal. **Modal code** stays in effect until cancelled by another code in the same group. The control remembers modal codes. This gives the programmer an opportunity to save programming time. **Non-modal code** stays in effect only for the block in which it is programmed. Afterwards, its function is turned off automatically. For instance G04 is a non-modal code to program a dwell. After one second, which is say, the programmed dwell time in one particular case, this function is cancelled. To perform dwell in the next blocks, this code has to be reprogrammed. The control does not memorize the non-modal code, so it is called as one shot codes. One-shot commands are **non-modal**. Commands known as "canned cycles" (a controller's internal set of preprogrammed subroutines for generating commonly machined features such as internal pockets and drilled holes) are non-modal and only function during the call.

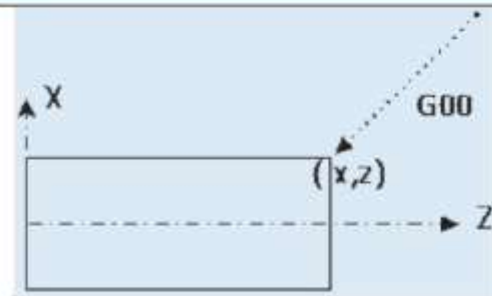
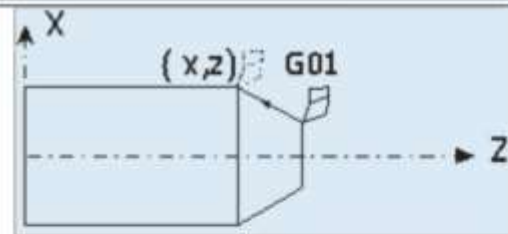
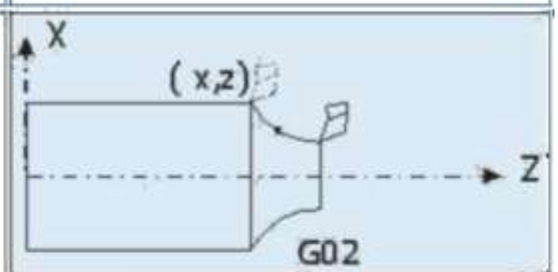
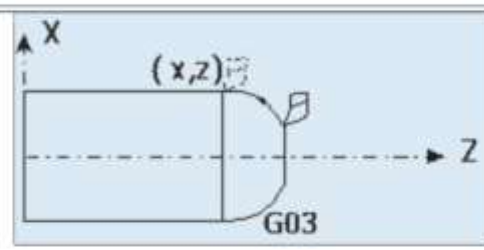
On some older controllers, cutter positioning (axis) commands (e.g., G00, G01, G02, G03, & G04) are non-modal requiring a new positioning command to be entered each time the cutter (or axis) is moved to another location.

<table>
<tr><th>Command group</th><th>G-code</th><th>Function and Command Statement</th><th>Illustration</th></tr>
<tr><td rowspan="4">Tool motion</td><td>G00</td><td>Rapid traverse
G00 Xx Yy Zz</td><td>
</td></tr>
<tr><td>G01</td><td>Linear interpolation
G01 Xx Yy Zz Ff</td><td>
</td></tr>
<tr><td>G02</td><td>Circular Interpolation in clock-wise direction

G02 Xx Yy Ii Jj
G02 Xx Zz Ii Kk
G02 Yy Zz Jj Kk</td><td>
</td></tr>
<tr><td>G03</td><td>Circular interpolation in counter- clockwise direction

G03 Xx Yy Ii Jj
G03 Xx Zz Ii Kk
G03 Yy Zz Jj Kk</td><td>
</td></tr>
</table>

Command group	G-Command	Function and Statement	Illustration code
Offset and compensation	G40	Cutter diameter compensation cancel	
	G41	Cutter diameter compensation left	
	G42	Cutter diameter compensation right	

Command group	G-code	Function and Command Statement	Illustration
Tool motion	G00	Rapid traverse G00 Xx Zz	
	G01	Linear interpolation G01 Xx Zz	
	G02	Circular Interpolation in clock-wise direction G02 Xx Zz Ii Kk (or) G02 Xx Zz Rr	
	G03	Circular interpolation in counter- clockwise direction G03 Xx Zz Ii Kk (or) G03 Yy Zz Rr	

Illustrative Example Program

A contour illustrated in figure 3 is to be machined using a CNC milling machine. The details of the codes and programs used are given below.

Example:

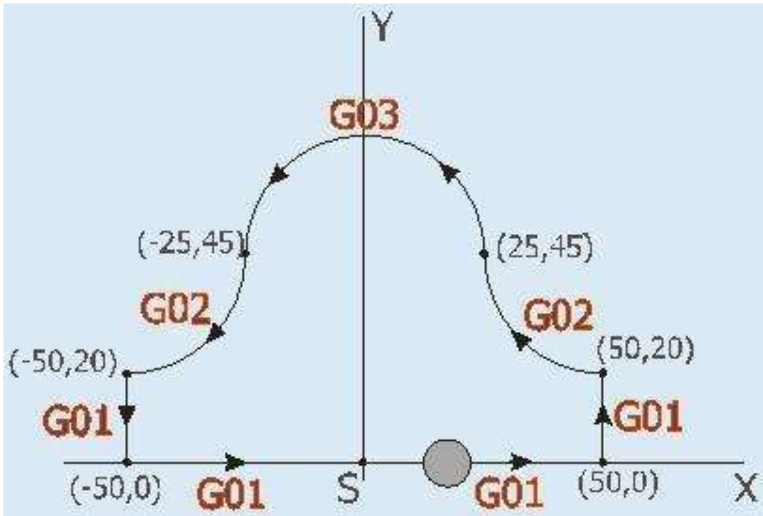


Figure 3 : An illustrative example

O5678	Program number
N02 G21	Metric programming
N03 M03 S1000	Spindle start clockwise with 1000rpm
N04 G00 X0 Y0	Rapid motion towards (0,0)
N05 G00 Z-10.0	Rapid motion towards Z=-10
N06 G01 X50.0	plane Linear interpolation
N07 G01 Y20.0	Linear interpolation
N08 G02 X25.0 Y45.0 R25.0	Circular interpolation clockwise(cw)
N09 G03 X-25.0 Y45.0 R25.0	Circular interpolation counter clockwise(ccw)
N10 G02 X-50.0 Y20.0 R25.0	Circular interpolation clockwise(cw)
N11 G01 Y0.0	Linear interpolation
N12 G01 X0.0	Linear interpolation
N13 G00 Z10.0	Rapid motion towards Z=10 plane
N14 M05 M09	Spindle stop and program end

4. CNC Part Programming II

In the previous section, fundamentals of programming as well basic motion commands for milling and turning have been discussed. This section gives an overview of G codes used for changing the programming mode, applying transformations etc.

4.1 Programming modes

Programming mode should be specified when it needs to be changed from absolute to incremental and vice versa. There are two programming modes, absolute and incremental and is discussed below.

4.1.1 Absolute programming (G90)

In absolute programming, all measurements are made from the part origin established by the programmer and set up by the operator. Any programmed coordinate has the absolute value in respect to the absolute coordinate system zero point. The machine control uses the part origin as the reference point in order to position the tool during program execution (Figure 4).

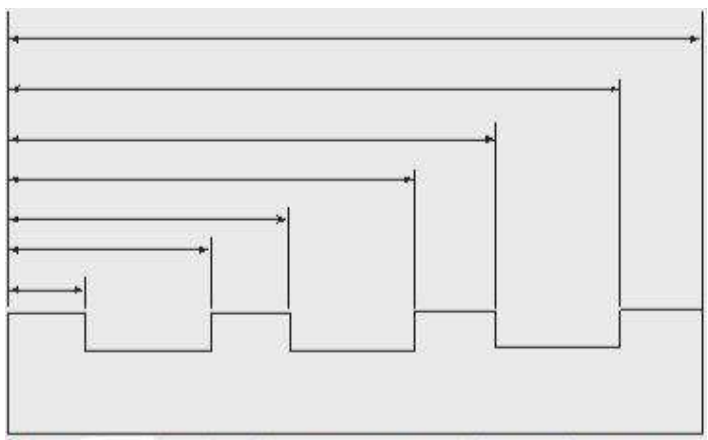


Figure 4 Absolute distances measured from reference zero

4.1.2 Relative programming (G91)

In incremental programming, the tool movement is measured from the last tool position. The programmed movement is based on the change in position between two successive points. The coordinate value is always incremented according to the preceding tool location. The programmer enters the relative distance between current location and the next point (Figure 5).

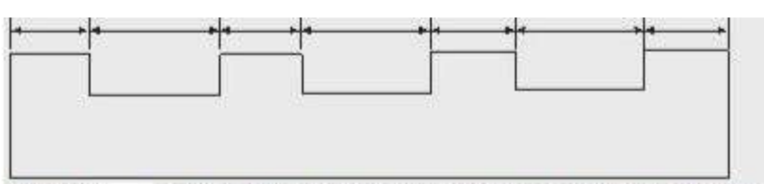


Figure 5 Incremental distances measured from previous locations

4.2 Spindle control

The spindle speed is programmed by the letter 'S' followed by four digit number, such as S1000. There are two ways to define speed :

1. Revolutions per minute (RPM
2. Constant surface speed

The spindle speed in revolutions per minute is also known as constant rpm or direct rpm. The change in tool position does not affect the rpm commanded. It means that the spindle RPM will remain constant until another RPM is programmed. Constant surface speed is almost exclusively used on lathes. The RPM changes according to diameter being cut. The smaller the diameter, the more RPM is achieved; the bigger the diameter, the less RPM is commanded. This is changed automatically by the machine speed control unit while the tool is changing positions. This is the reason that, this spindle speed mode is known as diameter speed.

4.3 Tool selection

Tool selection is accomplished using 'T' function followed by a four digit number where, first two digits are used to call the particular tool and last two digits are used to represent tool offset in the program. The tool offset is used to correct the values entered in the coordinate system preset block. This can be done quickly on the machine without actually changing the values in the program.

Using the tool offsets, it is easy to set up the tools and to make adjustments

4.4 Feed rate control

Cutting operations may be programmed using two basic feed rate modes:

1. Feed rate per spindle revolution
2. Feed rate per time

The feed rate per spindle revolution depends on the RPM programmed.

5.0 Tool radius Compensation

The programmed point on the part is the command point. It is the destination point of the tool. The point on the tool that is used for programming is the tool reference point. These points may or may not coincide, depending on the type of tool used and machining operation being performed. When drilling, tapping, reaming, countersinking or boring on the machining center, the tool is programmed to the position of the hole or bore center - this is the command point.

When milling a contour, the tool radius center is used as the reference point on the tool while writing the program, but the part is actually cut by the point on the cutter periphery. This point is at 'r' distance from the tool center. This means that the programmer should shift the tool center away from the part in order to perform the cutting by the tool cutting edge. The shift amount depends upon the part geometry and tool radius. This technique is known as tool radius compensation or cutter radius compensation.

In case of machining with a single point cutting tool, the nose radius of the tool tip is required to be accounted for, as programs are being written assuming zero nose radius. The tool nose radius center is not only the reference point that can be used for programming contours. On the tool there is a point known as imaginary tool tip, which is at the intersection of the lines tangent to the tool nose radius.

