Automation Slides With Notes

(2nd Semester 2023/2024)
Notes are written by Nada Ababneh

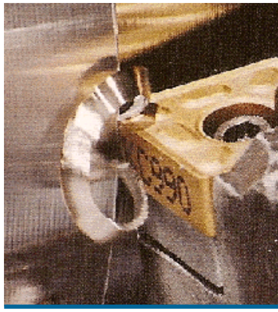
Automation

Chapter Four:

Introduction To Automation

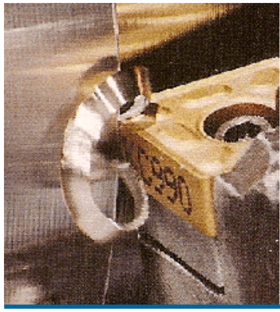
Dr. Eng. Baha'eddin Alhaj Hasan
Department of Industrial Engineering

- source of power
- level of Automation



Industry 4.0 Video

- https://www.youtube.com/watch?v=IWvipzHyL8c



Automation Defined

* Characteristics of Intelligent control system

- Adabtility
- Evoluability
- Flexibility
- Sustainability

Automation is the technology by which a process or procedure is accomplished without human assistance.

(or under human supervision)

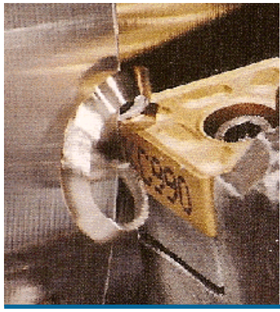
"Automation = Automatic Control"

- Basic elements of an automated system:

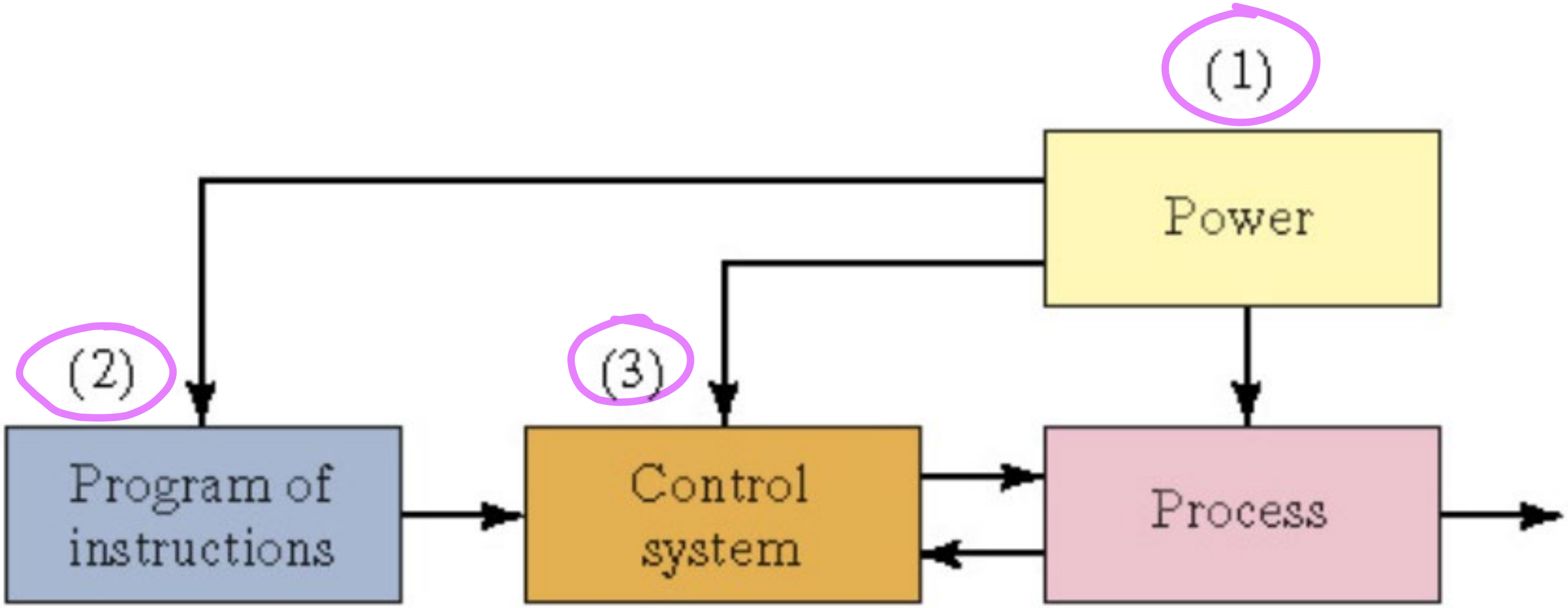
1. Power - to accomplish the process and operate the automated system
2. Program of instructions – to direct the process
3. Control system – to actuate the instructions

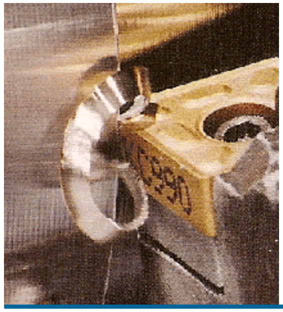
يشغل

+ to Automate sensor, program and actuator



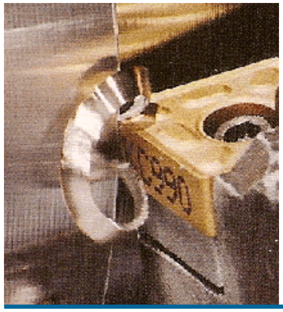
Elements of an Automated System





1- Electricity - The Principal Power Source

- Widely available at moderate cost
- Can be بسهولة readily converted to alternative forms, e.g., mechanical, thermal, light, etc.
- Low level power can be used for signal transmission, data processing, and communication.
- Can be stored in long-life batteries



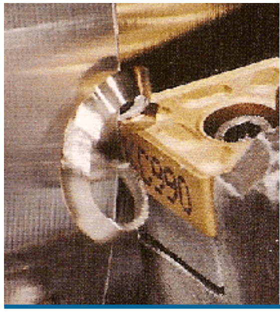
Power to Accomplish the Automated Process

❑ Power for the process:

- To drive the process itself
- To load and unload the work unit
- Transport between operations

❑ Power for automation:

- Controller unit
- Power to actuate the control signals يشغل
- Data acquisition and information processing الحصول على



برنامج التعليمات

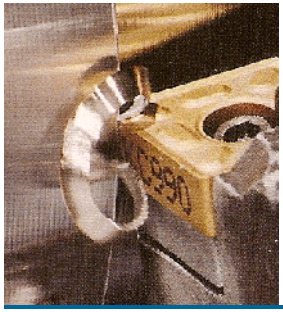
2- Program of Instructions

داخل الـ controller نفسه

تحدد

- Set of commands that specify the sequence of steps in the work cycle and the details of each step
- Example: CNC part program
- During each step, there are one or more activities involving changes in one or more process parameters
- Examples:
  - Temperature setting of a furnace مصهر
  - Axis position in a positioning system
  - Motor on or off

control the speed according to the position



3- Control System – Two Types

closed
open loop

1. *Closed-loop (feedback) control system* – a system in which the output variable is compared with an input parameter, and any difference between the two is used to drive the output into agreement with the input.

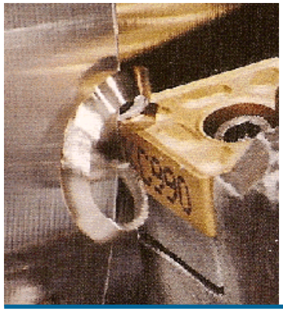
more complex

2. *Open-loop control system* – operates without the feedback loop

basic control system

ex: on/off

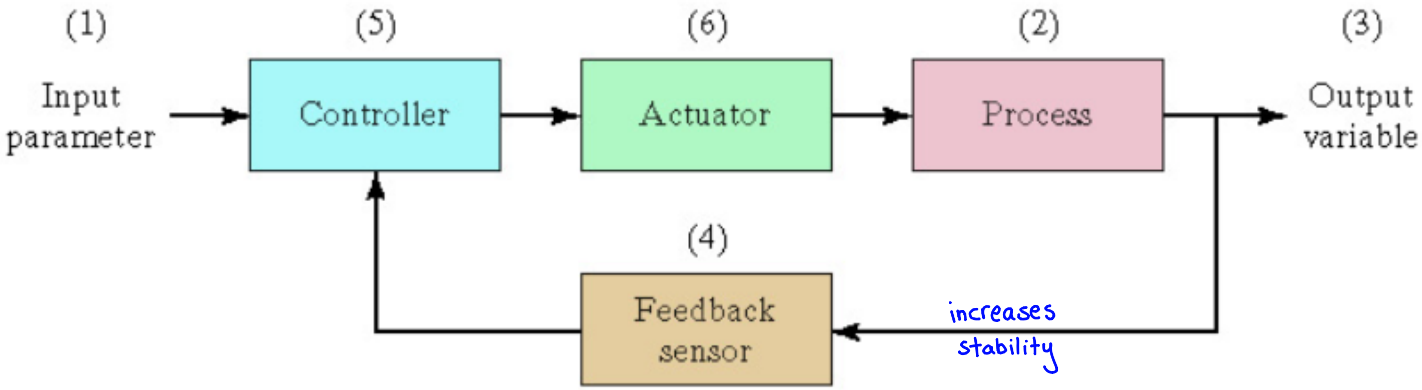
- Simpler and less expensive.
- Risk that the actuator will not have the intended effect.



(a) Feedback Control System and (b) Open-Loop Control System

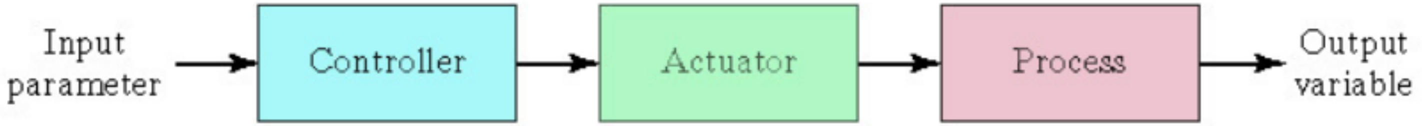
(a)

Closed Loop

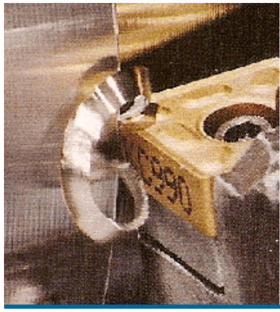


(b)

Open Loop

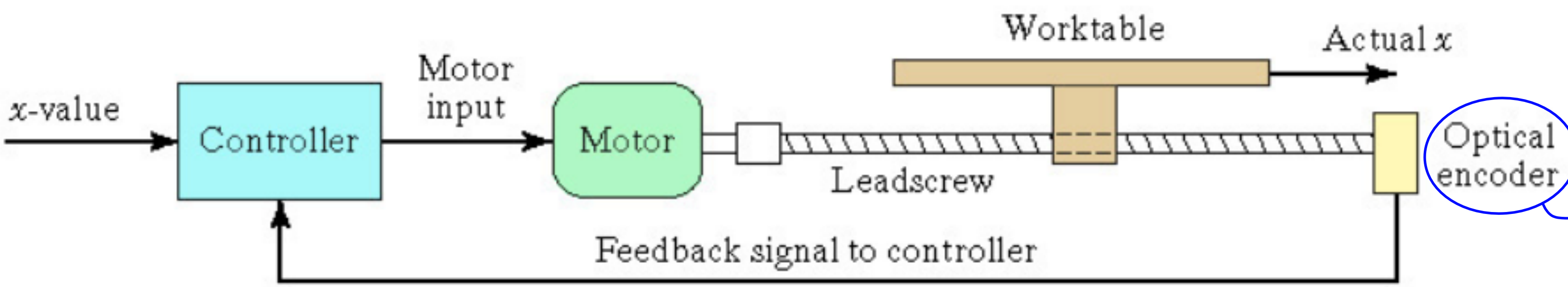


control the speed according to the position

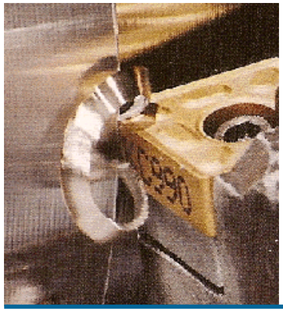


Example:

- Positioning System Using Feedback Control: A one-axis position control system consisting of a lead screw driven by a DC servomotor and using an optical encoder as the feedback sensor.



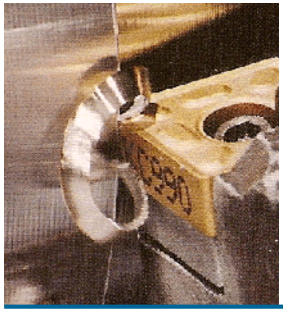
acts as feedback sensor



When to Use an Open-Loop Control System

- Actions performed by the control system are simple
- Actuating function is very reliable.
- Any reaction forces opposing the actuation are small enough as to have no effect on the actuation.

