Flexible Manufacturing Systems and Today Factories

١. Introduction

A flexible manufacturing system (FMS) is a manufacturing system in which there is some amount of flexibility to react in the case of changes, whether predicted or unpredicted. This flexibility can be divided into two categories:

١. Machine flexibility, covers the system's ability to be changed to produce new product types, and ability to change the order of operations executed on a part, and
٢. Routing flexibility, this consists of the ability to use multiple machines to perform the same operation on a part, as well as the system's ability to absorb large-scale changes, such as in volume, capacity, or capability.

Most FMS systems consist of three main systems.

١. The work machines which are often usingcomputerized machines,
٢. Material handling system to optimize parts flow, and
٣. The central control computer which controls material movements and machine flow.

An Industrial Flexible Manufacturing System (FMS) consists of robots, Computer-controlled Machines, Numerical controlled machines (CNC), instrumentation devices, computers, sensors, and other stand-alone systems such as inspection machines as shown in Figure ١.

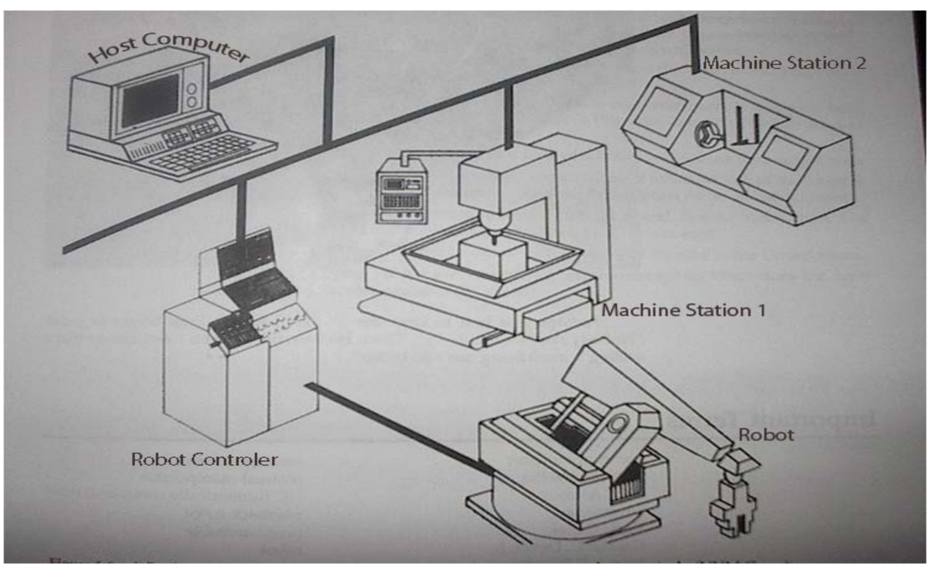

Figure ١, Illustration of FMS

The use of robots in the production segment of manufacturing industries promises a variety of benefits ranging from high utilization to high volume of productivity. Each Robotic cell or node will be located along a material handling system such as a conveyor or automatic guided vehicle as shown in Figure ٢.

Figure ٢, Robotic located along a material handling system.

The production of each part or work-piece will require a different combination of manufacturing nodes. The movement of parts from one node to another is done through the material handling system. At the end of part processing, the finished parts will be routed to an automatic inspection node, and subsequently unloaded from the Flexible Manufacturing System.

The FMS data traffic consists of large files and short messages, and mostly come from nodes, devices and instruments. The message size ranges between a few bytes to several hundreds of bytes. Executive software and other data, for example, are files with a large size, while messages for machining data, instrument to instrument communications, status monitoring, and data reporting are transmitted in small size. There is also some variation on response time. Large program files from a main computer usually take about ٦٠ seconds to be down loaded into each instrument or node at the beginning of FMS operation. Messages for instrument data need to be sent in a periodic time with deterministic time delay. Other type of messages used for emergency reporting is quite short in size and must be transmitted and received with almost instantaneous response.The demands for reliable FMS protocol that support all the FMS data characteristics are now urgent. The existing IEEE standard protocols do not fully satisfy the real time communication requirements in this environment. The delay of CSMA/CD is unbounded as the number of nodes increases due to the message collisions. Token Bus has a deterministic message delay, but it does not support prioritized access scheme which is needed in FMS communications. Token Ring provides prioritized access and has a low message delay, however, its data transmission is unreliable. A single node failure which may occur quite often in FMS causes transmission errors of passing message in that node. In addition, the topology of Token

Ring results in high wiring installation and cost. A design of FMS communication protocol that supports a real time communication with bounded message delay and reacts promptly to any emergency signal is needed. Because of machine failure and malfunction due to heat, dust, and electromagnetic interference is common, a prioritized mechanism and immediate transmission of emergency messages are needed so that a suitable recovery procedure can be applied. A modification of standard Token Bus to implement a prioritized access scheme was proposed to allow transmission of short and periodic messages with a low delay compared to the one for long messages.