Cutter compensation allows programming the geometry and not the toolpath. It also allows adjusting the size of the part, based on the tool radius used to cut part. This is useful when cutter of the proper diameter is not found. This is best explained in the Figure 11.

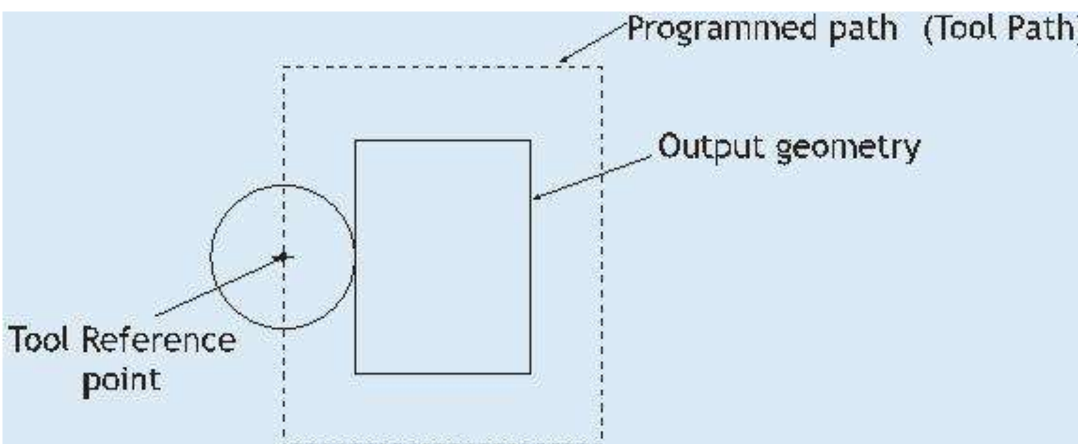


Figure 11. Cutter diameter compensation

The information on the diameter of the tool, which the control system uses to calculate the required compensation, must be input into the control unit's memory before the operation. Tool diameter compensation is activated by the relevant preparatory functions (G codes)
as shown in Figure 12.

Compensation for tool radius can be of either right or left side compensation. This can be determined by direction of tool motion. If you are on the tool path facing direction of tool path and if tool is on your left and workpiece is on your right side then use G41 (left side compensation). For, reverse use other code G42 (Right side compensation). Both the codes are modal in nature and remain active in the program until it is cancelled by using another code, G40.

5.1 Subroutines

Any frequently programmed order of instruction or unchanging sequences can benefit by becoming a subprogram. Typical applications for subprogram applications in CNC programming are :

- Repetitive machining motions
- Functions relating to tool change
- Hole patterns
- Grooves and threads
- Machine warm-up routines
- Pallet changing
- Special functions and others

Structurally, subprograms are similar to standard programs. They use the same syntax rules. The benefits of subroutines involve the reduction in length of program, and reduction in program errors. There is a definition statement and subroutine call function.

Standard sub-
routine N10
N20
N30
….
N70 G22 N5
N80
N90
….

N100
G24
….
N160 G20 N5

In the above example G22 statement defines the start block of the sub-routine and G24 marks the end of the sub-routine statement. The subroutine is called by another code G20 identified by the label N5.

Parametric subroutine

```
..
..
G23 N18
G01XP0YP1
G21 N18 P0=k10 P1=k20
```

In the above example G23 starts the subprogram label and starts the definition, and the parameters P0, P1 are defined for values of x and y. The G21 statement is used to call the subroutine and to assign the values to the parameters.

5.2 Canned Cycles

A canned cycle is a preprogrammed sequence of events / motions of tool / spindle stored in memory of controller. Every canned cycle has a format. Canned cycle is modal in nature and remains activated until cancelled. Canned cycles are a great resource to make manual programming easier. Often underutilized, canned cycles save time and effort.

5.2.1 Machining a Rectangular pocket

This cycle assumes the cutter is initially placed over the center of the pocket and at some clearance distance (typically 0.100 inch) above the top of the pocket. Then the cycle will take over from that point, plunging the cutter down to the "peck depth" and feeding the cutter around the pocket in ever increasing increments until the final size is attained. The process is repeated until the desired total depth is attained. Then the cutter is returned to the center of the pocket at the clearance height as shown in figure 14

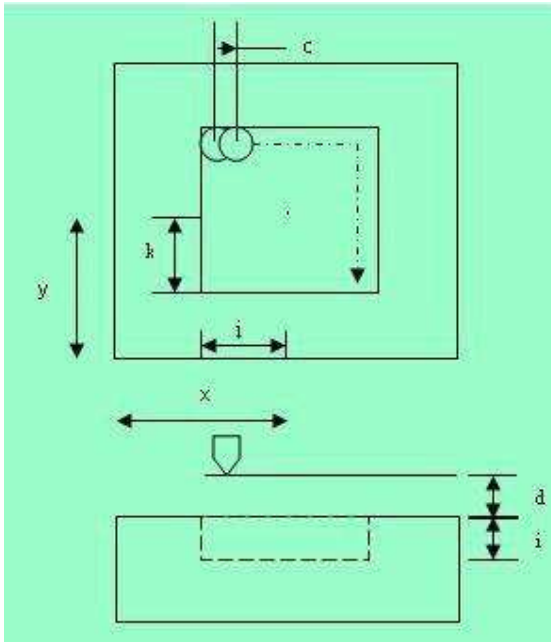


Figure 14. Pocket machining

The overall length and width of the pocket, rather than the distance of cutter motion, are programmed into this cycle.

The syntax is : G87 Xx Yy Zz Ii Jj Kk Bb Cc Dd Hh Ll Ss (This g code is entirely controller specific and the syntax may vary between controller to controller).

Description:
x,y - Center of the part

z - Distance of the reference plane from top of part i - Pocket depth

j,k - Half dimensions of the target geometry (pocket) b - Step depth c - Step over

d - Distance of the reference plane from top of part h - Feed for finish pass

l - Finishing allowance s - Speed

For machining a circular pocket, the same syntax with code G88 is used

Common G-Words:

TABLE A7.2 Common G-words (Preparatory Word)

G-word	Function
G00	Point-to-point movement (rapid traverse) between previous point and endpoint defined in current block. Block must include *x-y-z* coordinates of end position.
G01	Linear interpolation movement. Block must include *x-y-z* coordinates of end position. Feed rate must also be specified.
G02	Circular interpolation, clockwise. Block must include either arc radius or arc center; coordinates of end position must also be specified.
G03	Circular interpolation, counterclockwise. Block must include either arc radius or arc center; coordinates of end position must also be specified.
G04	Dwell for a specified time.
G10	Input of cutter offset data, followed by a P-code and an R-code.
G17	Selection of *x-y* plane in milling.
G18	Selection of *x-z* plane in milling.
G19	Selection of *y-z* plane in milling.
G20	Input values specified in inches.
G21	Input values specified in millimeters.
G28	Return to reference point.
G32	Thread cutting in turning.
G40	Cancel offset compensation for cutter radius (nose radius in turning).
G41	Cutter offset compensation, left of part surface. Cutter radius (nose radius in turning) must be specified in block.
G42	Cutter offset compensation, right of part surface. Cutter radius (nose radius in turning) must be specified in block.
G50	Specify location of coordinate axis system origin relative to starting location of cutting tool. Used in some lathes. Milling and drilling machines use G92.
G90	Programming in absolute coordinates.
G91	Programming in incremental coordinates.
G92	Specify location of coordinate axis system origin relative to starting location of cutting tool. Used in milling and drilling machines and some lathes. Other lathes use G50.
G94	Specify feed per minute in milling and drilling.
G95	Specify feed per revolution in milling and drilling.
G98	Specify feed per minute in turning.
G99	Specify feed per revolution in turning.

Note: Some G-words apply to milling and/or drilling only, whereas others apply to turning only.

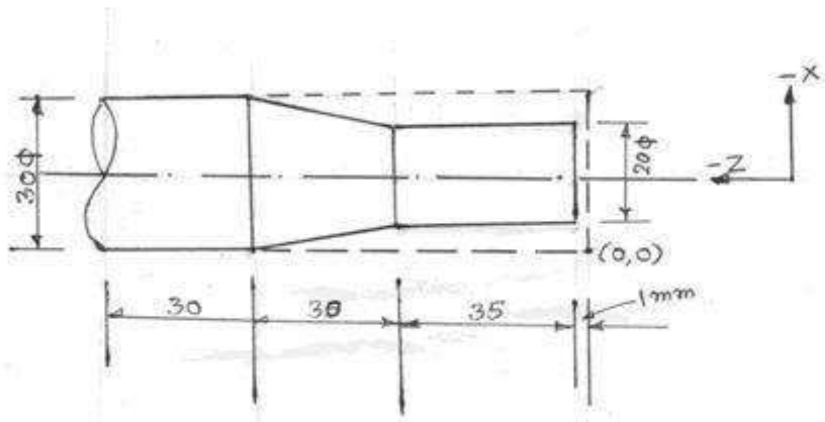
Common M-Words

TABLE A7.3 Common M-words Used in Word Address Format

M-Word	Function
M00	Program stop; used in middle of program. Operator must restart machine.
M01	Optional program stop; active only when optional stop button on control panel has been depressed.
M02	End of program. Machine stop.
M03	Start spindle in clockwise direction for milling machine (forward for turning machine).
M04	Start spindle in counterclockwise direction for milling machine (reverse for turning machine).
M05	Spindle stop.
M06	Execute tool change, either manually or automatically. If manually, operator must restart machine. Does not include selection of tool, which is done by T-word if automatic, by operator if manual.
M07	Turn cutting fluid on flood.
M08	Turn cutting fluid on mist.
M09	Turn cutting fluid off.
M10	Automatic clamping of fixture, machine slides, etc.
M11	Automatic unclamping.
M13	Start spindle in clockwise direction for milling machine (forward for turning machine) and turn on cutting fluid.
M14	Start spindle in counterclockwise direction for milling machine (reverse for turning machine) and turn on cutting fluid.
M17	Spindle and cutting fluid off.
M19	Turn spindle off at oriented position.
M30	End of program. Machine stop. Rewind tape (on tape-controlled machines).