If these conditions do not apply, then a closed-loop control system should be used



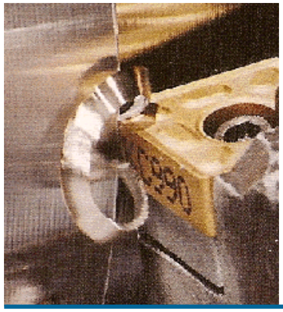
Examples of Automation

Day to Day life

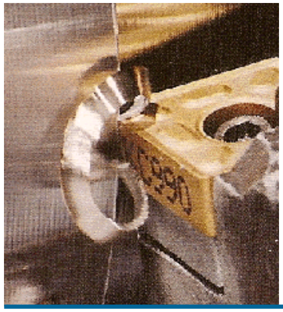
- ATM
- Vending machines
- Starting of the vehicle
- Car wipers

Industry

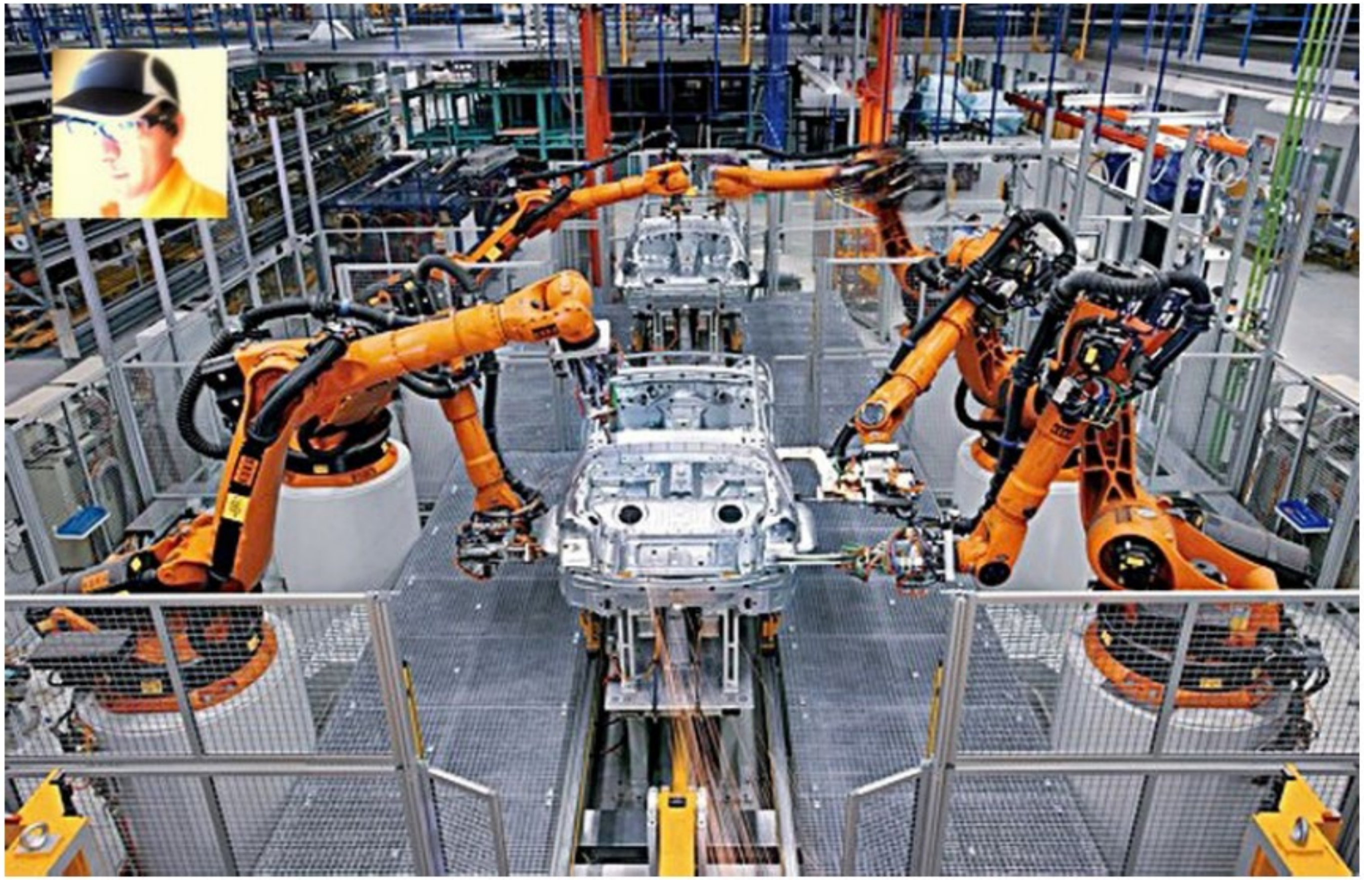
- Painting Robots in the automobile mfg industry
- Soldering Machines آلات لحام
- Automatic capping machines.
- Automatic filling machines

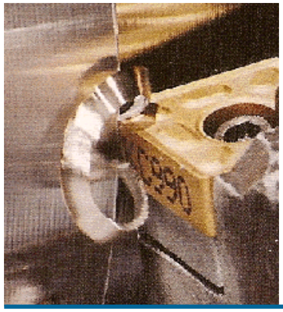


Example: car painting



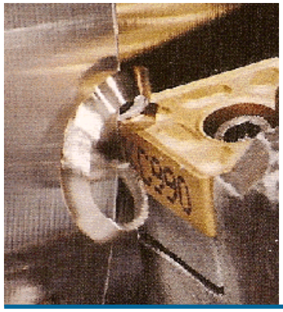
Example: cars manufacturing



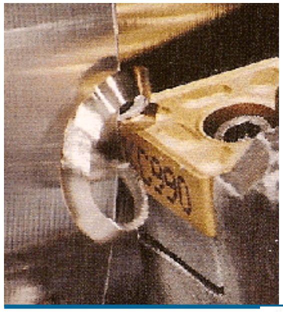


Example: soldering & brazing machine

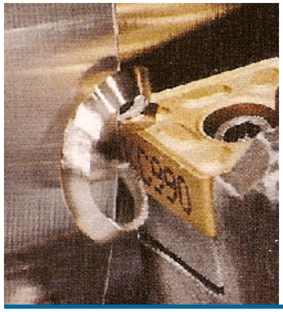
آلة لحام ولحام



Example: bottle filling & capping

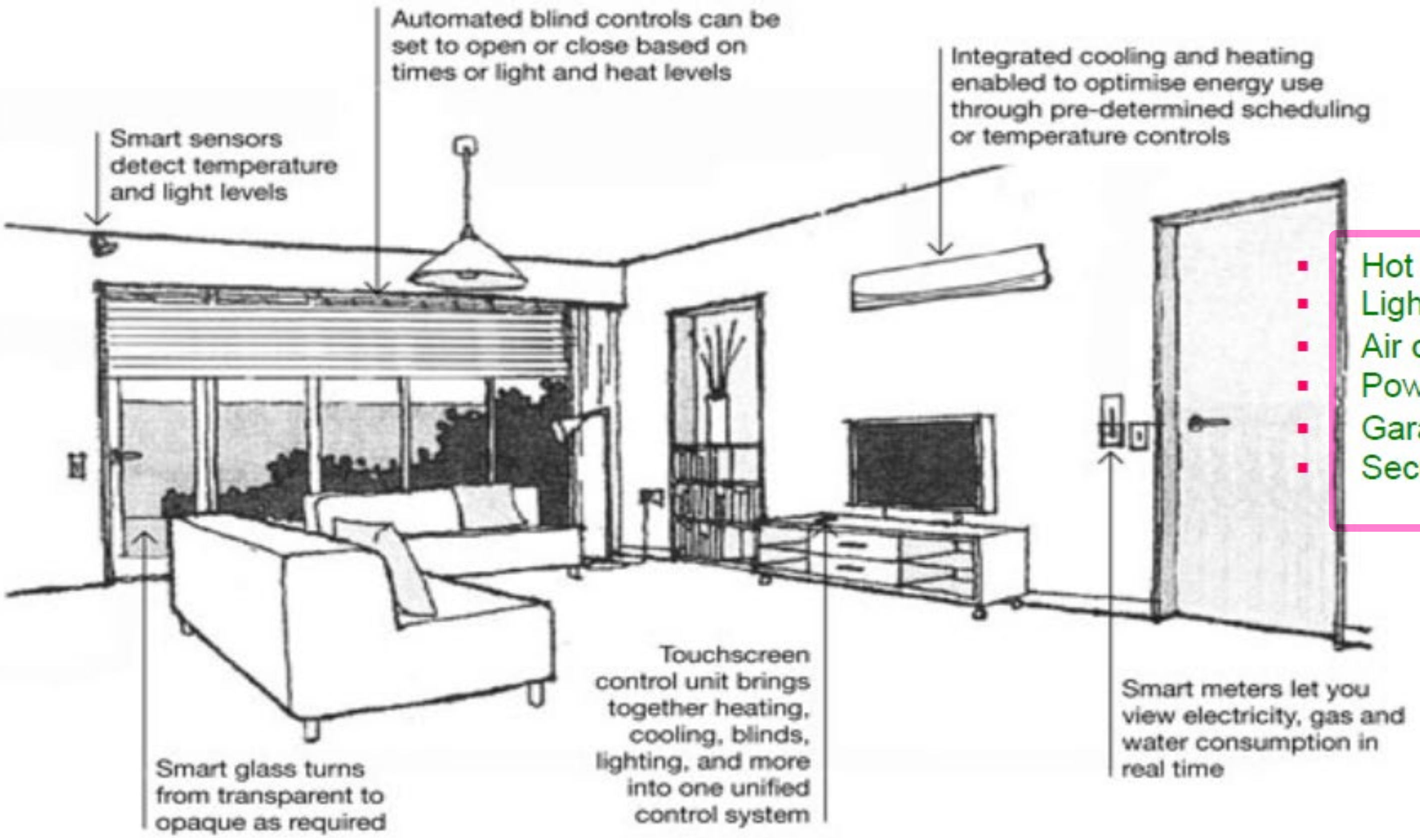


Example: packaging

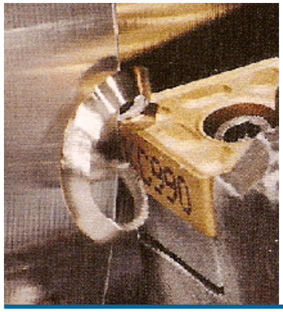


Examples of Automation

Home Automation



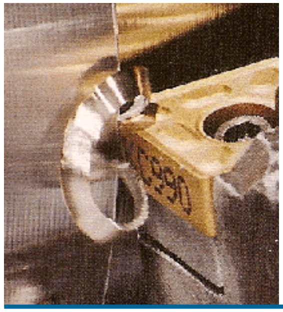
- Hot water systems.
- Lighting.
- Air conditioning.
- Powered window blinds.
- Garage doors.
- Security systems.



Advanced Automation Functions

- In addition to executing work cycle programs, an automated system may be capable of executing advanced functions that are not specific to a particular work unit.
- In general, functions are concerned with enhancing the safety and performance of the equipment.
- Advanced automation functions are made possible by special subroutines included in the program of instructions.

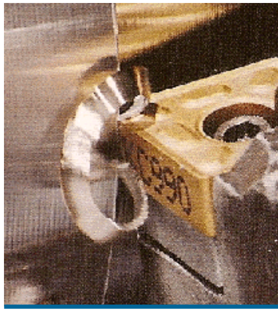
1. Safety monitoring
2. Maintenance and repair diagnostics
3. Error detection and recovery



Safety Monitoring

"Use of sensors to track the system's operation and identify conditions that are unsafe or potentially unsafe"

- Reasons for safety monitoring
  - To protect workers and equipment
- Possible responses to hazards:
  - Complete stoppage of the system
  - Sounding an alarm
  - Reducing operating speed of process
  - Taking corrective action to recover from the safety violation

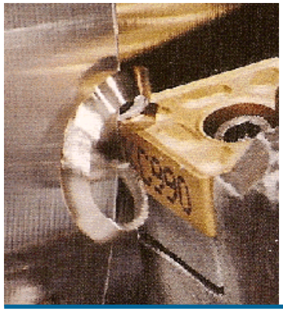


Safety Monitoring Examples

- Temperature sensors
- Heat or smoke detectors
- Pressure sensitive floor pads
- Vision systems

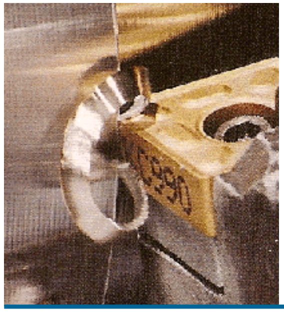
Maintenance and Repair Diagnostics

Maintenance and Repair Diagnostics refer to the capabilities of an automated system to assist in identifying the source of potential or actual malfunctions and failures of the system.



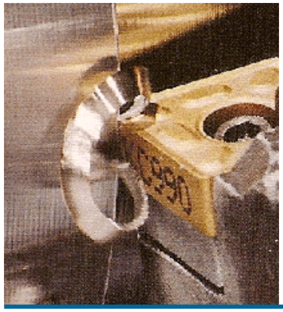
Maintenance and Repair Diagnostics

- Status monitoring
  - Monitors and records status of key sensors and parameters during system operation
  - Provide information for diagnosing a current failure
  - Provide data to predict a future malfunction or failure
- Failure diagnostics
  - Invoked when a malfunction occurs
  - Purpose: analyze recorded values so the cause of the malfunction can be identified
- Recommendation of repair procedure
  - Provides recommended procedure for the repair crew to effect repairs



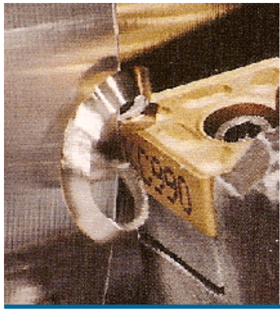
Errors

- *Random errors* occur as a result of the normal stochastic nature of the process
- *Systematic errors* are those that result from some assignable cause such as a change in raw material properties
- *Aberrrations (disorders)* result from either an equipment failure or a human mistake



Error Detection and Recovery

1. Error detection – functions:
   - Use the system's available sensors to determine when a deviation or malfunction has occurred
   - Correctly interpret the sensor signal
   - Classify the error
2. Error recovery – possible strategies:
   - Make adjustments at end of work cycle
   - Make adjustments during current work cycle
   - Stop the process to invoke corrective action
   - Stop the process and call for help

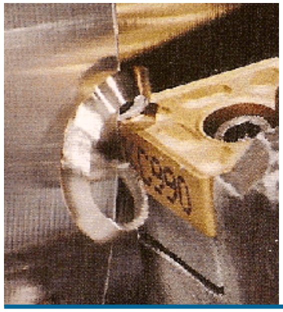


Why Automation is required ?