Advantages and disadvantages of FMSs implementation

Advantages

- Faster, lower- cost changes from one part to another which will improve capital utilization
- Lower direct labor cost, due to the reduction in number of workers
- Reduced inventory, due to the planning and programming precision
- Consistent and better quality, due to the automated control
- Lower cost/unit of output, due to the greater productivity using the same number of workers
- Savings from the indirect labor, from reduced errors, rework, repairs and rejects

Disadvantages

- Limited ability to adapt to changes in product or product mix (ex. machines are of limited capacity and the tooling necessary for products, even of the same family, is not always feasible in a given FMS)
- Substantial pre-planning activity
- Expensive, costing millions of dollars
- Technological problems of exact component positioning and precise timing necessary to process a component
- Sophisticated manufacturing systems

٢. CNC machine

CNC istheprocessofmanufacturingmachinedparts.Thisprocessiscontrolledbyacomputerizedcontrollercalled MachineControlUnit(MCU).TheMCUgenerates,stores,andprocessesCNCprograms.TheMCU usesmotorstodriveeachaxisofamachinetollandregulatesitsdirection,speed,andtheamountoftimeeachmotorrotates.

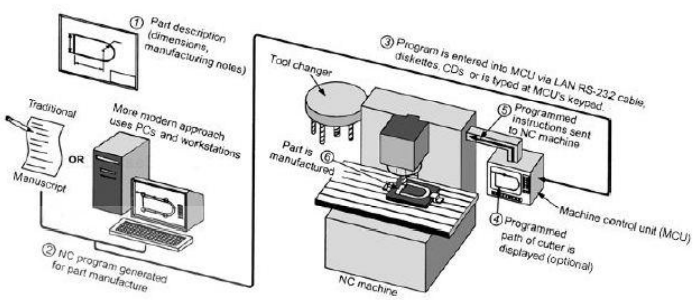

Figure ٣, schematic drawing of a CNC machine parts.

٢.١ **Types of system control**:

٢.١.١.**Point-to-Point Tool Movement**:The tool moves to a point on the part and execute an operation at that point only as shown in Figure ٤.The tool is not in continues contact with the part while it is being moved to aworking location.Operations:drilling, reaming, boring, tapping and punching.

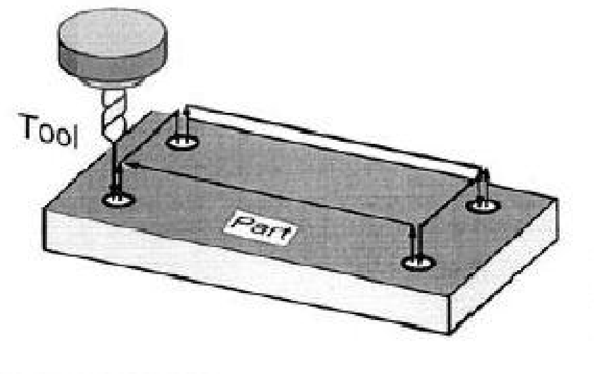

Figure ٤, Point-to-point tool movement.

٢.١.٢. Continuous Path Tool Movement: The tool maintains continuous contact with the part as the tool cuts a contourshape as shown in Figure ٥. The continuous path controllers output motion by interpolating each point.Interpolation is a mathematical method of approximating the true or exact positions required to follow a pre-calculatedpath. Operations**:**milling along lines at any angle, milling arcs, and lathe turning.

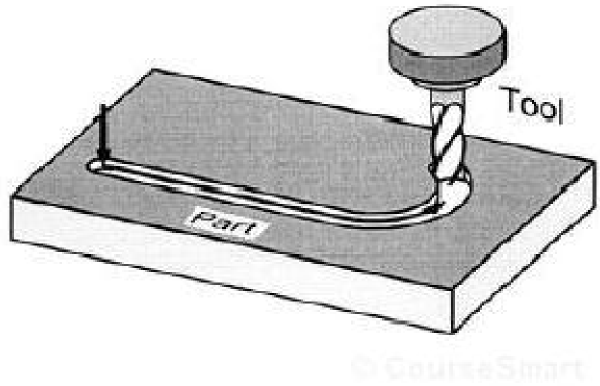

Figure ٥,Continuous tool movement.

٢.٢ Loop Systems For Controlling Tool Movement [CNC Machine Movement] :

A loop system sends electrical signals to drive motor controllers and receives some form of electrical feedback from the motor controllers. Toleranceto which a part can be cut depends on the loop system type.