Programming on turning centre

Example 1:



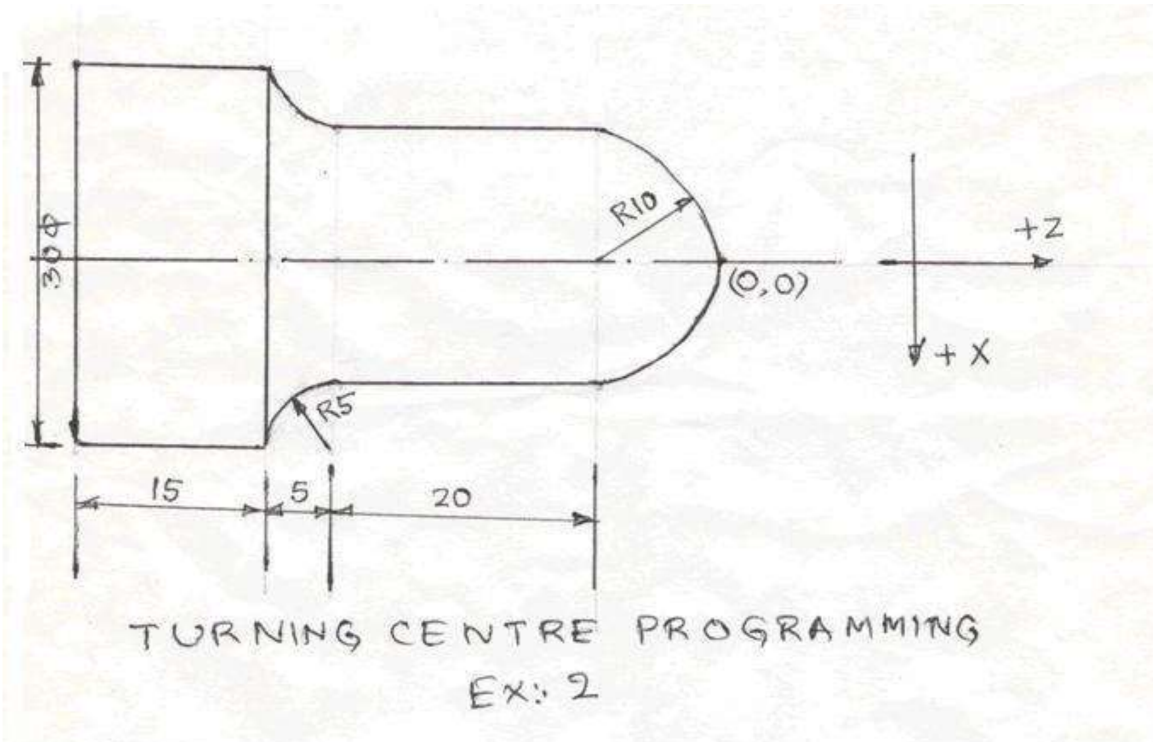
TURNING CENTRE PROGRAMMING, EX 1.

N01 G91 G71 M03 S800	(incremental mode,metric, spindle start with a speed of 800 rpm)
N02 G00 X1.0	(tool away from work piece 1mm, rapid)
N03 G00 Z-1.0	(tool to left 1mm for facing)
N04 G01 X-16.0 F200	(facing cut at a feed rate 200mm/min)
N05 G00 Z1.0	(move tool to right 1mm from that position)
N06 G00 X10.0	(move 10 mm away from the centre in x direction)
N07G01 Z-36.0	(plane turning over a length of 35 mm)
N08 G01 X5.0 Z-30.0	(simultaneous movement in X and Z directions for taper turning)
N09 G00 X1.0 Z66.0	(move to the starting position)
N10 M02	(end of program)

Note:

- I is the X offset is defined as the distance from the beginning of the arc to the centre of the arc in the X-direction
- K is the Z offset is defined as the distance from the beginning of the arc to the centre of the arc the Z direction

Example 2:



N01 G90 G71 M03 S800	(absolute, metric, start spindle at a speed 800 rpm)
N02 G00 X0.0 Y0.0	(move tool to the beginning of cut)
N03 G02 X10.0 Z-10.0 I 0.0 K-10.0 F150	(clockwise circular interpolation, I&K are offsets, feed rate 150mm/min)
N04 G00 Z-30.0	(move from point B to point C)
N05 G03 X15.0 Z-35.0 I5.0 K0.0	(counterclockwise interpolation, I&K are offsets, move to point D)
N06 M02	(end of program)

Note:

- I is the X offset is defined as the distance from the beginning of the arc to the centre of the arc in the X-direction
- K is the Z offset is defined as the distance from the beginning of the arc to the centre of the arc the Z direction

Program without the use of canned cycles:

N01 G00 X25.0 Y35.0 Z2.0 *
N02 G01 Z-18.0 F125 *
N03 G00 Z2.0 *
N04 X55.0 Y50.0 *
N05 G01 Z-18.0 F125 *
N06 G00 Z2.0 *
N07 X75.0 Y70.0 *
N08 G00 Z2.0 *
N09 X0 Y0 Z50.0 *

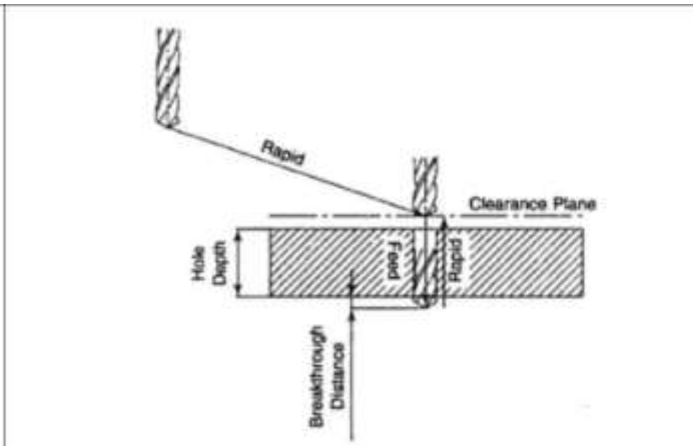


Fig. *Typical Motions Embedded in G81 Canned Cycle*

Program using canned cycles:

N01 G81 X25.0 Y35.0 Z-18.0 \R2.0 F125 *
N02 X55.0 Y50.0 *
N03 X75.0 Y70.0 *
N04 G80 X0 Y0 Z50.0

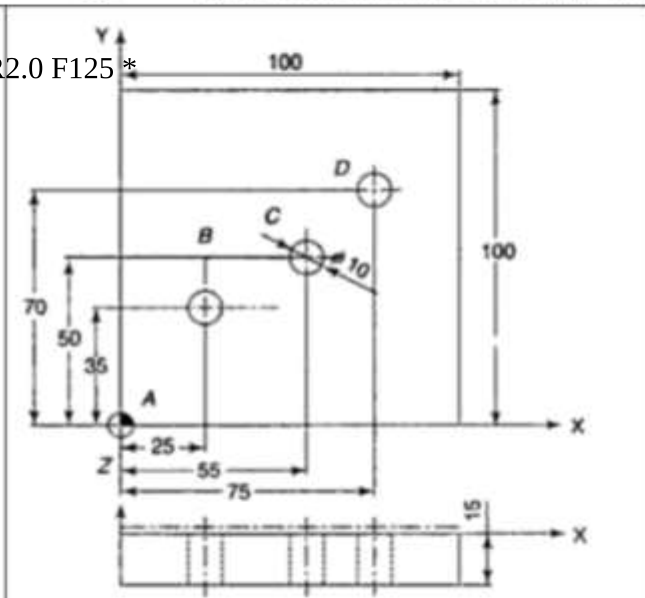


Fig. *Example for Canned Cycles*

7.6. PART PROGRAMMING WITH APT

APT is an acronym that stands for Automatically Programmed Tooling. It is a three dimensional NC part programming system that was developed in the late 1950s and early 1960s. Today it remains an important language in the United States and around the world, and most of the CAD/CAM approaches to part programming are based on APT. APT is also important because many of the concepts incorporated into it formed the basis for other subsequently developed systems in interactive graphics. APT was originally intended as a contouring language, but modern versions can be used for both point-to-point and contouring operations in upto five axes. Our discussion will be limited to the three linear axes, x, y and z. APT can be used for a variety of machining operations. Our coverage will concentrate on drilling (point-to-point) and milling (contouring) operations. There are more than 500 words in the APT vocabulary. Only a small (but important) fraction of the total lexicon will be covered here.

APT is not a language; it is also the computer program that processes the APT statements to calculate the corresponding cutter positions and generate the machine tool control commands. To program in APT, the programmer must first define the part geometry. Then the tool is directed to various point locations and along surfaces of the workpart to accomplish the required machining operations. The viewpoint of the programmer is that the workpiece remains stationary, and the tool is instructed to move relative to the part.

To complete the program, speeds and feeds must be specific, tools must be called, tolerances must be given for circular interpolation, and so forth. Thus, there are four basic types of statements in the APT language.

1. **Geometry statements** are used to define the geometry elements that comprise the part.
2. **Motion commands** are used to specify the tool path
3. **Postprocessor statements** control the machine tool operation, for example, to specify speeds and feeds, set tolerance values for circular interpolation, and actuate other capabilities of the machine tool.
4. **Auxiliary statements** are a group of miscellaneous statements used to name the part program, insert comments in the program, and accomplish similar functions.

OUTCOMES:

Students will be able to

1. Understand difference between NC, CNC and DNC systems.
2. Classify CNC systems on different criterias.
3. Construct a part program using NC Codes.

QUESSIONAIRE:

1. Differentiate between CNC turning and milling center.
2. List advantages, disadvantages and applications of CNC systems.
3. Differentiate between absolute and incremental dimensioning system.
4. Give the significance of G00, G01 and G02.

FURTHER READING:

1. http://nptel.ac.in/courses/112103174/37
2. http://nptel.ac.in/courses/112102103//Module%20E/Module%20E%287%29/p1.htm
3. http://nptel.ac.in/courses/112103174/module1/lec2/3.html

ROBOTICS

CONTENTS:

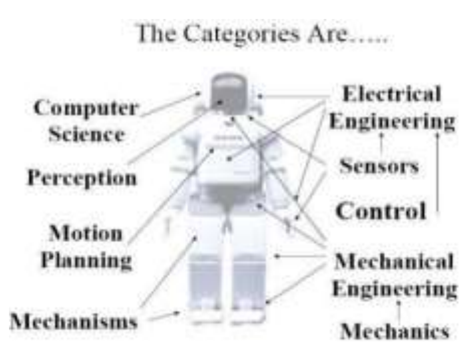
OBJECTIVES:

1. To understand anatomy and basic components of a robot.
2. To design different physical configurations of robots.
3. To understand different applications involved with robots.

8.1. INTRODUCTION

Robots are devices that are programmed to move parts, or to do work with a tool. Robotics is a multidisciplinary engineering field dedicated to the development of autonomous devices, including manipulators and mobile vehicles.

Categories in Robot Studies



Definition

An industrial robot is a general purpose, programmable machine possessing certain anthropomorphic characteristics. The most typical anthropomorphic or human like, characteristics of a robot is its arm. This arm, together with the robots capacity to be programmed, make it ideally suited to a variety of production tasks, including machine loading, spot welding, spray painting and assembly. The robot can be programmed to perform sequence of mechanical motions, and it can repeat that motion sequence over the over until programmed to perform some other job.

An industrial robot is a general purpose programmable machine that possesses certain anthropomorphic features

- The most apparent anthropomorphic feature of an industrial robot is its mechanical arm, or manipulator
- Robots can perform a variety of tasks such as loading and unloading machine tools, spot welding automobile bodies, and spray painting
- Robots are typically used as substitutes for human workers in these tasks

An industrial robot is a programmable, multi-functional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks.