- Increase in comfort.
- More safety.
- Improve the quality and precision.
- To do the job for which human beings will not have the capacity.
- To avoid monotonous work.

لتجنب العمل الرتيب
(لتجنب الروتين الممل)

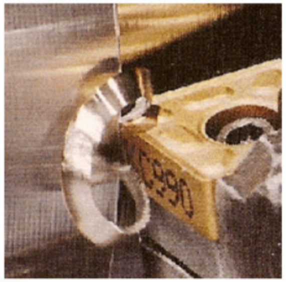
↑ level of Automation ↑ system is more smart ↑ system is flexible



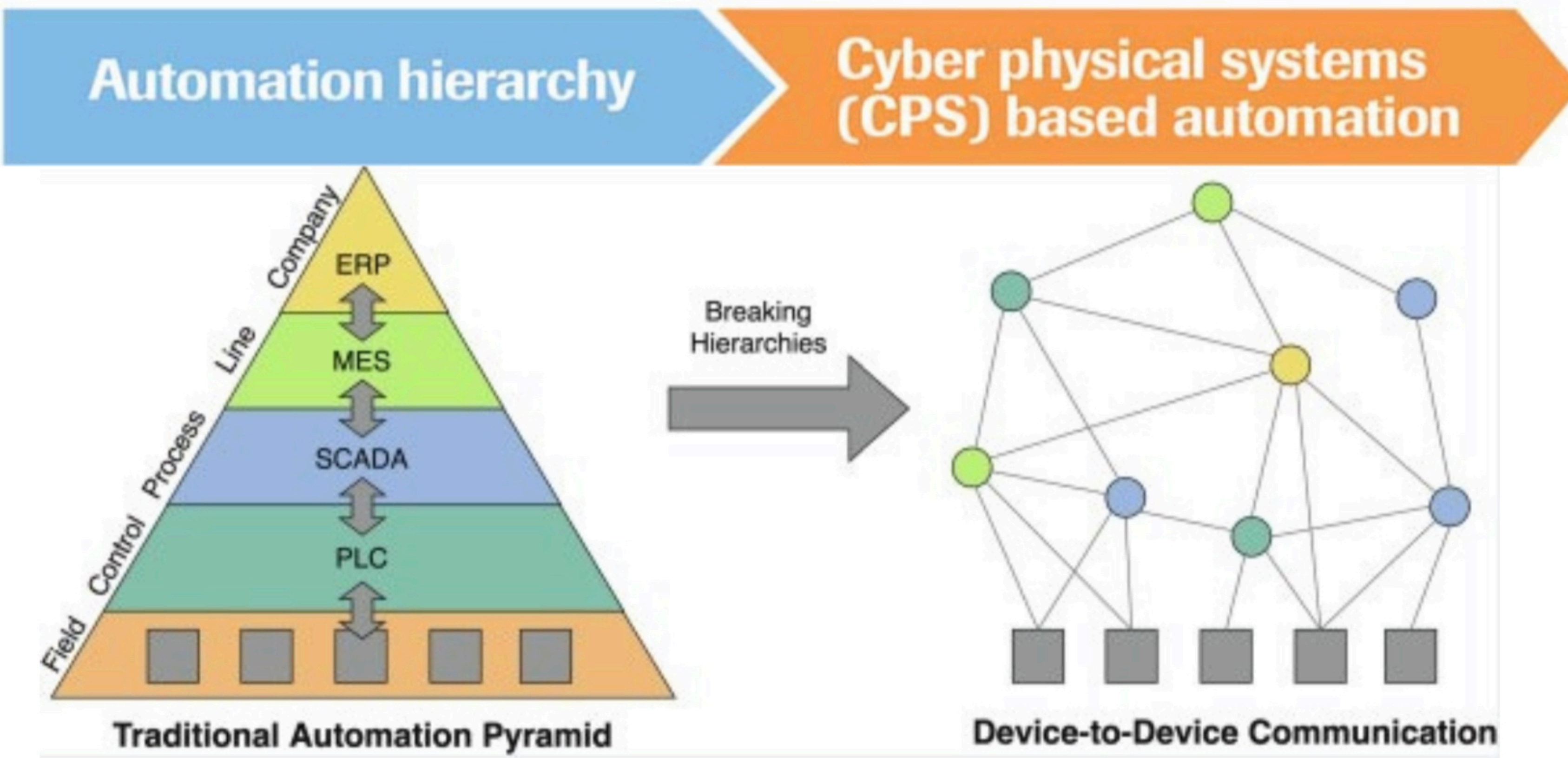
Manufacturing Systems

A manufacturing system can be defined as a collection of integrated equipment and human resources that performs one or more processing and/or assembly operations on a starting work material, part, or set of parts

- The integrated equipment consists of production machines, material handling and positioning devices, and computer systems
- The manufacturing systems accomplish the value-added work on the part or product.



Manufacturing Systems



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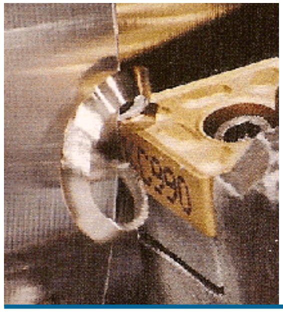
Traditional manufacturing system

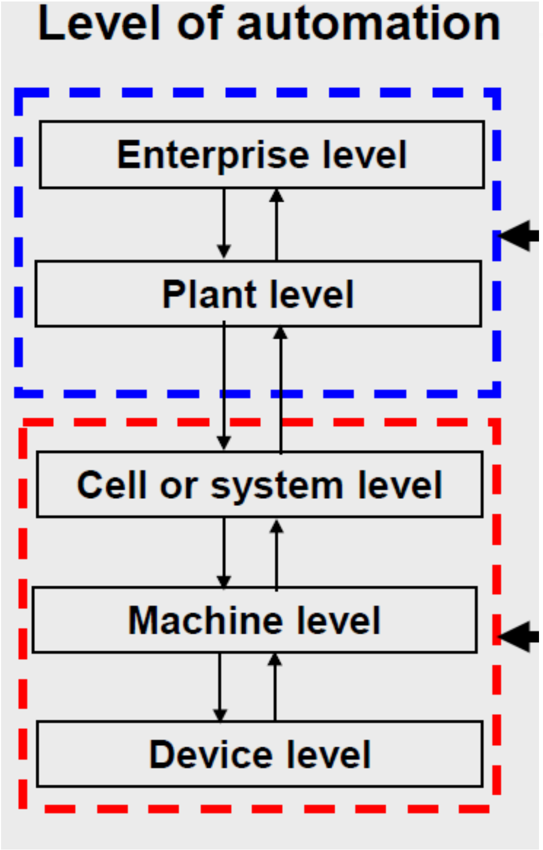
MES Manufacturing Execution System
ERP Enterprise Resource Planning
SCADA (supervisory control and data acquisition)

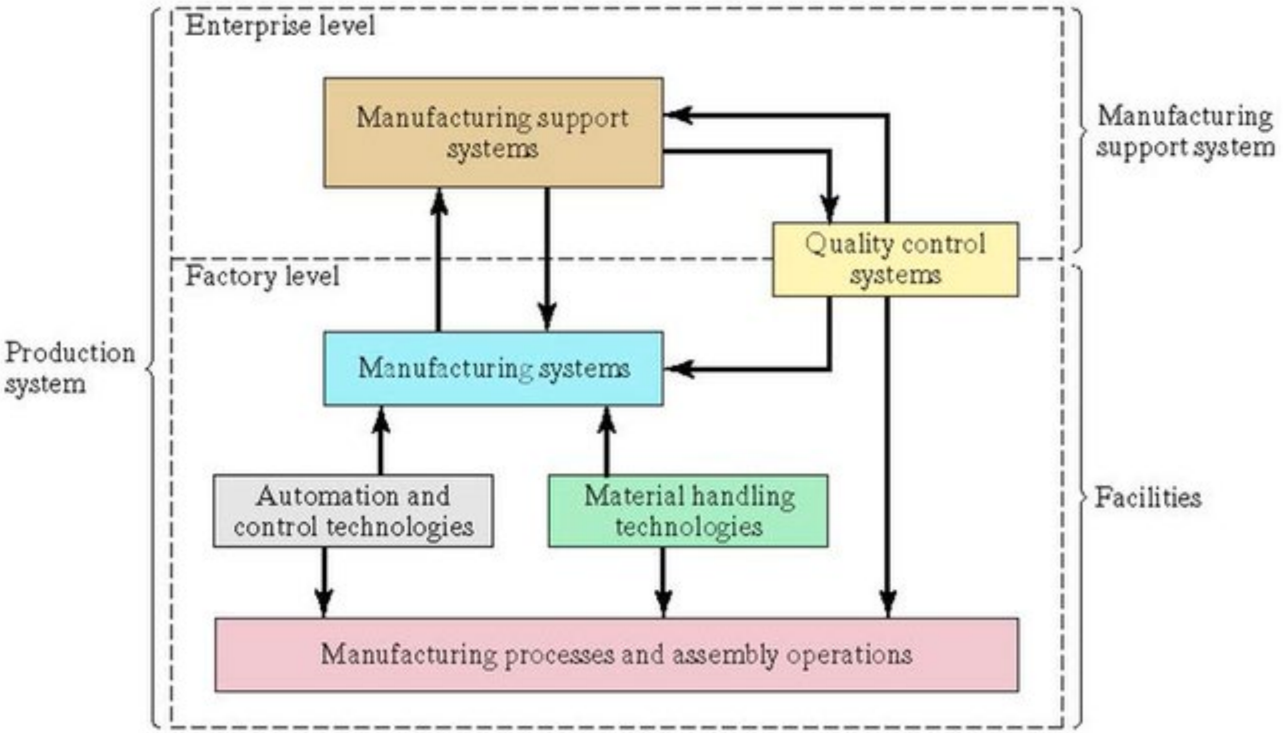
Smart manufacturing system

this system is more automated

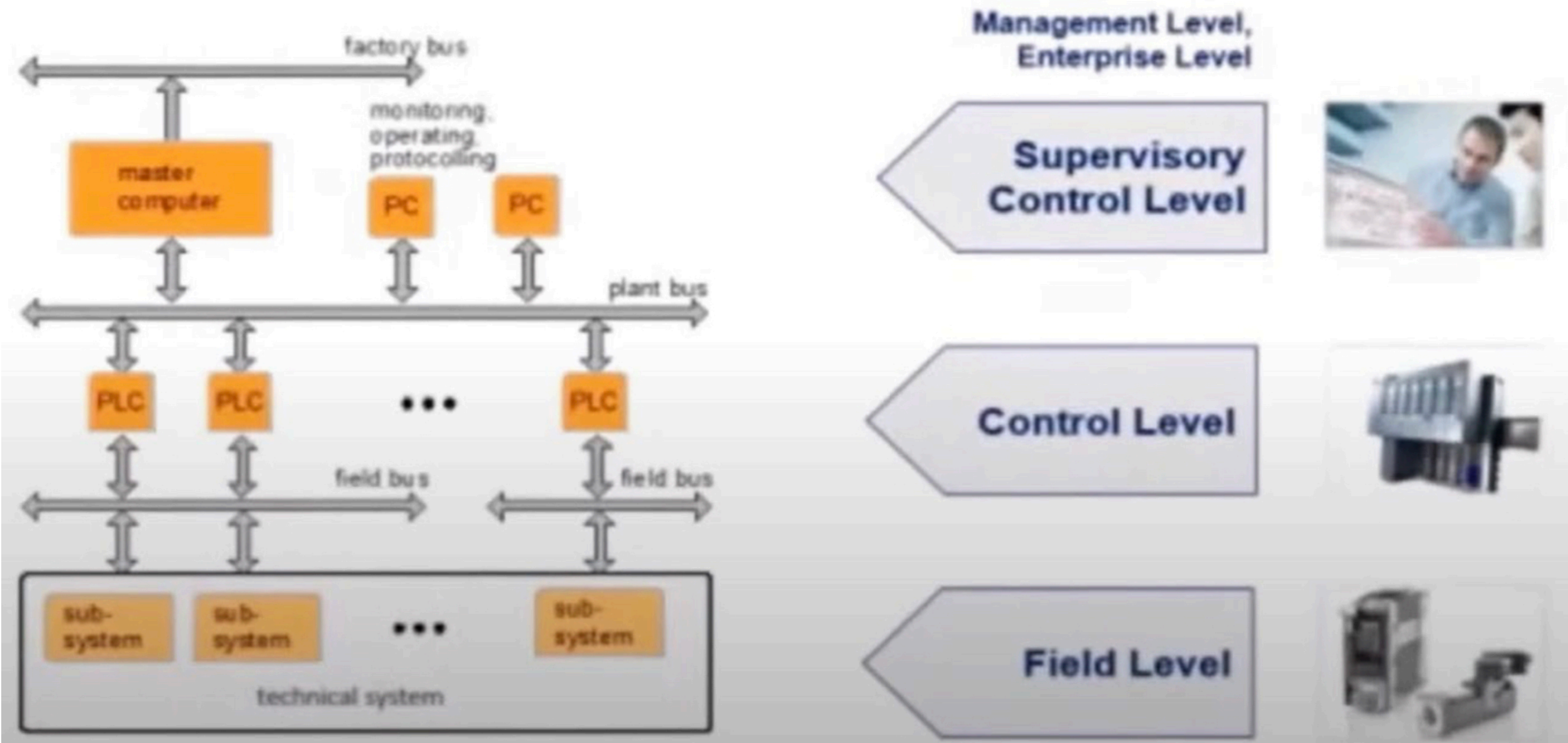


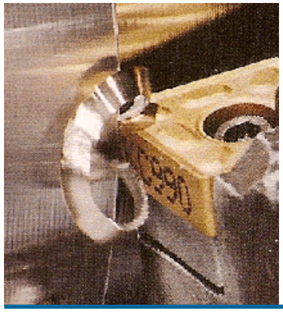
Automation in Manufacturing Systems





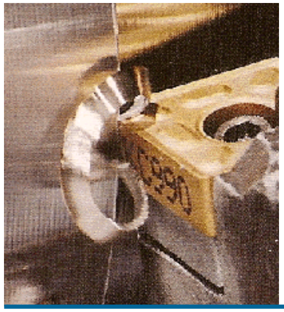
Automation in Manufacturing Systems





Levels of Automation

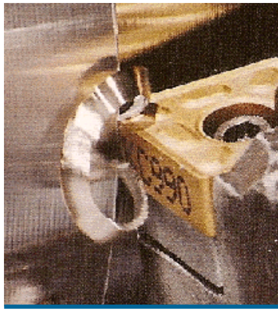
1. *Device level* – actuators, sensors, and other hardware components to form individual control loops for the next level (lowest level in the hierarchy)
2. *Machine level* – CNC machine tools and similar production equipment, industrial robots, material handling equipment