١. **Open Loop System:**Utilize stepping motors to create machine movements. Stepping motors rotate a fixed amount, usually ١.٨°for each pulse received. The motors are connected to the machine table lead screw and spindle. The motor controller send signals back indicating the end of motion. The feedback is not used to check the accuracy of machine movement with the exact movement programmed. Backlash is increased due to friction generated from the lead screw. Backlash can cause positioning errors when reversing the motion.

٢. **Closed Loop System**:Utilize servomotors to create machine movements. Motor types include AC servos,DC servos, and hydraulic servos. Hydraulic servos are the most powerful and used in large CNC machines. The speed

٣. of AC or DC servo is variableand dependson theamount of current passing through it. The feedbackfrom servo is sent to the MCU. The unit compares the motion command from MCU and the voltage feedback[motor speed] from the tachometer and outputs back to the motor the differencebetween the two values or error.

٢.٣ Controlling Backlash: All ball screws have some “slop” or backlash at assembly. This backlash causeserrors when the screw reverses direction and the nut lags behind. Modern machinetool laser calibration equipment is used to precisely measure the amount of pitcher or and backlash in CNC positioning system. The data is input into a backlashcompensation program installed in the MCU every ٣-٦ months.As the machine wears, the value of backlash increases.

٣. Robots

A robot is the main component of a flexible production system (*FPS*). Other components of this system are machine tools, transport machines, control devices, and different auxiliary elements. A flexible production system is an automatically operating production system that can be easily reprogrammed and adapted to manufacture different products. Robot centered modules of FPS, called robot modules or robot systems are intended for specified technological operations like welding, surface coating, packaging, etc. The robot module includes one or more robots (with manipulators and control devices), pallets for details or products, auxiliary positioning, transport devices, etc. Therefore, robot control means control of a complete robot module and a certain part of the production process

٣.١ The description of robot motion

The main function of robot control software (e.g. RobotWare) is the motion control of a robot. The motion of robot’s manipulator joints, the tool or the gripper can be described in different coordinate systems. These coordinate systems are used for the realization of several control functions, including off-line programming, program adjustment, coordination of the motion of several robots or a robot and additional servodrives, jogging motion, copy of programs from one robot to another, etc.

The main coordinate systems used to describe the motion of a robot are shown in Fig. ١.٤. In the motion control the control of the gripper or tool motion is the most important. Because different types of grippers and tools have different dimensions, a special point, not depending on the type of the tool and called tool centre point (TCP) is selected. This point is the origin point of the tool coordinate system. A similar point can be used to describe the gripper or the wrist coordinate system. The mutual connections of a tool, a wrist and other coordinate systems are shown in Figure٦.

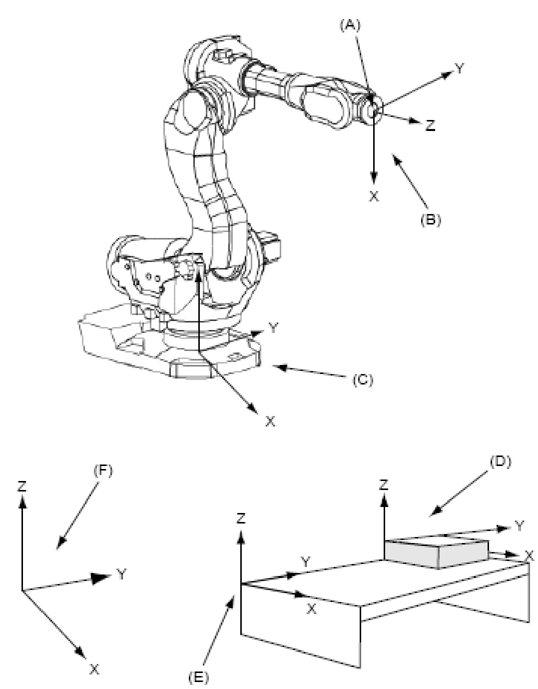

Figure ٦, Robot with available moving axis

The position of the robot and its movements are always related to the tool centre point (TCP). This point is normally defined as being somewhere on the tool, e.g. on top of the welding electrode or at the centre of a gripper. When a position is recorded, it is the position of the TCP that is recorded. This is also the point that moves along a given path at a given velocity.If the robot holding a work object and is working on a stationary tool, a stationary TCP is used. If that tool is active, the programmed path and speed are related to the work object.

٣.٢ Tool coordinate system

The orientation of a tool at a programmed position is given by the orientation of the tool coordinate system. The tool coordinate system refers to the wrist coordinate system, defined at the mounting flange on the wrist of the robot. The tool mounted on the mounting flange of the robot often requires its own coordinate system to enable the definition of its TCP, which is the origin of the tool coordinate system (Fig. ١.٥, a). The tool coordinate system can also be used to get appropriate motion directions when jogging the robot. If a tool is damaged or replaced, the tool coordinate system must be redefined.