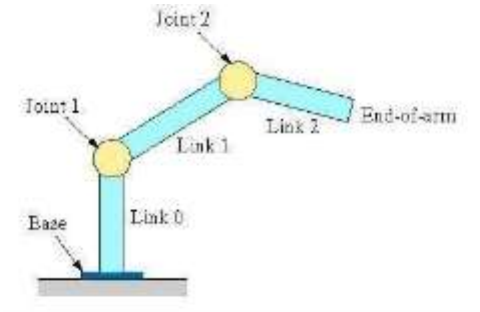
An industrial robot consists of a mechanical manipulator and a controller to move it and perform other related functions

- The mechanical manipulator consists of joints and links to position and orient the end of the manipulator relative to its base
- The controller operates the joints in a coordinated fashion to execute a programmed work cycle
- A robot joint is similar to a human body joint It provides relative movement between two parts of the body
- Typical industrial robots have five or six joints, Manipulator joints: classified as linear or rotating

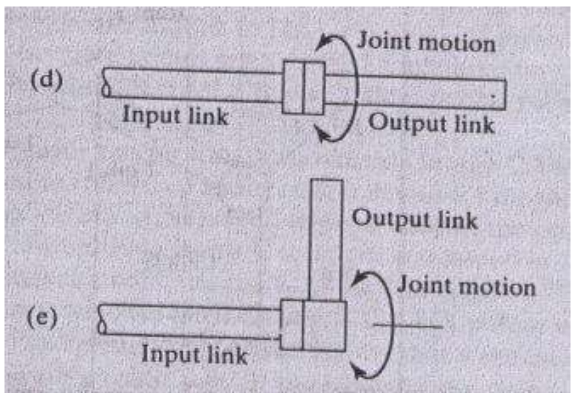
How are robots used?

- Industrial robots do tasks that are hazardous or menial.
- Exploratory robots explore environments that are inhospitable to humans such as space, military targets or areas of search and rescue operations.
- Assistive robots help handicapped individuals by assisting with daily tasks including wheelchair navigation and feeding.

8.2. ROBOT ANATOMY

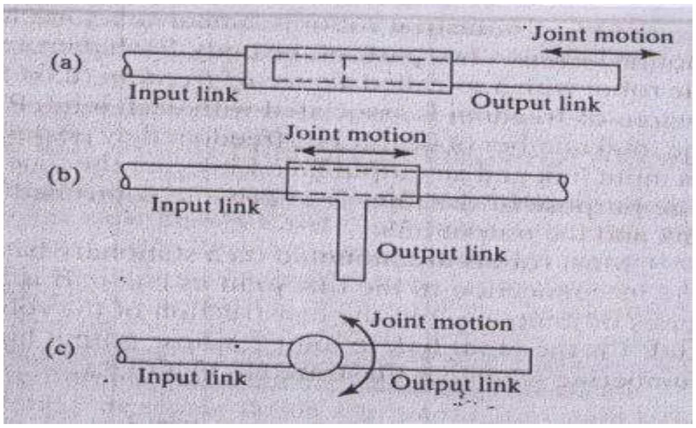


Translational motion
Linear joint (type L)
Orthogonal joint (type O)
Rotary motion Rotational
joint (type R) Twisting
joint (type T) Revolving
joint (type V)



Types of joints

(a) Linear joint (type L joint) , (b) orthogonal joint (type O joint) (c) Rotational joint (type R joint)



d) wisting joint (type T joint)   (e) revolving joint (type V joint)

8.3. Robot Physical Configuration

Industrial robots come in a variety of shapes and sizes. They are capable of various arm manipulations and they possess different motion systems.

Classification based on Physical configurations

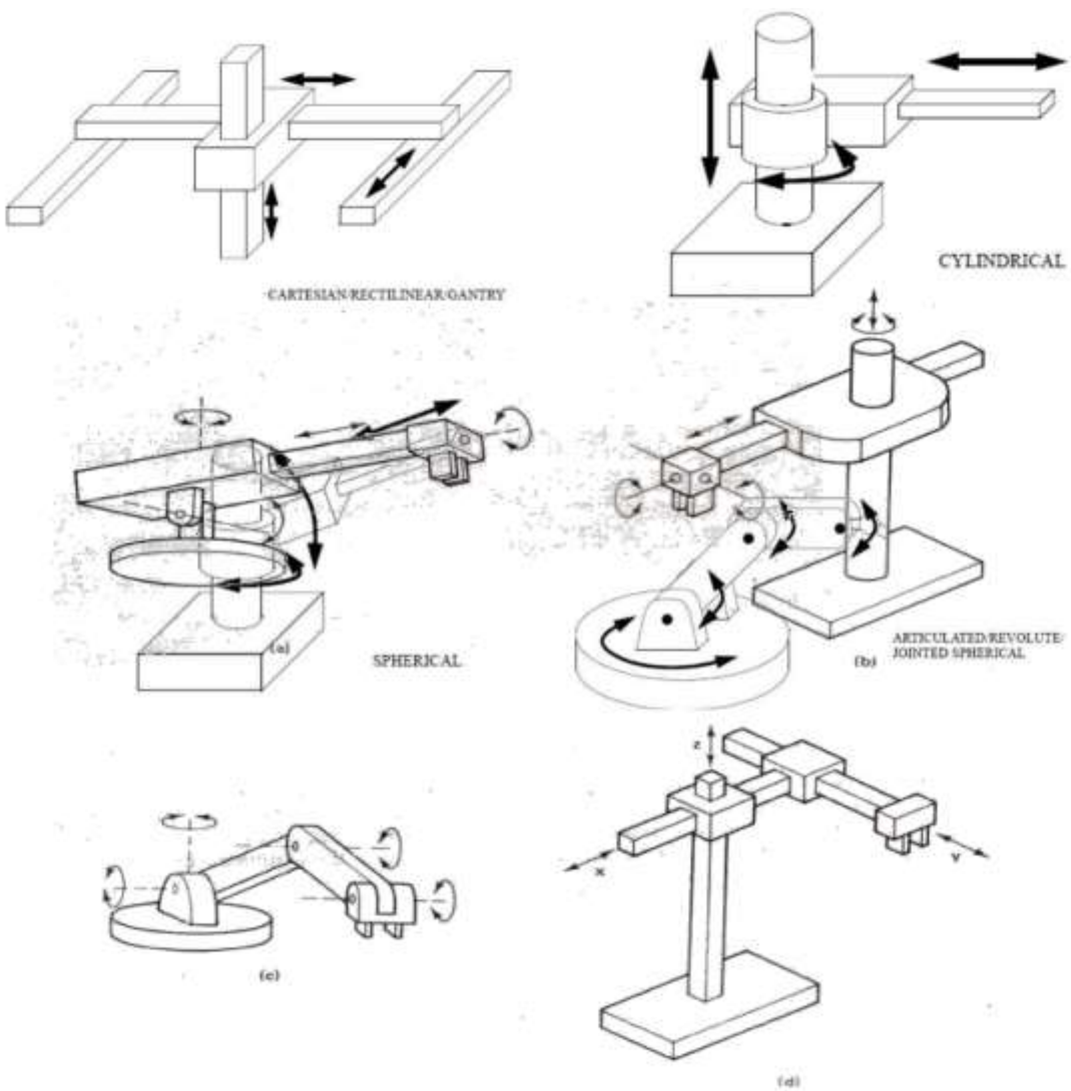
Four basic configurations are identified with most of the commercially available industrial robots

1. Cartesian configuration: A robot which is constructed around this configuration consists of three orthogonal slides, as shown in fig. the three slides are parallel to the x, y, and z axes of the Cartesian coordinate system. By appropriate movements of these slides, the robot is capable of moving its arm at any point within its three dimensional rectangularly spaced work space.

2. Cylindrical configuration: in this configuration, the robot body is a vertical column that swivels about a vertical axis. The arm consists of several orthogonal slides which allow the arm to be moved up or down and in and out with respect to the body. This is illustrated schematically in figure.

3. Polar configuration: this configuration also goes by the name "spherical coordinate" because the workspace within which it can move its arm is a partial sphere as shown in figure. The robot has a rotary base and a pivot that can be used to raise and lower a telescoping arm.

4. Jointed-arm configuration: is combination of cylindrical and articulated configurations. This is similar in appearance to the human arm, as shown in fig. the arm consists of several
straight members connected by joints which are analogous to the human shoulder, elbow, and wrist. The robot arm is mounted to a base which can be rotated to provide the robot with the capacity to work within a quasi-spherical space.



Basic Robot Motions

Whatever the configuration, the purpose of the robot is to perform a useful task. To accomplish the task, an end effector, or hand, is attached to the end of the robots arm. It is the end effector which adapts the general purpose robot to a particular task. To do the task, the robot arm must be capable of moving the end effectors through a sequence of motions and positions.

There are six basic motions or degrees of freedom, which provide the robot with the capability to move the end effectors through the required sequences of motions. These six degree of freedom are intended to emulate the versatility of movement possessed by the human arm. Not all robots are equipped with the ability to move in all sex degrees. The six basic motions consist of three arm and body motions and three wrist motions.

Arm and body motions

1. Vertical traverse: Up and down motion of the arm, caused by pivoting the entire arm about a horizontal axis or moving the arm along a vertical slide.

2. Radial traverse: extension and retraction of the arm (in and out movement)

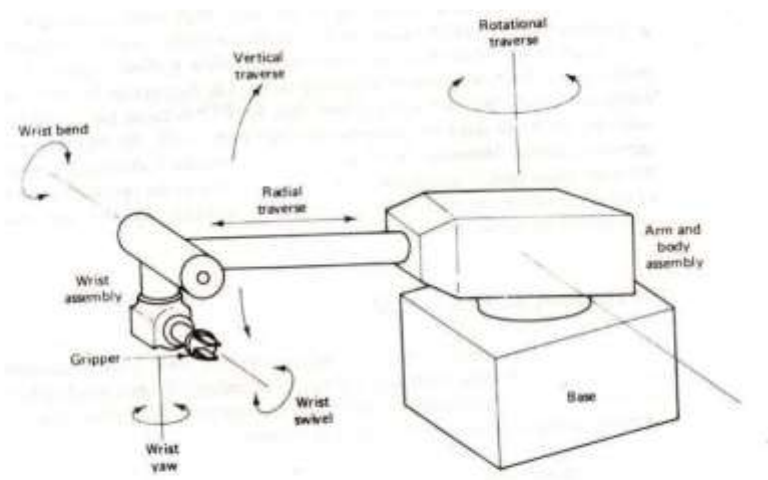
3. Rotational traverse: rotation about the vertical axis (right or left swivel of the robot arm)

Wrist Motion

- Wrist swivel: Rotation of the wrist

- Wrist bend: Up or down movement of the wrist, this also involves rotation movement.

- Wrist yaw: Right or left swivel of the wrist.



Advantages and disadvantages of 5 types of robots

Configurations	Advantages	Disadvantages
Cartesian coordinates	3 linear axes, easy to visualize,rigid structure ,easy programming	Can only reach front of itself, requirse long room space.
Cylindrical coordinates	2 linear axes +1 rotating can reach all around itself ,reach and height axes rigid ,rotational axis easy to seal	Can't reach above itself, base rotation axis as less rigid, linear axis is hard to seal.
SCARA coordinates	1 linear + 2 rotational axes is rigid, large work space area for floor space	2 ways to reach point ,difficult to program offline, highly complex arm
Spherical coordinates	1 linear + 2 rotational axes , long horizontal reach	Can't reach around obstacles .short vertical length
Revolve coordinates	3 rotational axes can reach above or below obstacles.	Difficult to program off-line , most complex manipulator

Motion system

1. **Point-to-point (PTP) control robot:** is capable of moving from one point to another point. The locations are recorded in the control memory. PTP robots do not control the path to get from one point to the next point. Common applications

include component insertion, spot welding, hole drilling, machine loading and unloading, and crude assembly operations.