Levels of Automation

3. *Cell or system level* – a manufacturing cell or system is a group of machines or workstations connected and supported by a material handling system, computer and other equipment appropriate to the manufacturing process
   - Part dispatching and machine loading
   - Coordination among machines and material handling system
   - Collecting and evaluating inspection data

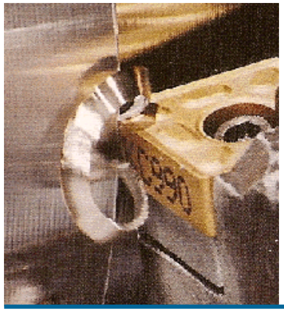
Assembly resources
manufacturing resources



Levels of Automation

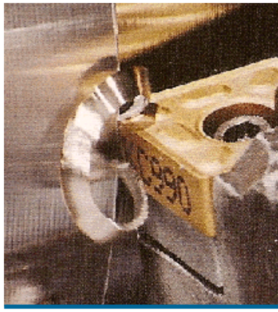
4. *Plant level* – factory or production systems level
   - Order processing
   - Process planning
   - Inventory control
   - Purchasing
   - Material Requirements Planning
   - Shop floor control
   - Quality control

هنا ال Automation functions زادو



Levels of Automation

5. *Enterprise level* – corporate information system
   - Marketing/Sales
   - Accounting
   - Design
   - Research
   - Aggregate planning
   - Master Production Scheduling



Three Basic Types of Automation

No change in product
(High Fixed volume)

- **Fixed automation** - the processing or assembly steps and their sequence are fixed by the equipment configuration

soft variety

- **Programmable automation** - equipment is designed with the capability to change the program of instructions to allow production of different parts or products

hard variety

- **Flexible automation** - an extension of programmable automation in which there is virtually no lost production time for setup changes or reprogramming

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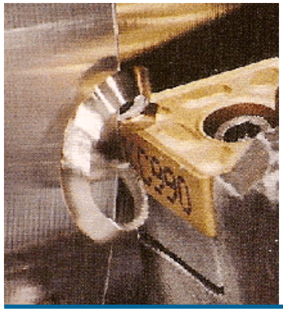
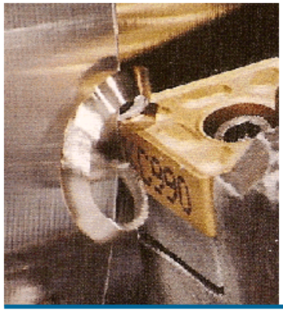


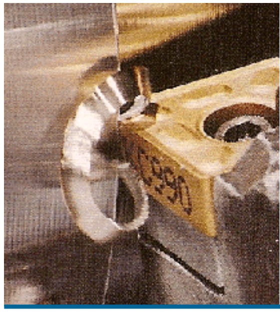
Features of Fixed Automation

- High initial investment for specialized equipment
- High production rates
- The program of instructions cannot be easily changed because it is fixed by the equipment configuration
  - Thus, little or no flexibility to accommodate product variety



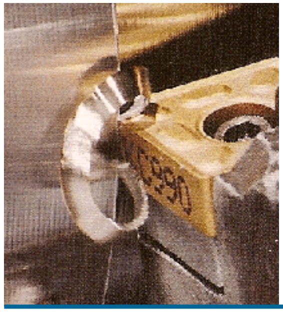
Features of Programmable Automation

- High investment in general purpose equipment that can be reprogrammed
- Ability to cope with product variety by reprogramming the equipment
- Suited to batch production of different product and part styles
  - Lost production time to reprogram and change the physical setup
- Lower production rates than fixed automation

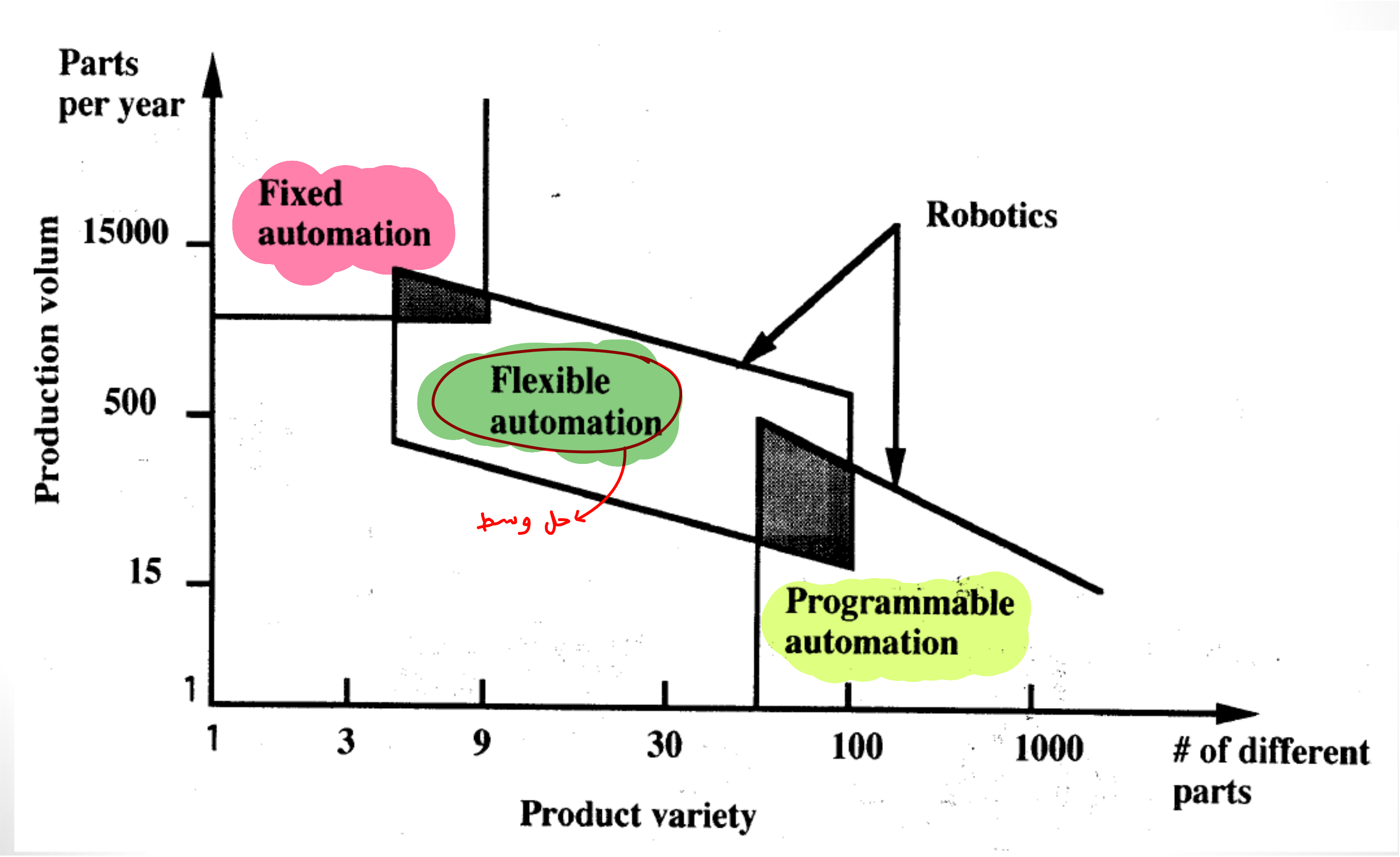


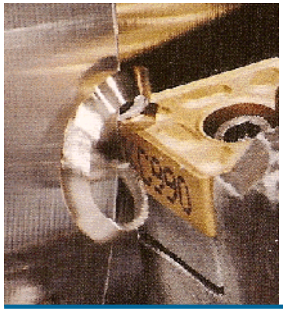
Features of Flexible Automation

- High investment cost for custom-engineered equipment
- Capable of producing a mixture of different parts or products without lost production time for changeovers and reprogramming
  - Thus, continuous production of different part or product styles
- Medium production rates
  - Between fixed and programmable automation types



Three Basic Types of Automation





Hardware Components for Automation

- Sensors
- Actuators
- Interface devices
- Process controllers - usually computer-based devices such as a programmable logic controller

Automation

Chapter Six:

Hardware Components for Automation and Process Control

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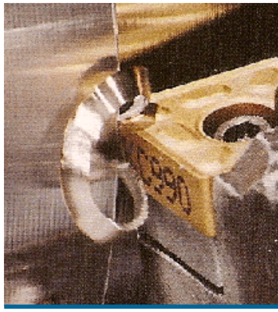
Automatic control → على الاغلب نتكلم عن closed Loop

اذاً بالعادة بستخدم Digital controller



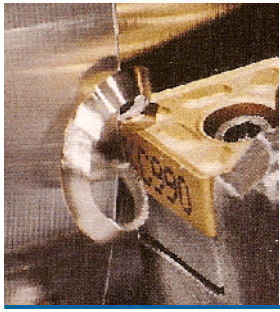
Chapter 6: Hardware Components

- Sections:

1. Sensors أجهزة الاستشعار
2. Actuators المحركات
3. Analog-to-Digital Conversion
4. Digital-to-Analog Conversion

Control : one of the functions of automation but not the only function.

* Automation :- can be divided into series of controlled processes

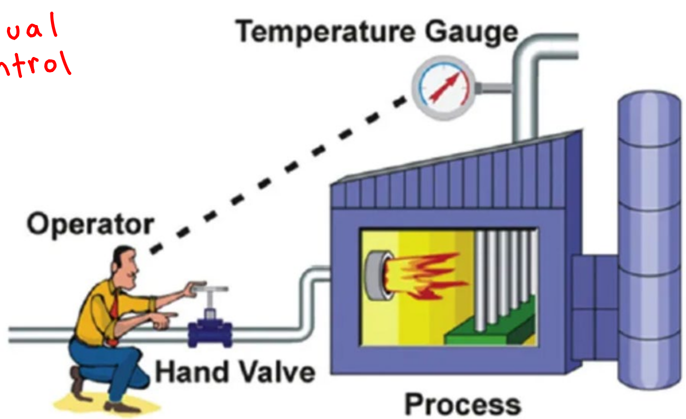


What is A process Control?

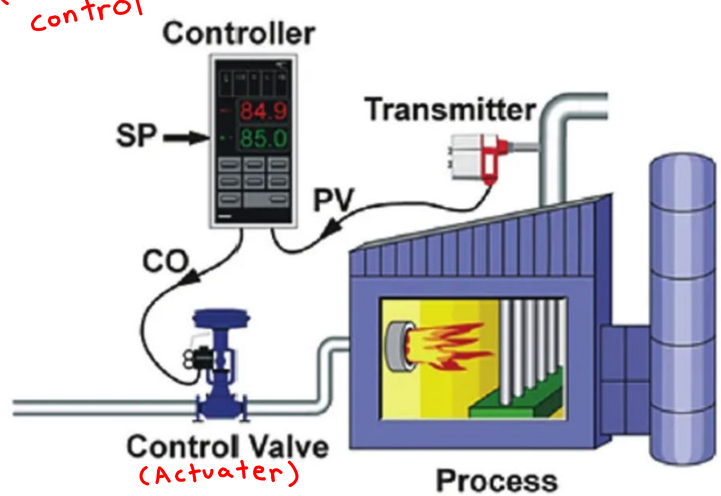
sequence of time dependent processes

- An industrial process control or simply process control is the deploying (نشر) of industrial control systems and control theory to monitor and adjust an industrial process to give a desired output. It is used in industry to (1) maintain quality and to (2) improve performance. Which could not be achieved purely by human manual control.