Wrist coordinate system In a simple application, the wrist coordinate system can be used to define the orientation of the tool; here the z-axis is coincident with axis ٦ of the robot (Fig. ١.٥, b). The wrist coordinate system cannot be changed and is always the same as the mounting flange of the robot in the following respects: The origin is situated at the centre of the mounting flange (on the mounting surface). The x-axis points in the opposite direction, towards the control hole of the mounting flange. The z-axis points outwards, at right angles to the mounting flange.*The x-axis* points forwards.

- *The y-axis* points to the left (from the perspective of the robot).
- *The z-axis* points upwards.

For example, floor-mounted robot can be easily programmed in the base coordinate system. If, however, the robot is mounted upside down (suspended), programming in the base coordinate system is more difficult because the directions of the axes are not the same as the principal directions in the working space. In such cases, it is useful to define a world coordinate system.

World coordinate system will be coincident with the base coordinate system if it is not specifically defined. If several robots work within the same working space at a plant, a common world coordinate system is used to enable the robot programs to communicate with one another. It can also be advantageous to use this type of a system when the positions are to be related to a fixed point in the workshop.

٤. material handling system

Material handling is the function of moving the right material to the right place in the right time, in the right amount, in sequence, and in the right condition to minimize production cost.The cost of MH estimates ٢٠-٢٥ of total manufacturing labor cost in the United States. The primary goal is to:

١. Reduce unit costs of production.
٢. Maintain or improve product quality, reduce damage of materials.
٣. Promote safety and improve working conditions.
٤. Promote productivity.
   a) Material should flow in a straight line
   b) Use gravity! It is free power
   c) Move more material at one time
   d) Mechanize material handling
   e) Automate material handling.

Material handling equipment includes:

- **Transport Equipment**: industrial trucks, Automated Guided vehicles (AGVs), monorails, conveyors, cranes and hoists.
- **Storage Systems**: bulk storage, rack systems, shelving and bins, drawer storage, automated storage systems.
- **Unitizing Equipment**: palletizers
- **Identification and Tracking systems**

٤.١ Principles of Material Handling

١. The Planning Principle

- Large-scale material handling projects usually require a team approach.
- Material handling planning considers every move, every storage need, and any delay in order to minimize production costs.
- The plan should reflect the strategic objectives of the organization as well as the more immediate needs.

٢. The systems principle: MH and storage activities should be fully integrated to form a coordinated, operational system that spans receiving, inspection, storage, production, assembly, shipping, and the handling of returns.

- Information flow and physical material flow should be integrated and treated as concurrent activities.

Methods should be provided for easily identifying materials and products, for determining their location and status within facilities and within the supply chain

٣. Simplification principle

- Simplify handling by reducing, eliminating, or combining unnecessary movement and/or equipment.
- Four questions to ask to simplify any job:
  - Can this job be eliminated?
  - If we can't eliminate, can we combine movements to reduce cost? (unit load concept)
  - If we can't eliminate or combine, can we rearrange the operations to reduce the travel distance?
  - If we can't do any of the above, can we simplify?

٤. Gravity principle

- Utilize gravity to move material whenever practical.

٥. Space utilization principle

- The better we use our building cube, the less space we need to buy or rent.
- Racks, mezzanines, and overhead conveyors are a few examples that promote this goal.

٦. Unit load principle

- Unit loads should be appropriately sized and configured at each stage of the supply chain.
- The most common unit load is the pallet
  - cardboard pallets
  - plastic pallets
  - wooden pallets
  - steel skids

٨. Automation principle

- MH operations should be mechanized and/or automated where feasible to improve operational efficiency, increase responsiveness, improve consistency and predictability, and decrease operating costs.

١٠. Equipment selection principle

- Why? What? Where? When? How? Who?
- If we answer these questions about each move, the solution will become evident.
- Look at pp ١٦٠-١٦١.

١١. The standardization principle

- standardize handling methods as well as types and sizes of handling equipment
- Too many sizes and brands of equipment results in higher operational cost.
- A fewer sizes of carton will simplify the storage.

١٢. The dead weight principle

- Try to reduce the ratio of equipment weight to product weight. Don't buy equipment that is bigger than necessary.
- Reduce tare weight and save money.

١٣. The maintenance principle

- Plan for preventive maintenance and scheduled repairs of all handling equipment.
- Pallets and storage facilities need repair too.

١٤. The capacity principle

- Use handling equipment to help achieve desired production capacity,i.e. material handling equipment can help to maximize production equipment utilization.