2. **Continuous-path (CP) control robot:** with CP control, the robot can stop at any specified point along the controlled path. All the points along the path must be stored explicitly in the robot's control memory. Typical applications include spray painting, finishing, gluing, and arc welding operations.

3. **Controlled-path robot:** the control equipment can generate paths of different geometry such as straight lines, circles, and interpolated curves with a high degree of accuracy. All controlled-path robots have a servo capability to correct their path.

Technical Features Of An Industrial Robot

The technical features of an industrial robot determine its efficiency and effectiveness at performing a given task. The following are some of the most important among these technical features.

Degree of Freedom (D.O.F) - Each joint on the robot introduces a degree of freedom. Each dof can be a slider, rotary, or other type of actuator. Robots typically have 5 or 6 degrees of freedom. 3 of the degrees of freedom allow positioning in 3D space, while the other 2or 3 are used for orientation of the end effector. 6 degrees of freedom are enough to allow the robot to reach all positions and orientations in 3D space. 5 D.O.F requires a restriction to 2D space, or else it limits orientations. 5 D.O.F robots are commonly used for handling tools such as arc welders.

Work Volume/Workspace - The robot tends to have a fixed and limited geometry. The work envelope is the boundary of positions in space that the robot can reach. For a Cartesian robot (like an overhead crane) the workspace might be a square, for more sophisticated robots the workspace might be a shape that looks like a 'clump of intersecting bubbles'.

section.

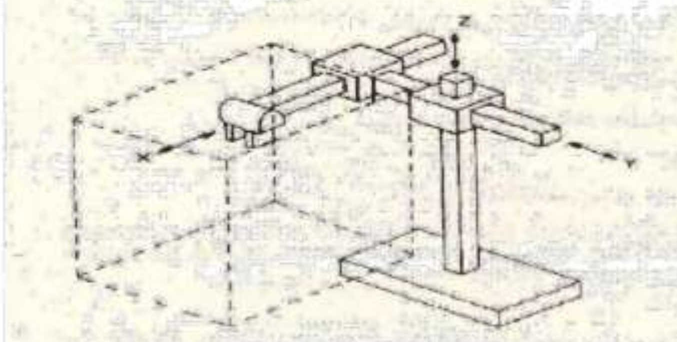
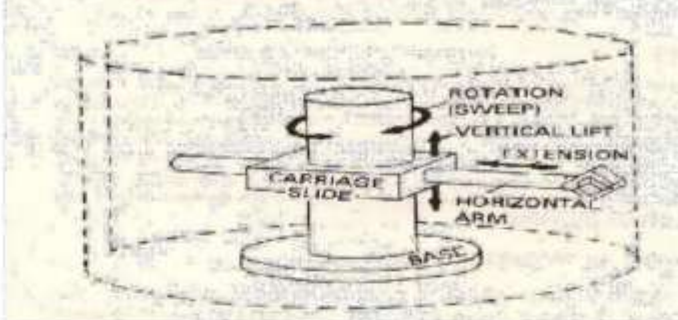


Fig. 10.3 Cartesian Workspace configuration



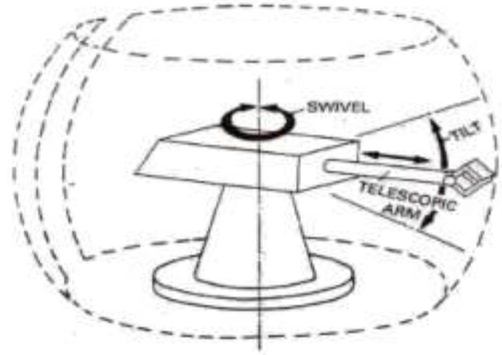
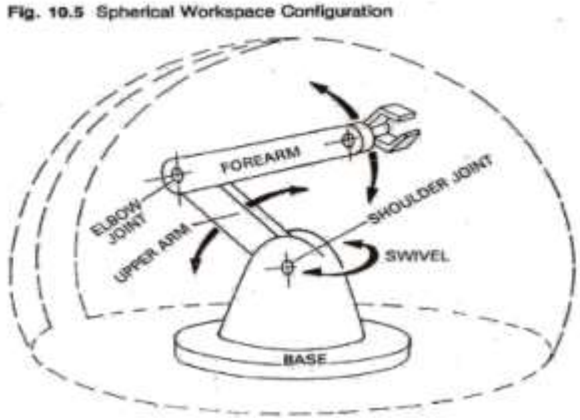


Fig. 10.5 Spherical Workspace Configuration



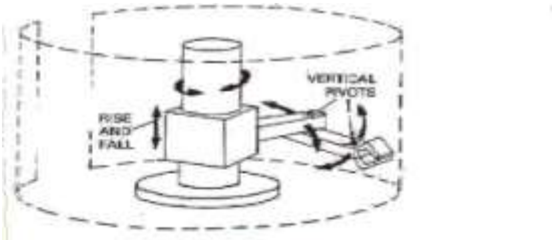


Fig. 10.7 Articulated or Jointed arm Configuration with Vertical pivots

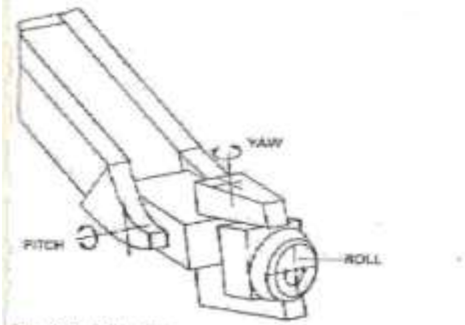


Fig. 10.8 Wrist Axes

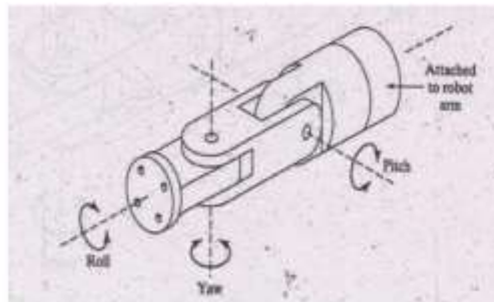


Figure Typical configuration of a three-degree-of-freedom wrist assembly showing roll, pitch, and yaw.

Precision Movement

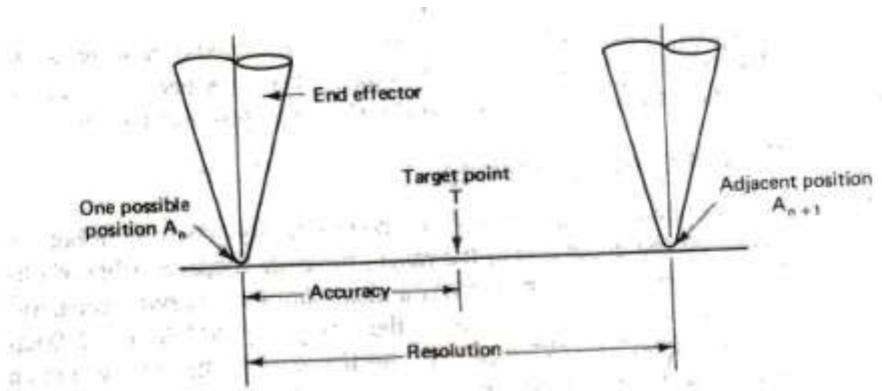
The precision with which the robot can move the end of its wrist is a critical consideration in most applications. In robotics, precision of movement is a complex issue, and we will describe it as consisting of three attributes:

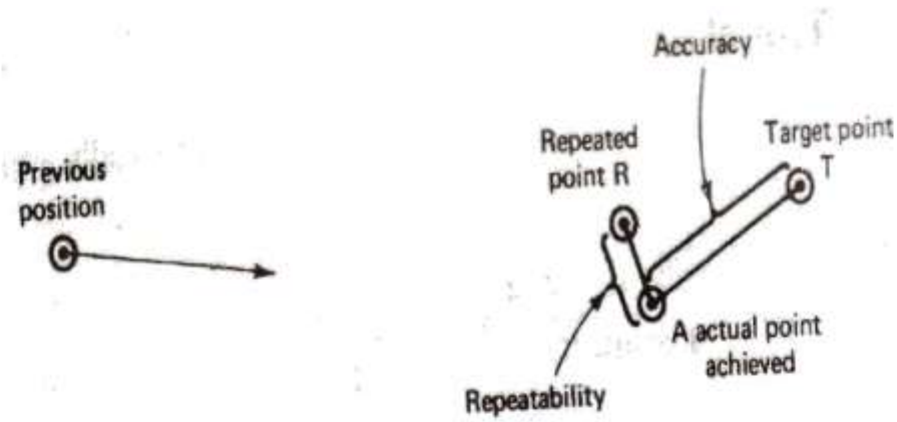
1. Control resolution
2. Accuracy
3. Repeatability

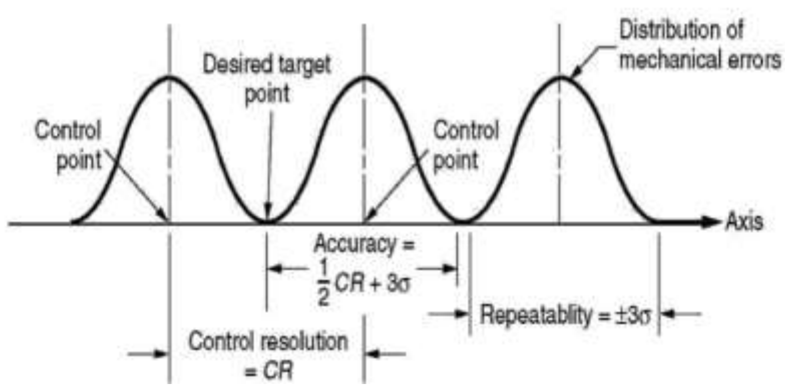
Control Resolution - This is the smallest change that can be measured by the feedback sensors, or caused by the actuators, whichever is larger. If a rotary joint has an encoder that measures every 0.01 degree of rotation, and a direct drive servo motor is used to drive the joint, with a resolution of 0.5 degrees, then the control resolution is about 0.5 degrees (the worst case can be 0.5+0.01).

Accuracy - This is determined by the resolution of the workspace. If the robot is commanded to travel to a point in space, it will often be off by some amount, the maximum distance should be considered the accuracy.

Repeatability - The robot mechanism will have some natural variance in it. This means that when the robot is repeatedly instructed to return to the same point, it will not always stop at the same position.







A portion of a linear positioning system axis, with showing control resolution, accuracy, and repeatability

Speed - refers either to the maximum velocity that is achievable by the TCP, or by individual joints. This number is not accurate in most robots, and will vary over the workspace as the geometry of the robot changes.

Weight Carrying Capacity (Payload) - The payload indicates the maximum mass the robot can lift before either failure of the robots, or dramatic loss of accuracy. It is possible to exceed the maximum payload, and still have the robot operate, but this is not advised. When

the robot is accelerating fast, the payload should be less than the maximum mass. This is affected by the ability to firmly grip the part, as well as the robot structure, and the actuators. The end of arm tooling should be considered part of the payload.