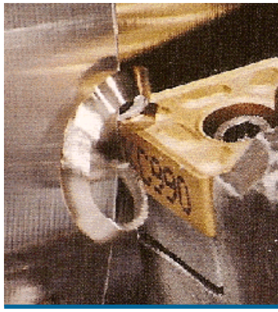
Manual control



Automatic control



*An example of Rotary Actuator → Butterfly Valve

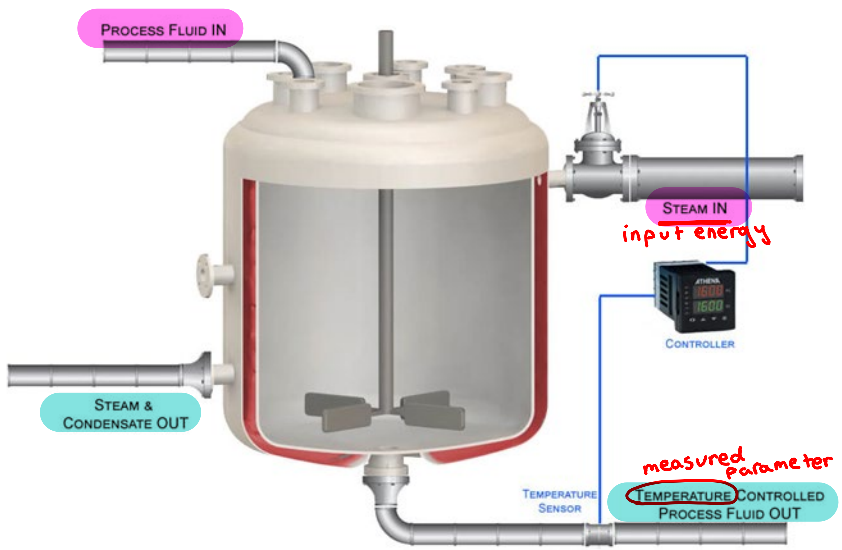


Example: Temperature closed loop process Control

Heat Exchanger

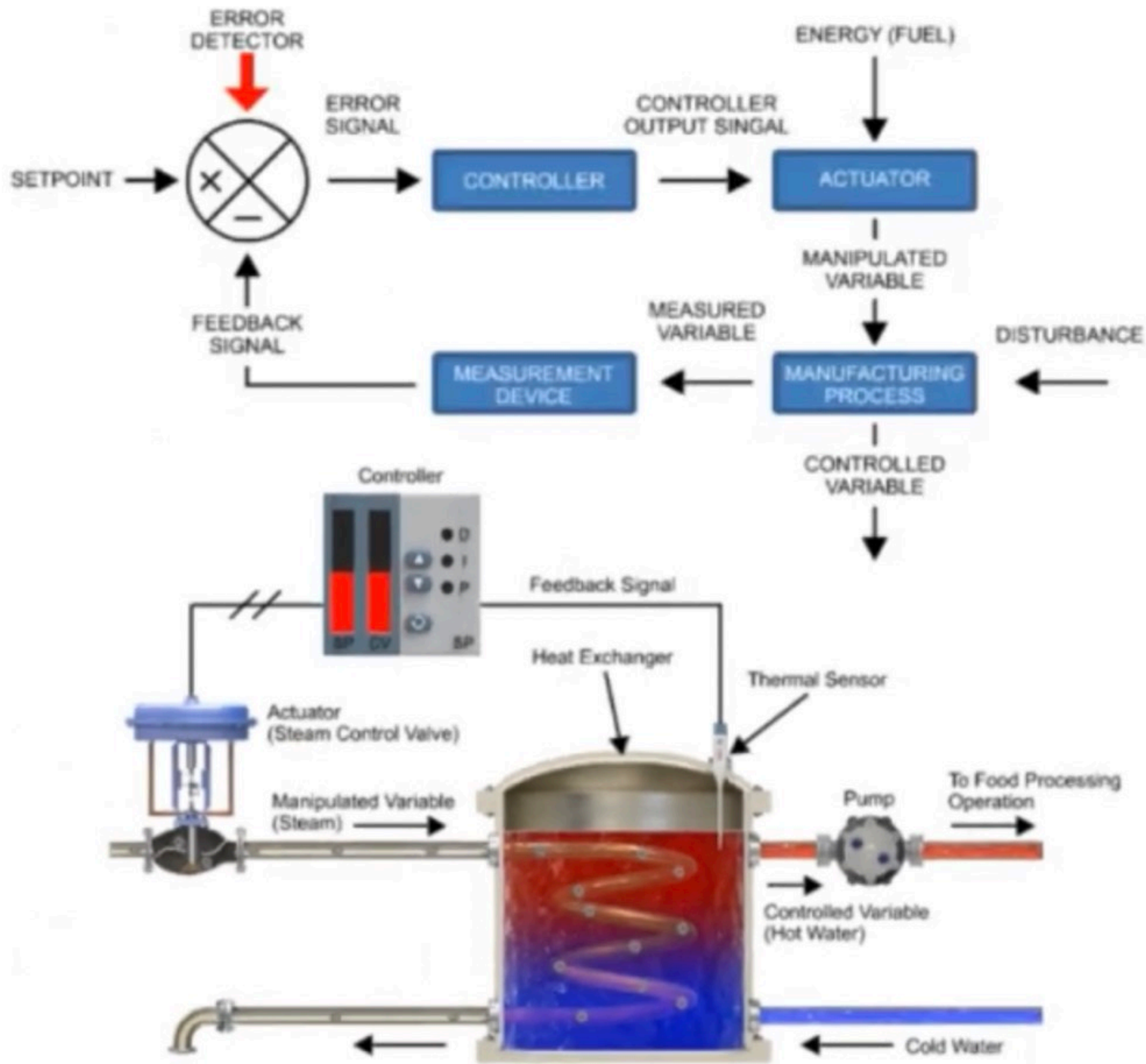
*Sensing elements : thermometer

*Actuator : valve



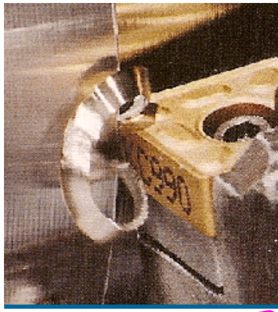
https://www.youtube.com/watch?v=maQyGdgvS4M

Closed Loop System



Digital controller → computer/ micro controller → Digital data

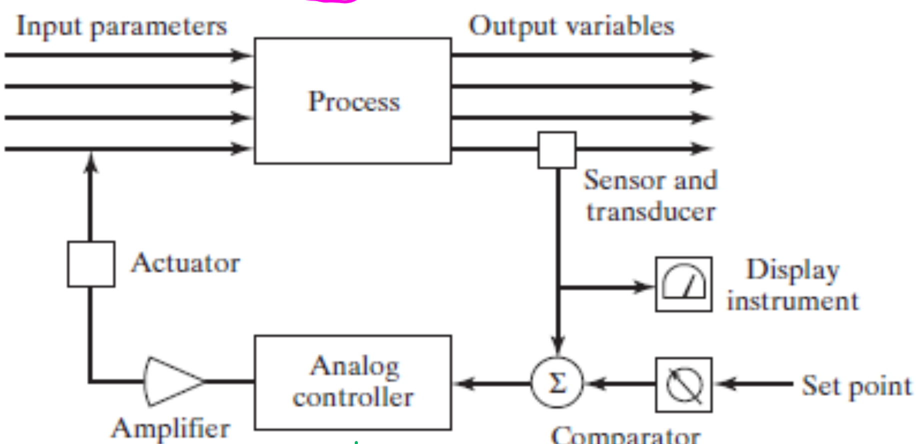
مابقدر استخدم Analog data لـ digital controller عشان هيك بستخدم ATD/DTA converters ← (بحول الـ data الداخلة على الـcomputer او الـcontroller)



Process Control: Analog / Digital Controller

Digital → computer

Analog



output (Analog signal)

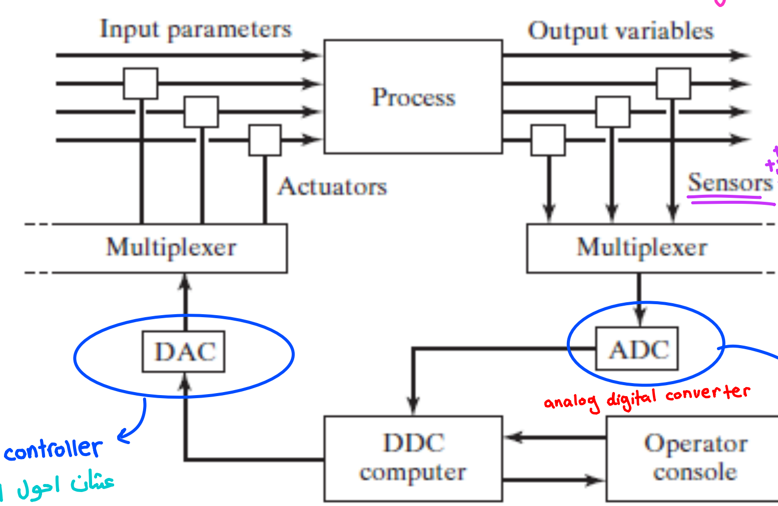
input (Analog signal)

عكس الـ computer

*control signal = electric signal = voltage signal
بقيسها بالـ v

Digital

input and output (digital signal)



Sensors: two types → analog, digital

ADC: analog digital converter

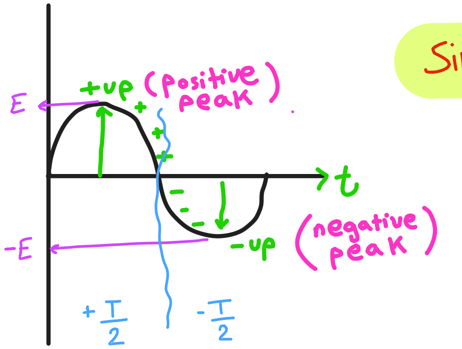
DAC: Digital to Analog controller
عشان احول الـ signals يلي راح تطلع من الـ computer

ADC: Analog to digital controller
عشان احول الـ signals يلي راح تدخل على الـcomputer

* Analog Signal

هي signal تتغير ال sign تبعها in a period of time

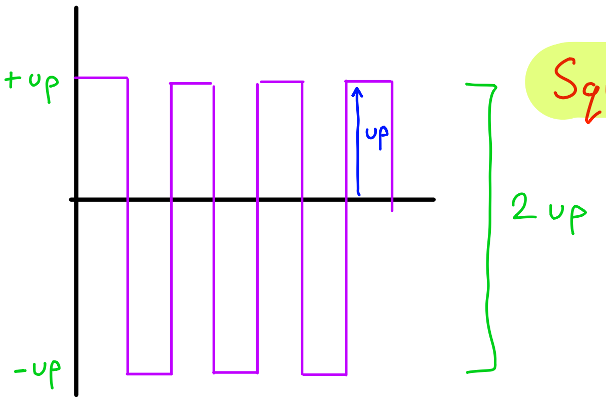
Sine-wave signal



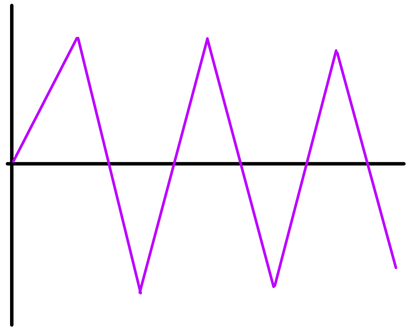
Amplitude = E up

= 2 E up- p

Squared signal



Triangle signal



* Digital Signal

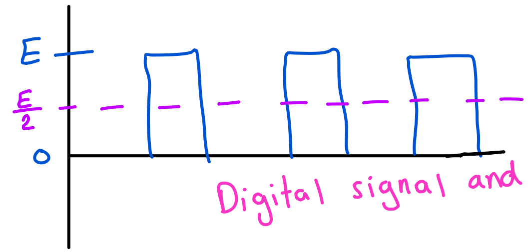
هي ال signal التي لا تتغير اشارتها

(Binary Pulses)

it is the signal that its sign doesn't change

or → positive always

→ negative always



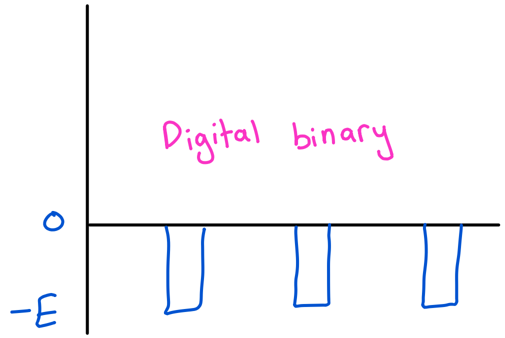
Digital signal and Binary data

↳ either zero or one

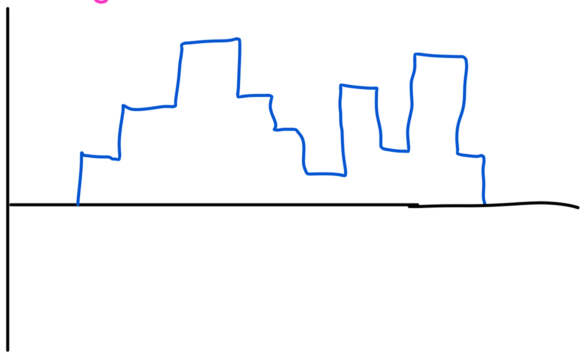
$\frac{E}{2}$ > Logic 1

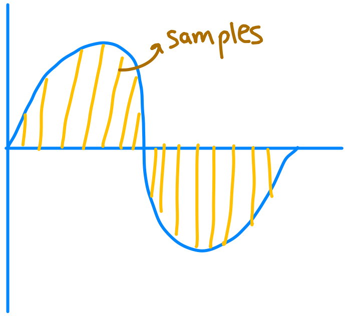
$\frac{E}{2}$ < Logic 0

Digital binary



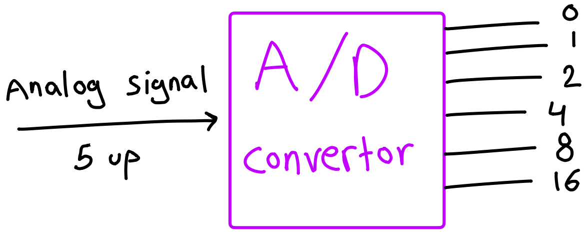
Digital signal not Binary





كل ما اخدت samples
اكتر كلما كان شغلي ادق

كل ما زاد عدد العينات
بزيد عدد ال Revolution (أكثر دقة)
عملية اسمها Coding



عملية ال
Digitalization

	64	32	16	8	4	2	1
0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	1
2	0	0	0	0	0	1	0
3	0	0	0	0	0	1	1
4	0	0	0	0	1	0	0

Auto $\rightarrow$ closed loop Control system

Computer controller $\rightarrow$ Digital controller

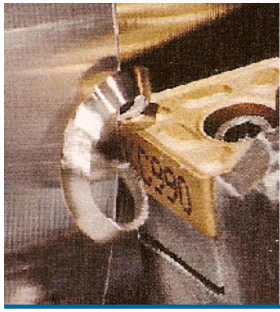
Output of the sensors depends on → Analog sensors / Digital sensors

Output of the sensor → Actuator

باخدها مباشرة / بحولها

Digital → باخدها

Analog → بحولها



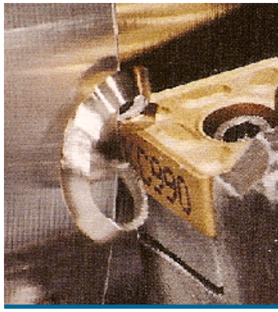
Computer-Process Interface

- To implement process control, the computer must collect data from and transmit signals to the production process.