Types Of Drive Systems

There are three basic drive system used in commercially available robots:

1. Hydraulic drive: gives a robot great speed and strength. These systems can be designed to actuate linear or rotational joints. The main disadvantage of a hydraulic system is that it occupies floor space in addition to that required by the robot.

2. Electric drive: compared with a hydraulic system, an electric system provides a robot with less speed and strength. Accordingly, electric drive systems are adopted for smaller robots. However, robots supported by electric drive systems are more accurate, exhibit better repeatability, and are cleaner to use.

3. Pneumatic drive: are generally used for smaller robots. These robots, with fewer degrees of freedom, carry out simple pick-and-place material handling operations.

8.4. PROGRAMMING THE ROBOT

There are various methods which robots can be programmed to perform a given work cycle. We divide this programming method into four categories.

1. Manual method
2. Walkthrough method
3. Lead through method
4. Off-line programming

Manual method:

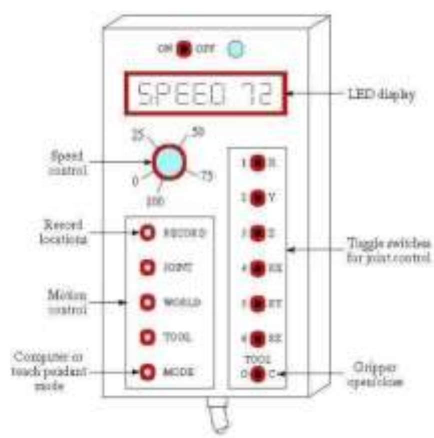
This method is not really programming in the conventional sense of the world. It is more like setting up a machine rather than programming. It is the procedure used for the simpler robots and involves setting mechanical stops, cams, switches or relays in the robots control unit. For these low technology robots used for short work cycles (e.g., pick and place operations), the manual programming method is adequate.

Walkthrough method:

In this method the programmer manually moves the robots arm and hand through the motion sequence of the work cycle. Each movement is recorded into memory for subsequent playback during production. The speed with which the movements are performed can usually be controlled independently so that the programmer does not have to worry about the cycle time during the walk through. The main concern is getting the position sequence correct. The walk through method would be appropriate for spray painting and arc welding.

Lead through method:

The lead through method makes use of a teach pendant to power drive the robot through its motion sequence. The teach pendant is usually a small hand held device with switches and dials to control the robots physical movements. Each motion is recorded into memory for future playback during work cycle. The lead through method is very popular among robot programming methods because of its ease and convenience.



On-Line/Lead -Through programming

Advantage:

Easy

No special programming skills or training

Disadvantages:

not practical for large or heavy robots

High accuracy and straight -line movements are difficult to achieve, as are any other kind of geometrically defined trajectory, such as circular arcs, etc.

difficult to *edit out* unwanted operator moves difficult to incorporate external sensor data

Synchronization with other machines or equipment in the work cell is difficult

A large amount of memory is required

Off- line programming:

This method involves the preparation of the robot program off-line, in a manner similar to NC part programming. Off-line robot programming is typically accomplished on a computer terminal. After the program has been prepared, it is entered in to the robot memory for use during the work cycle. The advantaged of off-line robot programming is that the production time of the robot is not lost to delay in teaching the robot a new task. Programming off-line can be done while the robot is still in production on the preceding job. This means higher utilization of the robot and the equipment with which it operates.

Another benefit associated with off-line programming is the prospect of integrating the robot into the factory CAD/CAM data base and information system.

<u>Robot Programming Languages</u>

Non computer controlled robots do not require programming language. They are programmed by the walkthrough or lead through methods while the simpler robots are programmed by manual methods. With the introduction of computer control for robots came the opportunity and the need to develop a computer oriented robot programming language.

The VAL^{TM} Language

- The VAL language was developed for PUMA robot
- VAL stands for Victors Assembly Language

- It is basically off-line language in which program defining the motion sequence is can be developed off-line but various point location used in the work cycle are defined by lead through.
- VAL statements are divided into two categories a) Monitoring command b) Programming instructions.
- Monitor command are set of administrative instructions that direct the operation of the robot system. Some of the functions of Monitor commands are

    Preparing the system for the user to write programs for PUMA

    Defining points in space

    Commanding the PUMA to execute a program

    Listing program on the CRT

- Examples for monitor commands are: EDIT, EXECUTE, SPEED, HERE etc.
- Program instructions are a set of statements used to write robot programs. One statement usually corresponds to one movement of the robots arm or wrist.
- Example for program instructions are Move to point, move to a point in a straight line motion, open gripper, close gripper. (MOVE, MOVES, APPRO, APPROS, DEPART,
  OPENI, CLOSEI, AND EXIT)

The MCL Language

- MCL stands for Machine Control Language developed by Douglas.
- The language is based on the APT and NC language. Designed control complete manufacturing cell.
- MCL is enhancement of APT which possesses additional options and features needed to do off-line programming of robotic work cell.
- Additional vocabulary words were developed to provide the supplementary capabilities intended to be covered by the MCL. These capability include Vision, Inspection and Control of signals
- MCL also permits the user to define MACROS like statement that would be convenient to use for specialized applications.
- MCL program is needed to compile to produce CLFILE.
- Some commands of MCL programming languages are DEVICE, SEND, RECEIV, WORKPT, ABORT, TASK, REGION, LOCATE etc.

Textual Statements

Language statements taken from commercially available robot languages

1 The basic motion statement is:

MOVE P1

Commands the robot to move from its current position to a position and orientation defined by the variable name P1.The point p1 must be defined.

The most convenient method way to define P1 is to use either powered lead through or manual leads through to place the robot at the desired point and record that point into the memory.

HERE P1

OR

LEARN P1

Are used in the lead through procedure to indicate the variable name for the point

What is recorded into the robot's control memory is the set of joint positions or coordinates used by the controller to define the point.

For ex, (236,157,63,0,0,0)

The first values give joint positions of the body and arm and the last three values(0,0,0) define the wrist joint positions.

MOVES P1

Denotes a move that is to be made using straight line interpolation. The suffix's' designates a straight line motion.

DMOVE (4,125)

Suppose the robot is presently at a point defined by joint coordinates(236,157,63,0,0,0) and it is desired to move joint 4from 0 to 125. The above statement can be used to accomplish this move. DMOVE represents a delta move.

Approach and depart statements are useful in material handling operations.

APPROACH P1, 40 MM

MOVE P1

(Command to actuate the gripper)

DEPART 40 MM

The destination is point p1 but the approach command moves the gripper to a safe distance(40mm) above the point.

Move statement permits the gripper to be moved directly to the part for grasping.

A path in a robot program is a series of points connected together in a single move. A path is given a variable name

DEFINE PATH123=PATH(P1,P2,P3)

A move statement is used to drive the robot through the path.

MOVE PATH123

SPEED 75 the manipulator should operate at 75% of the initially commanded velocity. The initial speed is given in a command that precedes the execution of the robot program.

For example,

SPEED 0.5 MPS

EXECUTE PROGRAM1

Indicates that the program named PROGRAM1 is to be executed by the robot at a speed of 0.5m/sec.

Interlock And Sensor Statements

The two basic interlock commands used for industrial robots are WAIT and SIGNAL. The wait command is used to implement an input interlock.

For example,

WAIT 20,ON

Would cause program execution to stop at this statement until the input signal coming into the robot controller at port 20 was in “ON” condition.this might be used in a situation where the robot needed to wait for the completion of an automatic machine cycle in a loading and unloading application.

The SIGNAL statement is used to implement an output interlock. This is used to communicate to some external piece of equipment.

For example,

SIGNAL 20, ON

Would switch on the signal at output port 20, perhaps to actuate the start of of an automatic machine cycle.

The above interlock commands represent situations where the execution of the statement appears.

There are other situations where it is desirable for an external device to be continuously monitored for any change that might occur in the device.

For example,in safety monitoring where a sensor is setup

to detect the presence of humans who might wander into the robot’s work volume.the sensor reacts to the presence of humans by signaling the robot controller.

REACT 25, SAFESTOP

This command would be written to continuously monitor input port 25 for any changes in the incoming signal. If and when a change in the signal occurs, regular program execution is interrupted and the control is transferred to a subroutine called SAFESTOP.This subroutine would stop the robot from further motion and/or cause some other safety action to be taken.

Commands for controlling the end-effectors

Although end effectors are attached to to the wrist of the manipulator,they are very much like external devices. Special command are written for controlling the end effector. Basic commands are

OPEN (fully open)

and

CLOSE (fully close)

For grippers with force sensors that can be regulated through the robot controller, a command such as ,

CLOSE 2.0 N

Controls the closing of the gripper until a 20.N force is encountered by the grippers. A similar command would be used to close the gripper to a given opening width is,

CLOSE 25 MM

A special set of statements is often required to control the operation of tool type end effectors
.(such as spot welding guns, arc welding tools, spray painting guns and powered spindles).

8.5. End Effectors

In the terminology of robotics, end effectors can be defined as a device which is attached to the robots wrist to perform a specific task. The task might be work part handling, spot welding, spray painting, or any of a great variety of other functions. The possibilities are limited only by the imagination and ingenuity of the application engineers who design robot systems. The end effectors are the special purpose tooling which enables the robot to perform a particular job. It is usually custom engineered for that job, either by the company that owns the robot or company that sold the robots. Most robot manufacturer has engineered groups which design and fabricate end effectors or provide advice to their customers on end effectors design.

For purpose organization, we will divide the various types of end effectors into two categories: grippers and tools.

1. **Grippers:** are generally used to grasp and hold an object and place it at a desired location. Grippers can be classified as

   Mechanical grippers

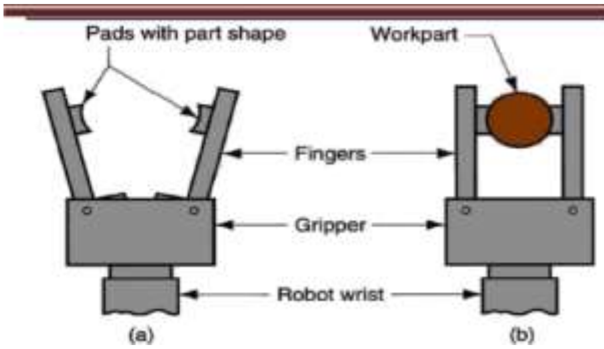
   Vacuum or suction cups

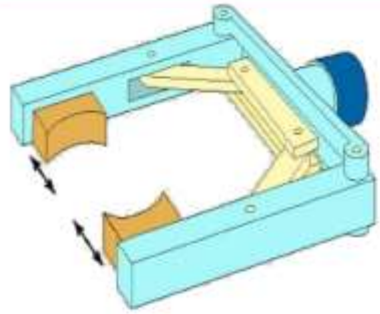
   Magnetic grippers

   Adhesive grippers

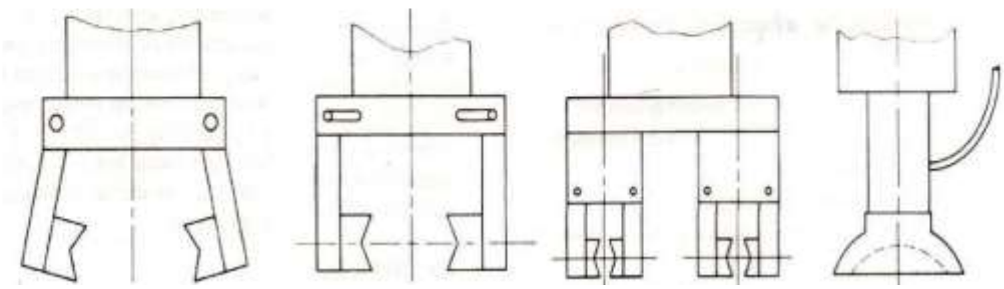
   Hooks,

   Scoops, and so forth.





Tools: a robot is required to manipulate a tool to perform an operation on a work part. Here the tool acts as end-effectors. Spot-welding tools, arc-welding tools, spray-painting nozzles, and rotating spindles for drilling and grinding are typical examples of tools used as end-effectors.



Work Cell Control And Interlocks

Work cell control: industrial robots usually work with other things: processing equipment, work parts, conveyors, tools and perhaps human operators. A means must be provided for coordinating all of the activities which are going on within the robot workstations. Some of the activities occur sequentially, while others take place simultaneously to make certain that the various activities are coordinated and occur in the proper sequence, a device called the work cell controller is used. The work cell controller usually resides within the robots and has overall responsibility for regulating the activities of the work cell components.

Functions of work cell controller

1. Controlling the sequence of activities in the work cycles
2. Controlling simultaneous activities
3. Making decisions to proceed based on incoming signals
4. Making logical decisions

5. Performing computations

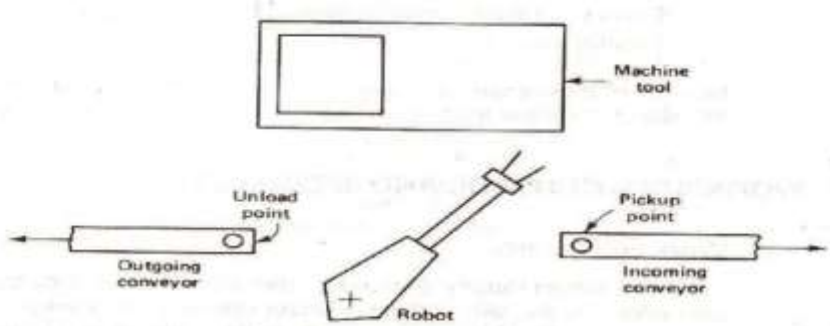
6. Dealing with exceptional events

7. Performing irregular cycles, such as periodically changing tools

Interlocks

An interlock is the feature of work cell control which prevents the work cycle sequence from continuing until a certain conditions or set of conditions has been satisfied. In a robotic work cell, there are two types: outgoing and incoming. The outer going interlock is a signal sent from the workstation controller to some external machine or device that will cause it to operate or not to operate for example this would be used to prevent a machine from initiating its process until it was commanded to process by the work cell controller, an incoming interlock is a single from some external machine or device to the work controller which determines whether or not the programmed work cycle sequence will proceed. For example, this would be used to prevent the work cycle program from continuing until the machine signaled that it had completed its processing of the work piece.

The use of interlocks provides an important benefit in the control of the work cycle because it prevents actions from happening when they should not, and it causes actions occur when they should. Interlocks are needed to help coordinate the activities of the various independent components in the work cell and to help avert damage of one component by another. In the planning of interlocks in the robotic work cell, the application engineer must consider both the normal sequences of the activities that will occur during the work cycle, and the potential malfunction that might occur. Then these normal activities are linked together by means of limit switches, pressure switches, photo electric devices, and other system components. Malfunction that can be anticipated are prevented by means of similar devices.



8.6. ROBOTIC SENSORS

For certain robot application, the type of workstation control using interlocks is not adequate the robot must take on more human like senses and capabilities in order to perform the task in a satisfactory way these senses and capability includes vision and hand eye coordination, touch, hearing accordingly we will dived the types of sensors used in robotics into the following three categories.

1. Vision sensors
2. Tactile and proximity sensors
3. Voice sensors

Vision sensors

This is one of the areas that is receiving a lot of attention in robotics research computerized visions systems will be an important technology in future automated factories. Robot vision is made possible by means of video camera a sufficient light source and a computer programmed to process image data. The camera is mounted either on the robot or in a fixed position above the robot so that its field of vision includes the robots work volume. The computer software enables the vision system to sense the presence of an object and its position and orientation. Vision capability would enable the robot to carry out the following kinds of operations.

Retrieve parts which are randomly oriented on a conveyor

Recognize particular parts which are intermixed with other objects

Perform assembly operations which require alignment

Tactile and proximity sensor

Tactile sensors provide the robot with the capability to respond to contact forces between itself and other objects within its work volume. Tactile sensors can be divided into two types:

1. Touch sensors
2. Stress sensors

Touch sensors are used simply to indicate whether contact has been made with an object. A simple micro switch can serve the purpose of a touch sensor. Stress sensors are used to measure the magnitude of the contact force. Strain gauge devices are typically employed in force measuring sensors.

Potential use of robots with tactile sensing capabilities would be in assembly and inspection operations. In assembly, the robot could perform delicate part alignment and joining operations. In inspection, touch sensing would be used in gauging operations and dimensional measuring activities. Proximity sensors are used to sense when one object is close to another

object. On a robot, the proximity sensors would be located n or near the end effectors. This sensing capability can be engineered by means of optical proximity devices, eddy-current proximity detectors, magnetic field sensors, or other devices.

In robotics, proximity sensors might be used to indicate the presence or absence of a work part or other object. They could also be helpful in preventing injury to the robots human coworkers in the factory.

Voice sensors

Another area of robotics research is voice sensing or voice programming. Voice programming can be defined as the oral communication of commands to the robot or other machine. The robot controller is equipped with a speech recognition system which analyzes the voice input and compares it with a set of stored word patterns when a match is found between the input and the stored vocabulary word the robot performs some actions which corresponds to the word. Voice sensors could be useful in robot programming to speed up the programming procedure just as it does in NC programming. It would also be beneficial in especially in hazardous working environments for performing unique operations such as maintenance and repair work. The robot could be placed in hazardous environment and remotely commanded to perform the repair chores by means of step by step instructions.

8.7. ROBOT APPLICATIONS

Need to replace human labor by robots:

- Work environment hazardous for human beings
- Repetitive tasks
- Boring and unpleasant tasks

- Multi shift operations
- Infrequent changeovers
- Performing at a steady pace
- Operating for long hours without rest
- Responding in automated operations
- Minimizing variation

Industrial Robot Applications can be divided into:

Material-handling applications:

- Involve the movement of material or parts from one location to another.
- It includes part placement, palletizing and/or depalletizing, machine loading and unloading.

Processing Operations:

- Requires the robot to manipulate a special process tool as the end effectors.

- The application include spot welding, arc welding, riveting, spray painting, machining, metal cutting, deburring, polishing.

Assembly Applications:

- Involve part-handling manipulations of a special tools and other automatic tasks and operations.

Inspection Operations:

- Require the robot to position a work part to an inspection device.

- Involve the robot to manipulate a device or sensor to perform the inspection.

OUTCOMES:

Students will be able to

1. Classify different physical configurations of an industrial robot.
2. List applications of robots in different sectors.
3. Classify different types of end effectors used in robots.

QUESSIONAIRE:

1. Explain different configurations of an industrial robot with a neat sketch.
2. Write a note on programming languages in robots.
3. Write a note on end effectors.
4. List and explain any three robot sensor systems.

FURTHER READING:

1. http://nptel.ac.in/courses/112101098/
2. http://nptel.ac.in/courses/112101099/
3. http://nptel.ac.in/courses/112108093/

ADDITIVE MANUFACTURING

Introduction to Additive Manufacturing: Introduction to AM, AM evolution, Distinction between AM & CNC machining, Advantages of AM, AM process chain: Conceptualization, CAD, conversion to STL, transfer to AM, STL file manipulation, Machine setup, build, removal and clean up, post processing.

Classification of AM processes: Liquid polymer system, Discrete particle system, Molten material systems and Solid sheet system.

Post processing of AM parts: Support material removal, surface texture improvement, accuracy improvement, aesthetic improvement, preparation for use as a pattern, property enhancements using non-thermal and thermal techniques.

Guidelines for process selection: Introduction, selection methods for a part, challenges of selection

AM Applications:

Functional models, Pattern for investment and vacuum casting, Medical models, art models, Engineering analysis models, Rapid tooling, new materials development, Bi-metallic parts, Re-manufacturing. Application examples

Additive Manufacturing (AM) is an appropriate name to describe the technologies that build 3D objects by adding layer-upon-layer of material. Common to AM technologies is the use of a computer, 3D modeling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object.

The term AM encompasses many technologies including subsets like 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication. AM application is limitless. Early use of AM in the form of Rapid Prototyping focused on preproduction visualization models. More recently, AM is being used to fabricate end-use products in aircraft, dental restorations, medical implants, automobiles, and even fashion products.

Advantages of Additive Manufacturing

Speed: The rapid character of the technology is not only about the time it takes to build parts but also it enhances the whole product development process.

Ease of Data Conversion: Since 3D CAD is being used as the starting point and the transfer to AM is relatively seamless, there is much less concern over data interpretation.

Reduction of Process Steps: Regardless of the complexity of parts to be built, building within an AM machine is generally performed in a single step.

Reduction in Process Time: Irrespective of the complexity of the product, added features the time required for manufacturing is less compared to CNC Manufacturing.

Reduction in Cost: Since the process is carried out in a single step, the process brings down manufacturing cost to minimum compared to conventional manufacturing processes.

Wide Range of Application: With some supporting technologies it can be possible to manufacture a vast range of parts with different characteristics.

General steps

1. **Conceptualization and CAD**

All AM parts must start from a software model that fully describes the external geometry. This can involve the use of almost any professional CAD solid modeling software, but the output must be a 3D solid or surface representation.

2. **Conversion to STL**

Nearly every AM machine accepts the STL file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

3. **Transfer to AM Machine and STL File Manipulation**

The STL file describing the part must be transferred to the AM machine. Here, there may be some general manipulation of the file so that it is the correct size, position, and orientation for building.

4. **Machine Setup**

The AM machine must be properly set up prior to the build process. Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc

5. **Build**

Building the part is mainly an automated process and the machine can largely carry on without supervision. Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place.

6. **Removal**

Once the AM machine has completed the build, the parts must be removed. This may require interaction with the machine, which may have safety interlocks to ensure for example that the operating temperatures are sufficiently low or that there are no actively moving parts.

7. Post processing

Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed.

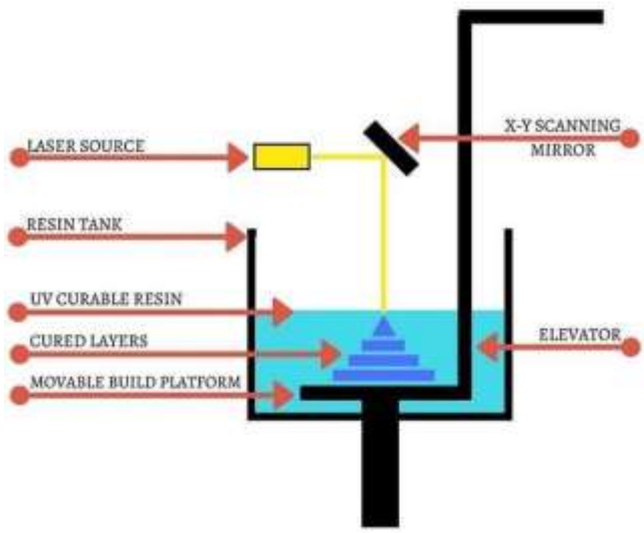
8. Application

Parts may now be ready to be used. However, they may also require additional treatment before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish.