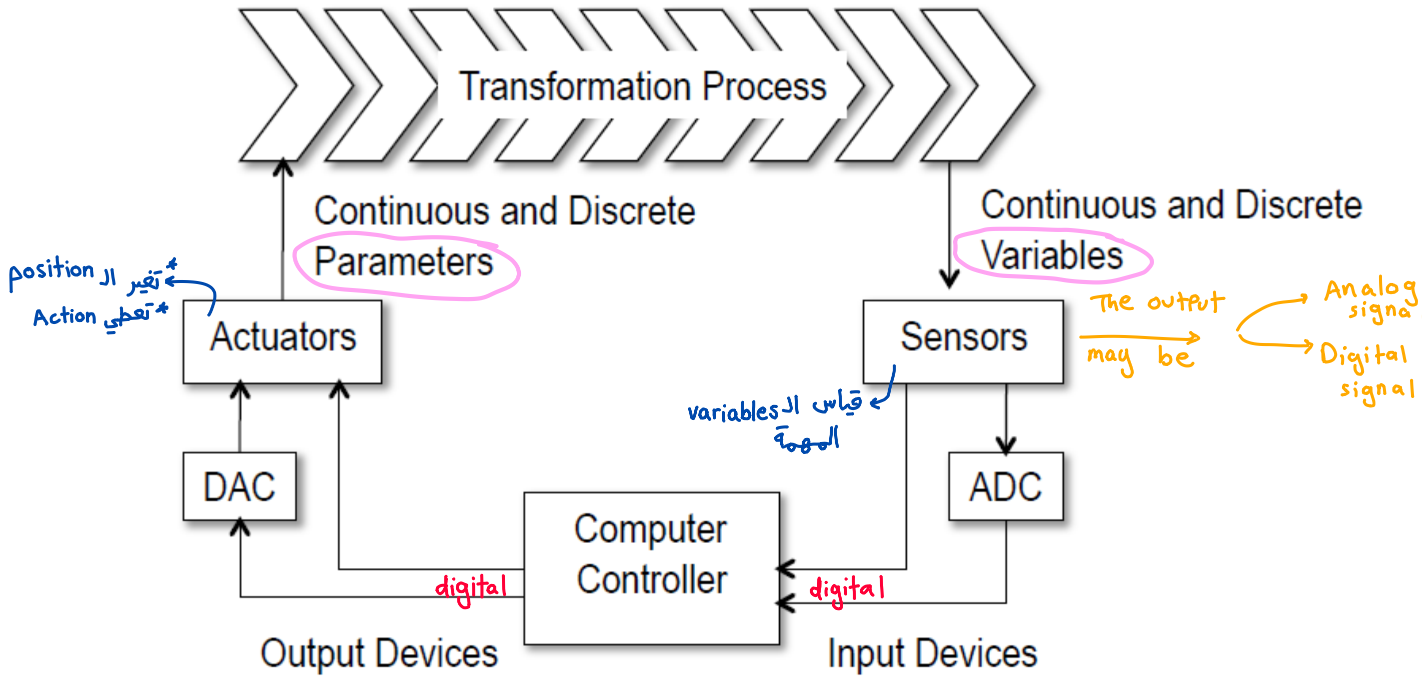
- Components required to implement the interface: للتنفيذ
  1. Sensors to measure continuous and discrete process variables.
  2. Actuators to drive continuous and discrete process parameters.
  3. Devices for ADC and DAC.
  4. I/O devices for discrete data.

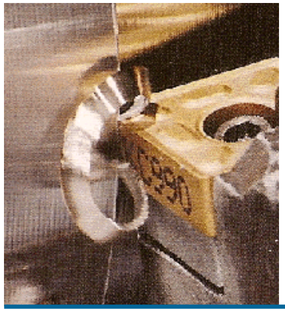
Output of controller is always Digital → digital actuator (on/off)

No Open loop system
has a digital controller



Computer Process Control System





Section 6.1: Sensors

محول

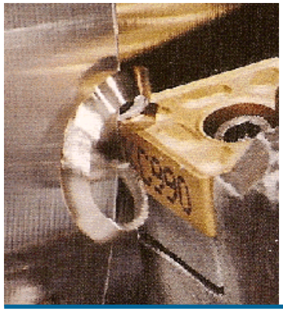
- A sensor is a transducer that converts a physical stimulus from one form into a more useful form to measure the stimulus

مُحَفِّز

* convert natural phenomena to physical quantity

Sensor categories by stimulus

Stimulus	Example
Mechanical	Positional variables, velocity, acceleration, force, torque, pressure, stress, strain, mass, density
Electrical	Voltage, current, charge, resistance, conductivity, capacitance
Thermal	Temperature, heat, heat flow, thermal conductivity, specific heat
Radiation	Type of radiation (e.g. gamma rays, x-rays, visible light), intensity, wavelength
Magnetic	Magnetic field, flux, conductivity, permeability
Chemical	Component identities, concentration, pH levels, presence of toxic ingredients, pollutants



Section 6.1: Sensors

(Analog) continuous

Discrete

- Sensors can be classified into two basic categories:

1. Analog (continuous)

   Examples: thermocouple, strain gauges, potentiometers.

2. Discrete

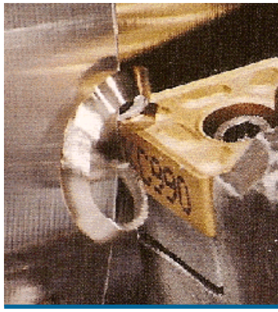
   Binary (on/off)

   Examples: Limit switch, photoelectric switches.

   Digital (e.g., pulse counter)

   Examples: photoelectric array, optical encoder.

[انظمة التبريد المفاعلات النووية] → Needs High Sensetivity



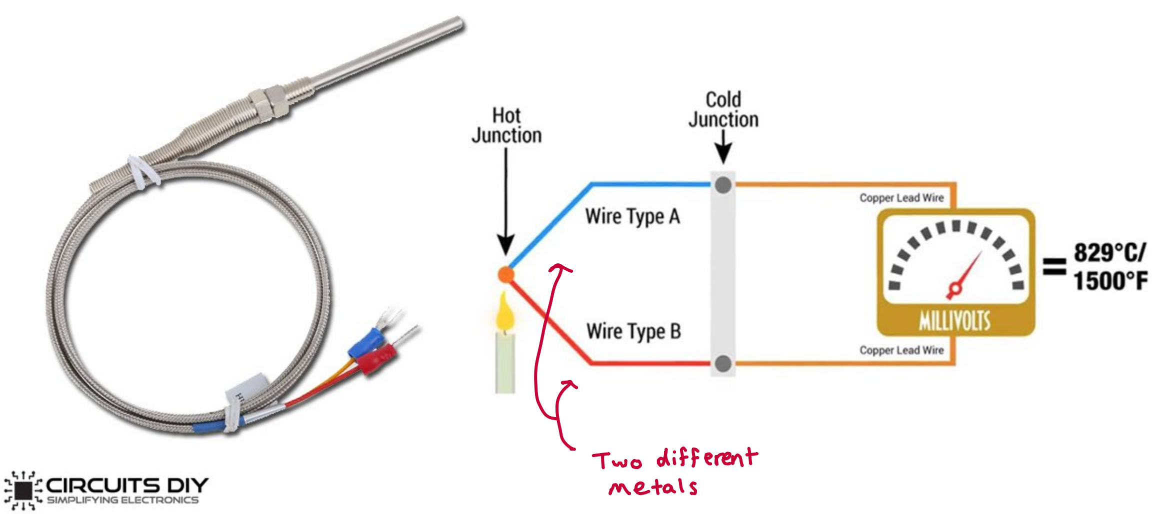
Section 6.1: Sensors

→ Application dependent device

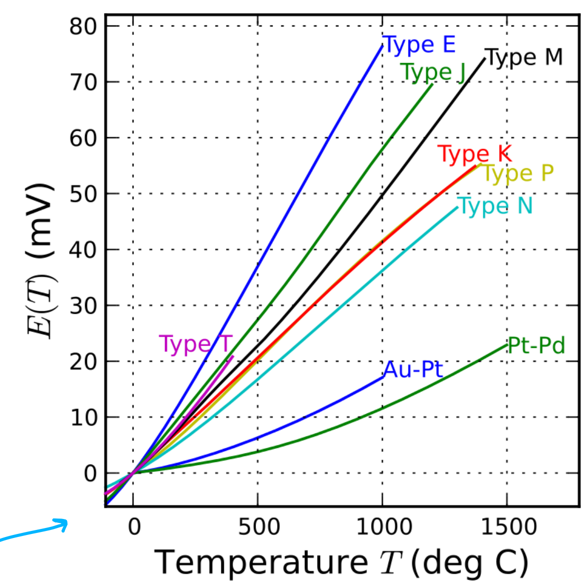
- Thermocouple: Analog temperature-measuring device based on thermoelectric effect.

*the most important characteristic of a sensor is the Linear relationship between inputs and outputs

Thermocouple How it Works

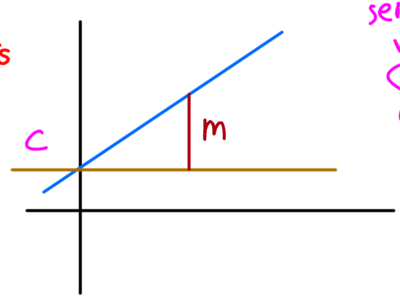


Two different metals



العلاقة Linear [T vs E(T)]

* I can't do Linearization
it will reduce the Reliability of the sensors



sensitivity

$\delta = c + ms$

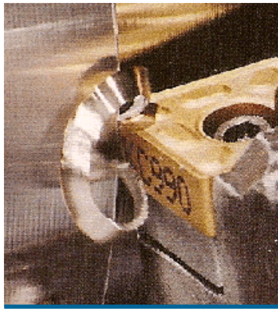
proportional sensitivity

when $c=0$

pure Linear

* Differences :-

- Responsiveness is effected by:
- How accurate is the Linearity
- Temperature Range
- Accuracy → depends on the sensitivity



Section 6.1: Sensors

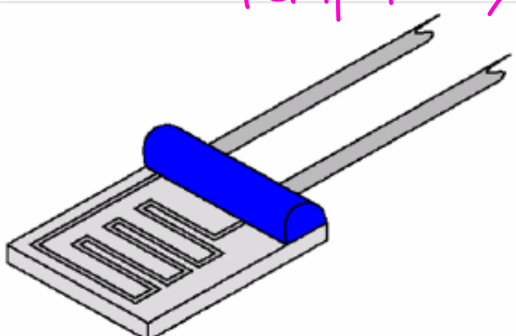
RTD

- Resistance-temperature detector: Analog temperature measuring device based on increase in electrical resistance of a metallic material as temperature increases.

made from Metal (Like Thermocouples)

علاقة طردية ↑ ↑

temp ↑ ⇒ R ↑



$R = \rho \frac{L}{A}$

RTD (Resistance Temperature Detector)

→ RTD → metal → Linear relationship

→ Thermistor → semiconductor → inverse relationship

Feature	RTD	Thermocouple
Measuring range	-200 Celsius (C) to +850 C	-250 Celsius (C) to +1800
Accuracy	Accuracy up to 1 degree C is typical	Accurate, from 2-4 degrees C is typical
Sensitivity	Very good and high sensitivity	Low sensitivity
Response time	Slower typically from 1 to 7 seconds	Fast <= 0.1 seconds is typical

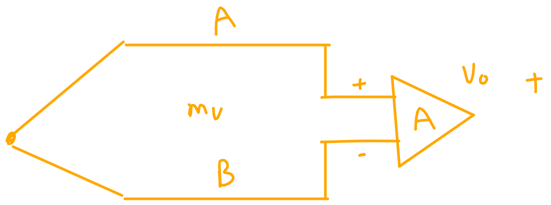
موقع (Google)

Platinium RTDs

$V = IR$

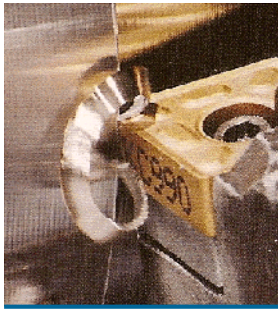
signal conditioning surface

Deffrential Amplifier



$V_o = A(V_+ - V_-)$

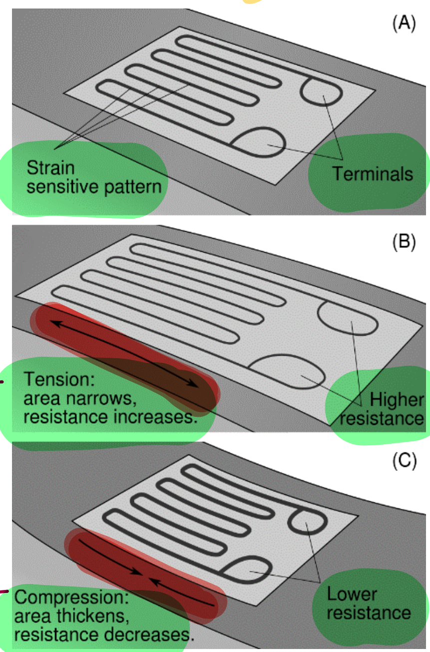
أي سلك بالعالم ← له مقاومة



Section 6.1: Sensors

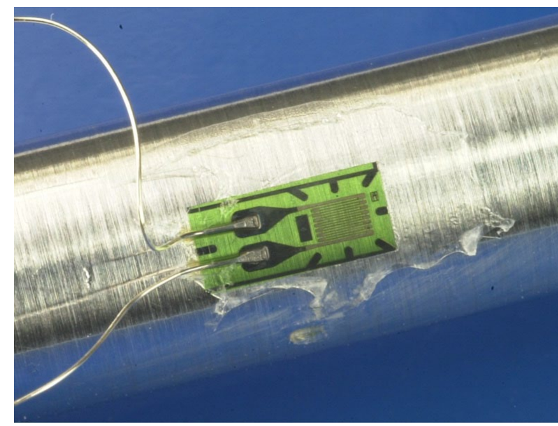
- strain gauges: Widely used analog sensor to measure force, torque, or pressure.

F τ P



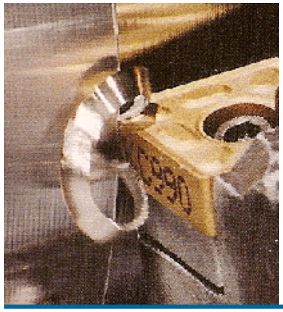
Tension
$A\downarrow \cdots\cdots R\uparrow$

Compression
$A\uparrow \cdots\cdots R\downarrow$



$$R = \frac{\rho L}{A}$$

Discrete sensor



Section 6.1: Sensors

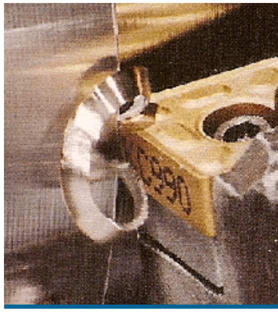
sensor output: voltage signals or change in signals

electrical signals = voltage signals

- Limit switch (mechanical): Binary contact sensor in which lever arm or pushbutton closes or opens an electrical contact.

digital sensors

Digital sensors

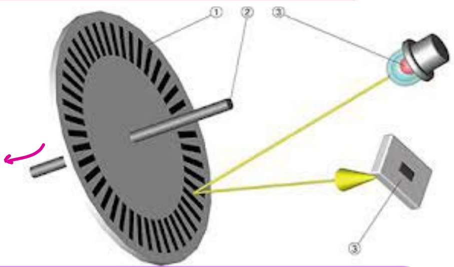


Section 6.1: Sensors

نستعمله غالباً لقياس سرعة ال motor

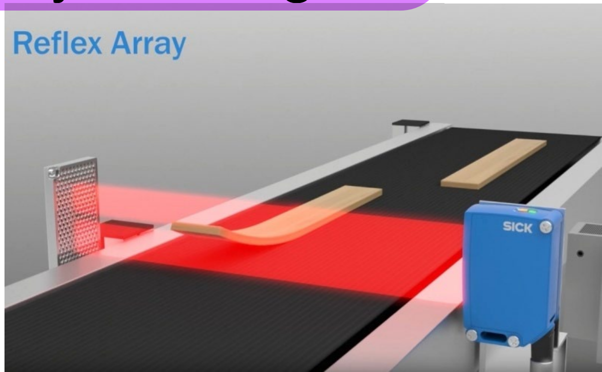
- Optical encoder: Digital device used to measure position and/or speed, consisting of a slotted disk separating a light source from a photocell.

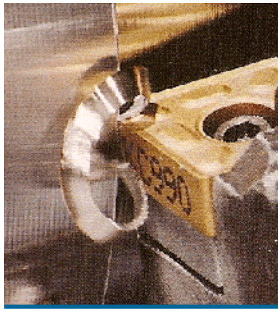
gives us indication on the revolution per minute



نستخدمه لقراءة ال Barcode

- Photoelectric sensory array: Digital sensor consisting of linear series of photoelectric switches. Array is designed to indicate height or size of objects.





Input/output relation of Sensors

stimulus

$$S = \underbrace{f}_{\text{functional relationship}}(s)$$

output signal

where S = output signal; s = stimulus; and *f(s)* = functional relationship

For binary sensors: $S = 1$ if $s \geq 0$ and $S = 0$ if $s \leq 0$.

The ideal functional form for an analogue measuring device is a simple proportional relationship, such as:

$$S = C + ms$$ ← Linear Relationship

where C = output value at a stimulus value of zero

and m = constant of proportionality (sensitivity)

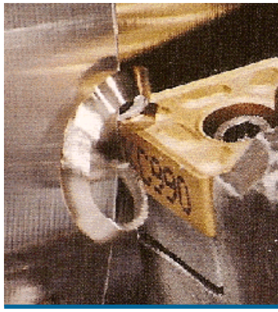
$$\boxed{S = C + ms}$$

output signal

output value at a stimulus value of zero (constant offset)

constant of Proportoinality (sensetivity) slope, determines the relationship between S and s

stimulus



Example

- The output voltage of a particular thermocouple sensor is registered to be 42.3 mV (S) at temperature 105°C (s). It had previously been set to emit a zero (C = 0) voltage at 0°C.

  $V=0$ @ $T=0 \Rightarrow C=0$

- Determine

  $m = \frac{42.3\ mV}{105\ °C} = 0.4 \Longrightarrow S = 0.4\,s$ (Voltage, Temperature)

  $S = c + ms$

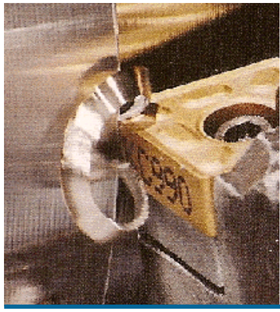
  (1) the $\boxed{\text{transfer function}}$ of the thermocouple, and

  (2) the temperature corresponding to a voltage output of 15.8 mV.

$\boxed{s = \ldots °C}$

$\boxed{S = Tf}$

$\boxed{Tf = \frac{V_{out}}{V_{in}}}$



Solution

$$S = C + ms$$

Voltage Output

constant (at T=0°C)

slope

Temperature

- (1)

  42.3 mV = 0 + m(105°C) = m(105°C)

  or m = 0.4028571429

  Transfer Function

  S = 0.4 (s)

- (2)

  Temperature

  15.8 mV = 0.4 (s)

  15.8 / 0.4 = s

  s = 39.22°C

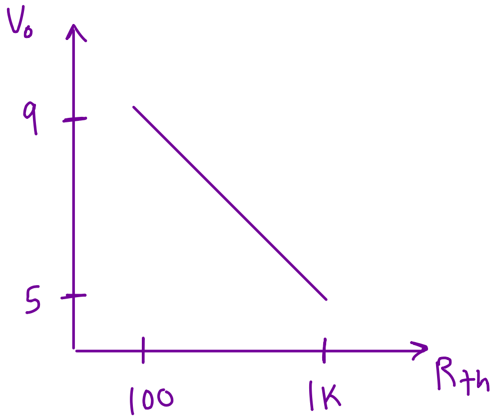
* Lets say

$V_s = 10\,v$ $\quad R = 1\,K\Omega$

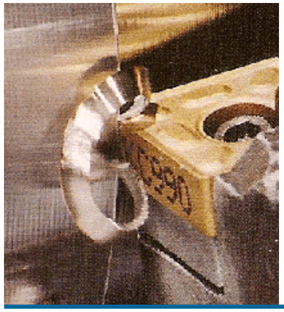
$$V_{out}(R_{th} = 100\,\Omega) \approx 9\,v$$

$$V_{out}(R_{th} = 1\,K\Omega) \approx 5\,v$$

$$R_{th} \left.\begin{matrix}1\,K\Omega \\ \\ 100\,\Omega\end{matrix}\right] \longrightarrow V \left.\begin{matrix}5\,V \\ \\ 9\,V\end{matrix}\right]$$



Linear Amplifier :- *easier for calculations
*track the accuracy



Sensor Signal Conditioning Circuits

To make the Signal Larger if it was too small
(when the output is very small (mv), so we use an amplifier to enlarge the signal)

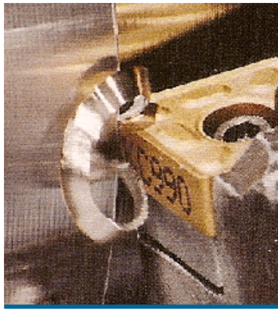
تكييف الإشارة

- Signal conditioning is an electronic circuit that manipulates a signal in a way that prepares it for the next stage of processing.

الغرض الوحيد

- The sole purpose of signal conditioning is to take the signals from the sensors and prepare them for further processing.

- https://www.youtube.com/watch?v=HSHJXXFigz8



Example: Temperature Measuring Voltage Divider

indoor invironment

owms Law

$\boxed{V = I \times R}$

Voltage Divider Circuit

$$V_o = V_s \times \frac{R}{R + R_{TH}}$$

$V = IR$

$I = \frac{V_s}{R_{th} + R}$

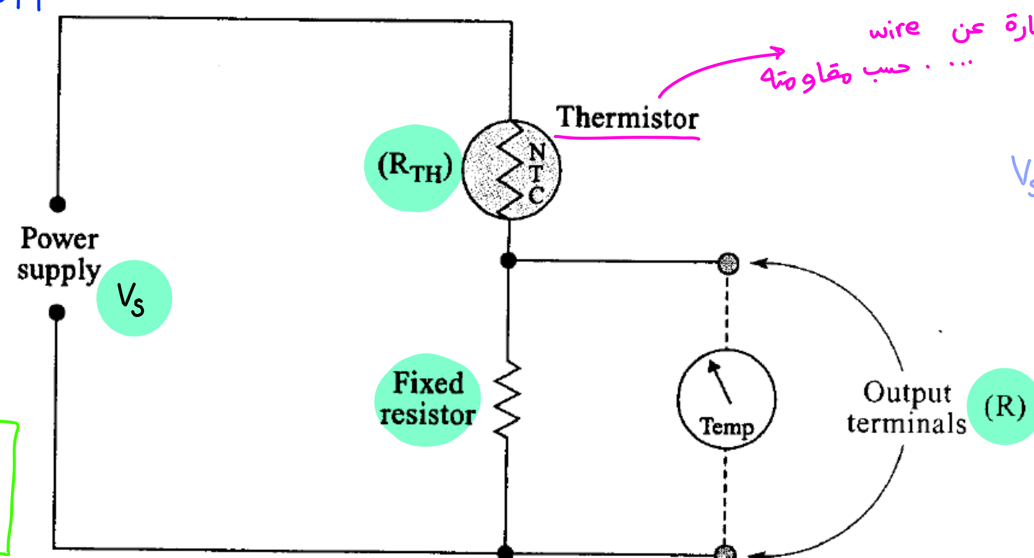
$V_{R_{Th}} = (R_{Th}) \times \left(\frac{V_s}{R_{th}+R}\right)$

$= V_s \frac{R}{R_{th} + R_L}$

$V_o = V_s \frac{R}{R_{Th} + R}$

عبارة عن wire

... . حسب مقاومته



$V_s = V_1 + V_2$

$= IR_{th} + IR$

$= I(R_{th} + R)$

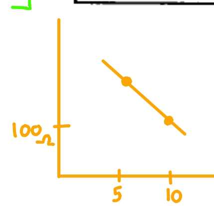
Thermistor — Signal controller

1KΩ

100Ω

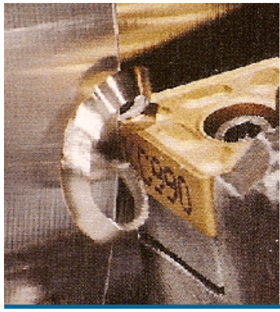
$V_o\big|_{10} = 10 \times \frac{10}{10 \times 100} = 5\ v$

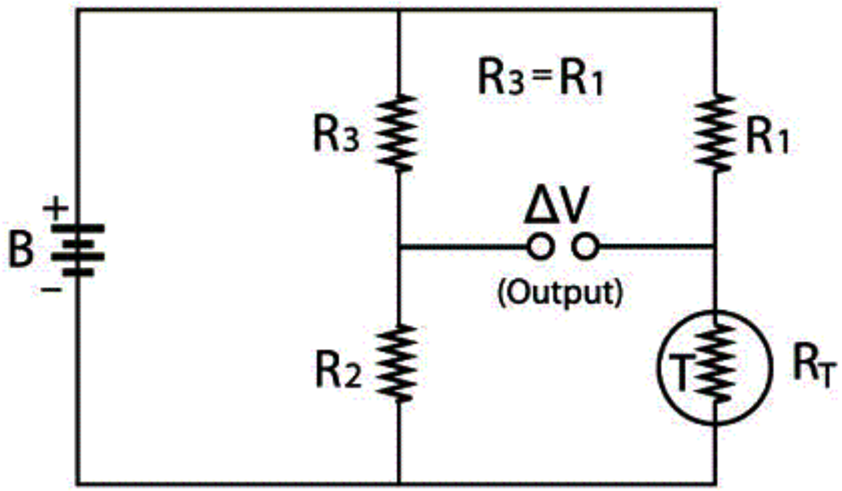
في غلط



$V_o\big]_{100\Omega} = \frac{10 \times 1\ K\Omega}{1.1\ K\Omega}$

Example: Temperature Measuring Wheatstone Bridge





$$\Delta V = V_2 - V_1$$
$$= E\left(\frac{R_2}{R_2+R_3} - \frac{R_T}{R_T+R_1}\right)$$

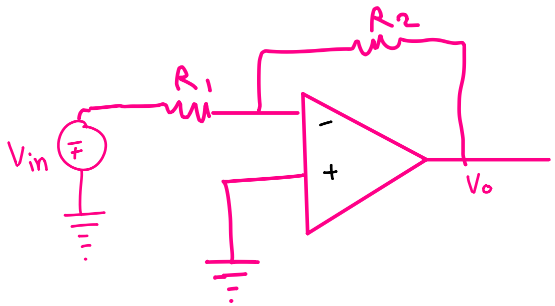
$$\Delta V = E\left(\frac{R_2}{R_2+R_3} - \frac{R_T}{R_1+R_T}\right)$$

Assume R1 = R3. Then,

$$\Delta V = E\left(\frac{R_2}{R_1+R_2} - \frac{R_T}{R_1+R_T}\right)$$

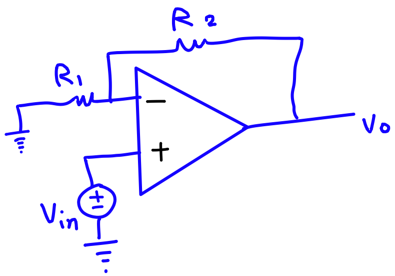
يهمنا الـ Transfer Function
فقط و ليس المكونات و هكذا

Inverted Amplifier



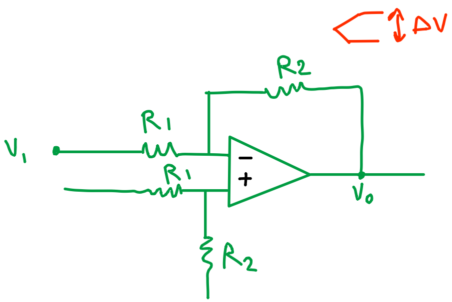
$$\text{Transfer function} \Longrightarrow \boxed{\frac{V_o}{V_{in}} = -\frac{R_2}{R_1}}$$

Non-Inverting Amplifier

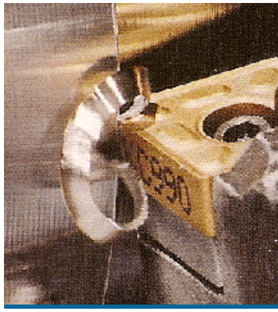


$$\text{Transfer function} \Longrightarrow \boxed{\frac{V_o}{V_{in}} = 1 + \frac{R_2}{R_1}}$$

Deffrential Amplifier



$$\text{Transfer function} \Longrightarrow \boxed{\frac{V_o}{V_{in}} = \frac{R_2}{R_1}(V_2 - V_1)}$$



Section 6.2: Actuators

المحركات

it is the muscle of the control system (move/open/close)

- Actuators: are hardware devices that convert a controller command signal into a change in a physical parameter.