Liquid Polymer Systems

Liquid polymers appears to be a popular material for Additive Manufacturing. The first ever commercial RP systems were resin-based systems commonly called stereo lithography or SLA. The resin is a liquid photosensitive polymer that cures or hardens when exposed to ultraviolet radiation. The source supplies the energy that is needed to induce a chemical reaction (curing reaction), bonding large no of small molecules and forming a highly cross-linked polymer. An advantage of photopolymer systems is that accuracy is generally very good, with thin layers and fine precision where required compared with other systems.

Stereo Lithography:



The SLA process is based fundamentally on following principles:

1. Parts are built from a photo-curable liquid resin that cures when exposed to a laser beam (basically, undergoing the photo polymerization process) which scans across the

surface of the resin.

2. The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completion of each layer.

Working Procedure:

a. SLAs have four main parts: a tank that can be filled with liquid plastic (photopolymer), a perforated platform that is lowered into the tank, an ultraviolet laser and a computer controlling the platform and the laser.
b. In the initial step of the SLA process, a thin layer of photopolymer (usually between 0.05- 0.15mm) is exposed above the perforated platform. The UV laser hits the perforated platform, “painting” the pattern of the object being printed.
c. The UV-curable liquid hardens instantly when the UV laser touches it, forming the first layer of the 3D printed object.
d. Once the initial layer of the object has hardened, the platform is lowered, exposing a new surface layer of liquid polymer. The laser again traces a cross section of the object being printed, which instantly bonds to the hardened section beneath it.
e. This process is repeated again and again until the entire object has been formed and is fully submerged in the tank.
f. The platform is then raised to expose a three-dimensional object. After it is rinsed with a liquid solvent to free it of excess resin, the object is baked in an UV oven to further cure the plastic.
g. Objects made using stereo lithography generally have smooth surfaces, but the quality of an object depends on the quality of the SLA machine used to print it.

Advantages

1) The SLA can be used continuously and unattended round the clock.
2) The computerized process serves as good user support.
3) The different SLA machines have built volumes ranging from small to large to suit the needs of different users.
4) The SLA has good accuracy and can thus be used for many application areas.
5) The SLA can obtain one of the best surface finishes amongst RP technologies.
6) Wide range of materials can be used ranging from general purpose materials to special materials for specific applications.

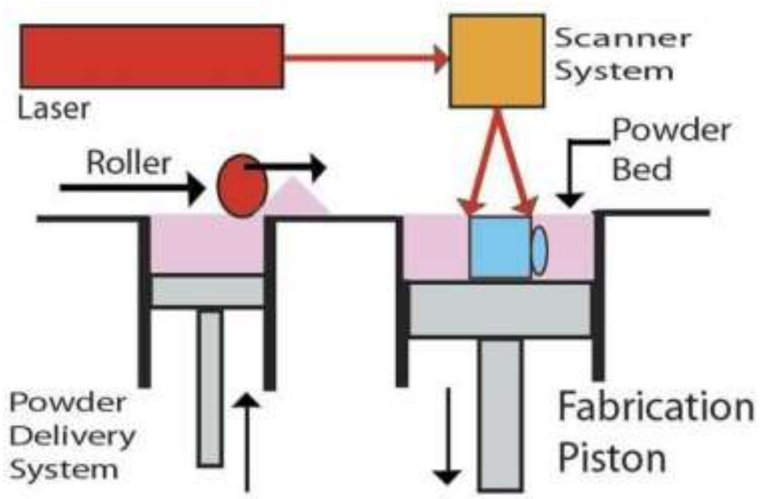
Disadvantages

1) **Requires support structures:** Structures that have overhangs and undercuts must have supports that are designed and fabricated together with the main structure.
2) **Requires post-processing:** Post-processing includes removal of supports and other unwanted materials, which is tedious, time consuming and can damage the model.
3) **Requires post-curing:** Post-curing may be needed to cure the object completely and ensure the integrity of the structure.

Applications of SLA:

1) Models for conceptualization, packaging and presentation.
2) Prototypes for design, analysis, verification and functional testing.
3) Parts of prototype tooling and low volume production tooling.
4) Patterns for investment casting, sand casting and moulding.
5) Tools for fixture and tooling design and production tooling.

Discrete Particle Systems



Discrete particles are normally powders that are generally graded into a relatively uniform size and shape and narrow distribution. The conventional approach is to use a laser, to produce thermal energy in a controlled manner and, therefore, raise the temperature sufficiently to melt the powder. Polymer powders must therefore exhibit thermoplastic behavior so that they can be melted and re-melted to permit bonding of one layer to another. The main polymer-based systems commercially available are the Selective Laser Sintering (SLS) technology.

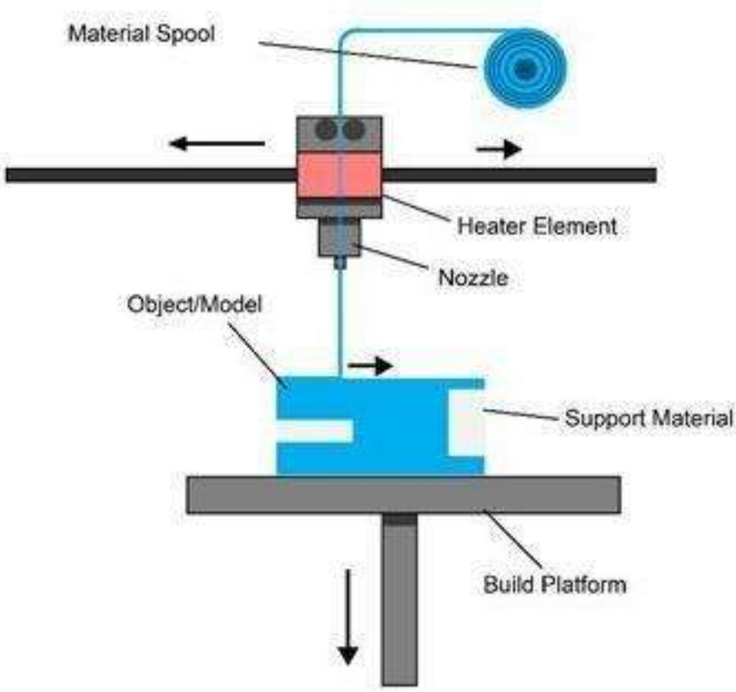
The SLS process is based on the following principles:

1. Parts are built by sintering when a CO_2 laser beam hits a thin layer of powdered material. The interaction of the laser beam with the powder raises the temperature to the point of melting, resulting in particle bonding, fusing the particles to them and the previous layer to form a solid.
2. The building of the part is done layer by layer. Each layer of the building process contains the cross-sections of one or many parts. The next layer is then built directly on top of the sintered layer after an additional layer of powder is deposited via a roller mechanism on top of the previously formed layer.

The SLS process involves the following steps:

1. CAD date files are converted to STL file format are first transferred to the system where they are sliced.
2. A thin layer of heat-fusible powder is deposited onto the part building chamber.
3. Each cross-sectional slice of the CAD part under fabrication is selectively drawn (or scanned) on the layer of powder by heat generating CO_2 laser.
4. The interaction of the laser beam with the powder elevates the temperature to the point of melting, fusing the powder particles to form a solid mass.
5. Surrounding powder remains a loose compact and serves as supports.
6. When the cross-section is completely drawn, an additional layer of powder is deposited via a roller mechanism on top of the previously scanned layer. This prepares the next layer for scanning.
7. With each layer fusing to the layer below it, successive layers of powder are deposited and the process is repeated until the part is completed.

Fused Deposition Modelling (FDM) Process:

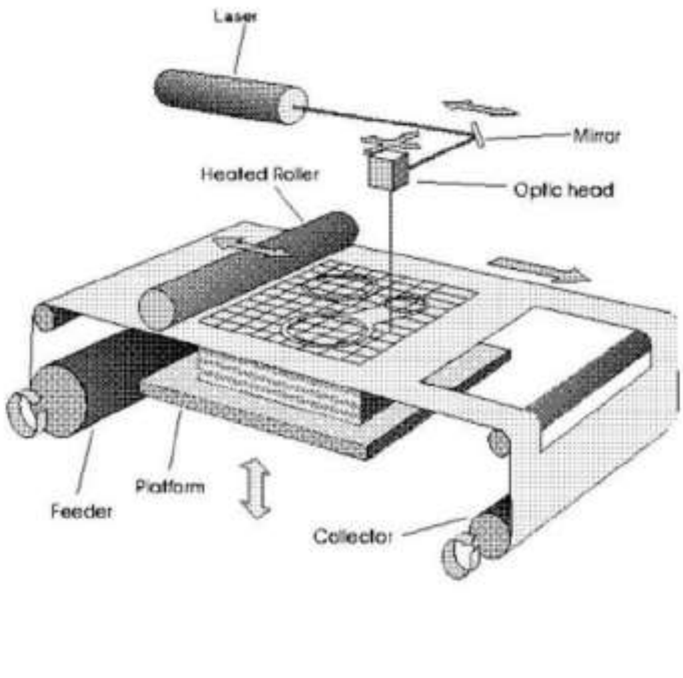


A geometric model of a conceptual design is created on CAD software which uses IGES or STL formatted files. It can be imported into the workstation where it is processed through. The CAD file is sliced into horizontal layers after the part is oriented for the optimum build position, and any necessary support structures are automatically detected and generated.

The nozzle is heated to melt the plastic filament and is mounted to a mechanical stage which can be moved in both horizontal directions. As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer and create a two-dimensional cross section of the model. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The platform then descends where the next layer is extruded upon the previous. This continues until the model is completed. The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic.

Once all the layers are drawn and the model is complete, the model is then removed from the platform, and the support structures are removed from the part.

Solid Sheet Systems



One of the earliest AM technologies was the Laminated Object Manufacturing (LOM) system. This technology used a laser to cut out profiles from sheet paper, supplied from a continuous roll, which formed the layers of the final part. Layers were bonded together using a heat-activated resin that was coated on one surface of the paper. Once all the layers were bonded together the result was very like a wooden block. A hatch pattern cut into the excess material allowed the user to separate away waste material and reveal the part.

In this process, the material consists of paper laminated which is coated with thermoplastic adhesive and rolled up on spools. A feeder mechanism advances the sheet over the build platform, where a base is made up from paper and double-sided foam tape. A heated roller applies pressure to bond the paper to the base. CO_2 laser traces the outline of the CAD data fed in the computer. After the laser cutting is completed the platform moves down and a fresh sheet of laminated paper is rolled on. The process is repeated as needed to build the part. LOM process is used in pattern making and toy designing as this process is cheaper and high volume production cab ne achieved.

Disadvantages of Additive Manufacturing

1. Limited Material Selection.
2. Differences in Material Properties.
3. High Initial Investment and Required Maintenance Expertise.