يعتمد على الوظيفة يلي بدي اياها

- The change is usually mechanical (e.g., position or velocity).
- An actuator is also a transducer because it changes one type of physical quantity into some alternative form (e.g. electric current to rotational speed of electric motor).

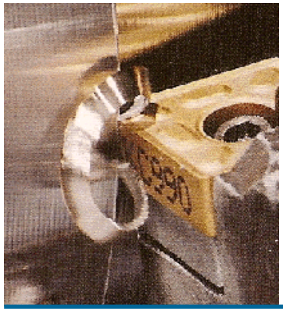
in terms of motion: Linear / Rotatory

in terms of source of energy :-

Pneumatic / hydrolic / electrical

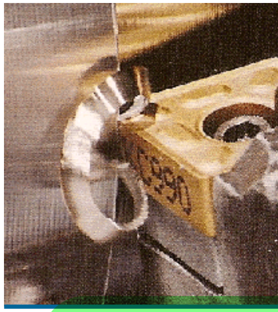
compressed air / fluid / electrical energy

راح يتحولو الى Mechanical Energy



Section 6.2: Actuators

- https://www.youtube.com/watch?v=LHn7O6PUaoY



Types of Actuators

- **Electrical actuators:**
  - Electric motors (linear or rotational)
    (Piston) (valves)
  - DC servomotors
  - AC motors
  - Stepper motors
  - ملفات لولبية
    Solenoids
  - Relay

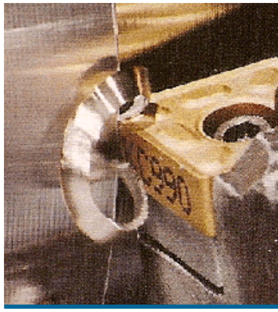
- **Hydraulic actuators:** converts types of energy

  such as oil/Liquids

  Use hydraulic fluid as the driving force

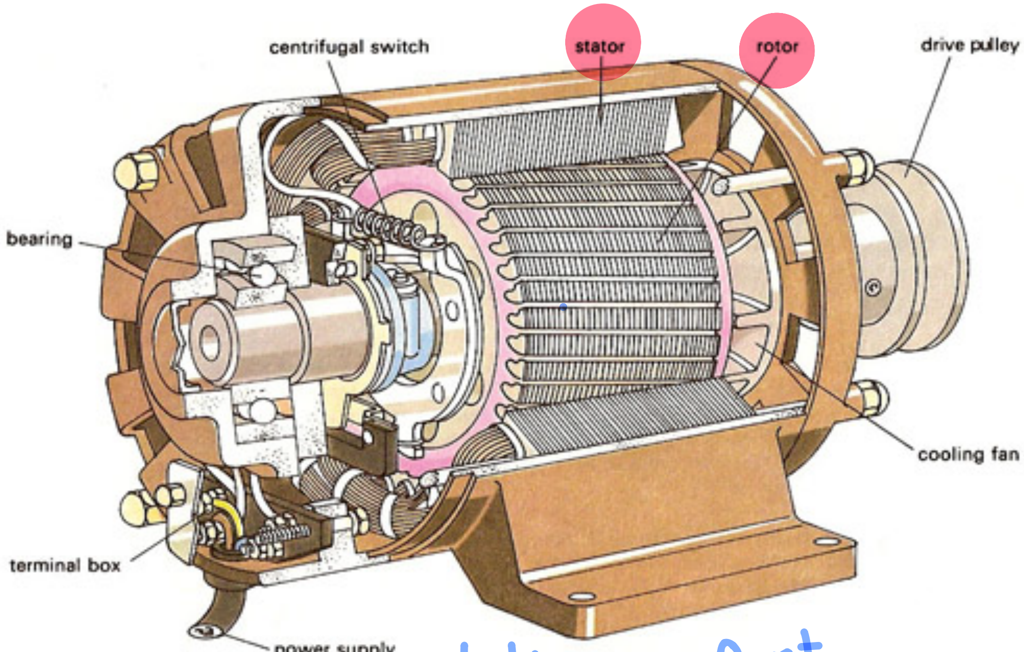
- **Pneumatic actuators:** المحركات الهوائية:

  Use compressed air as the driving force



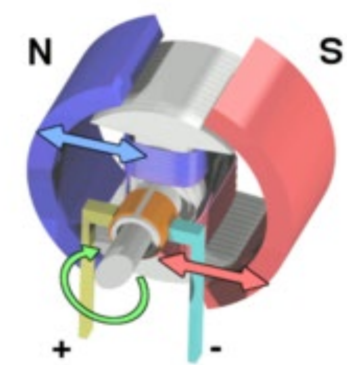
Electric motors

(Actuator)



Stationary Part

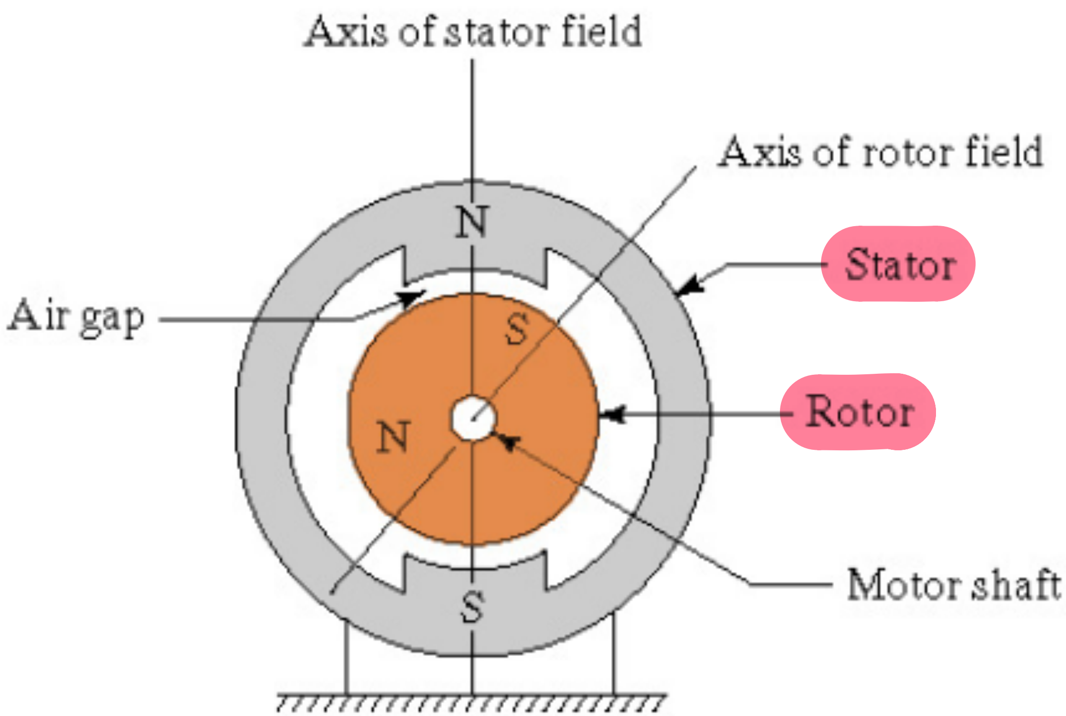
Rotatory Part

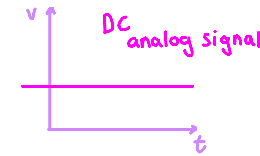


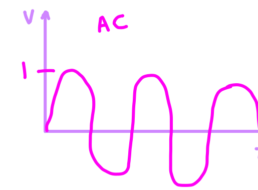
تمرير تيار كهربائي بالـ (2 parts) ← راح يولد مجال مغناطيسي

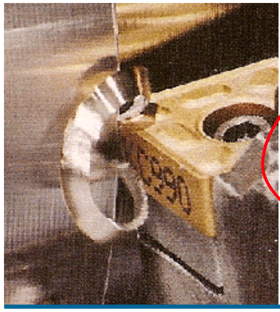
[التنافر بالأقطاب بين الـ Stationary part و الـ Rotatory part هو الذي يسبب الحركة لـ motor الـ (Actuating)]

A Rotating Electric Motor





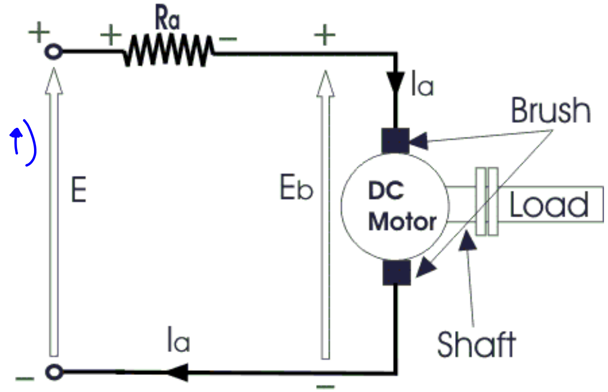




DC motors

Direct Current Motor

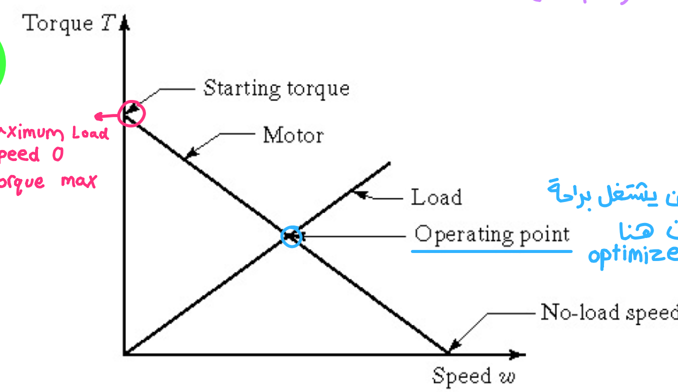
(Voltage ↑)
(magnetic field strength ↑)
(Repulsion ↑)
(motor speed ↑)



Rotational Energy (output)

- DC motors are widely used:
  - Convenience of using direct current.
  - E.g. motors in automobiles.
  - Linear Torque-Speed relationship.

example : electrical cars
hybrid cars
مساحات السيارة
المروحة

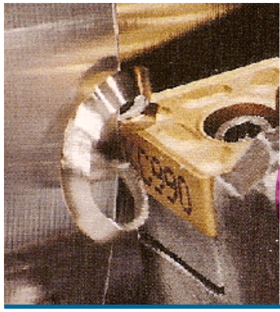


Maximum Load
speed 0
Torque max

عشان يشتغل براحة
يكون هنا
optimize

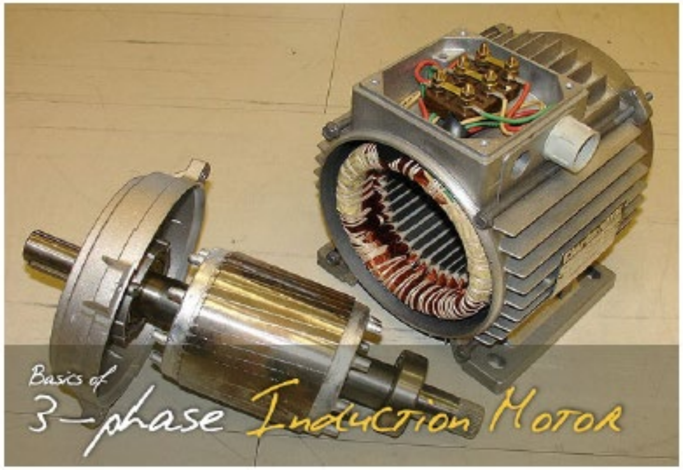
The Relationship between variables must be Linear

- One special type of DC motors is *Servomotors*. A feedback back loop is used to control speed.



AC motors

example → water motors used in home

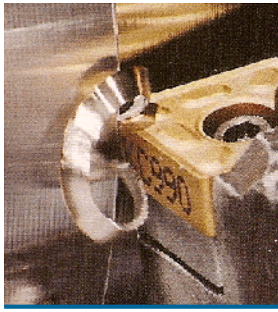


- Most used in industry.
- Advantages:
  - Higher power supply
  - Ease of maintenance
- Two types:
  - Induction motor محرك الحث
  - Synchronous motor محرك متزامن

high input and output energy
hard to change
for portable applications

input = pulses

Acctuators
تعتمد بشكل كبير على applications



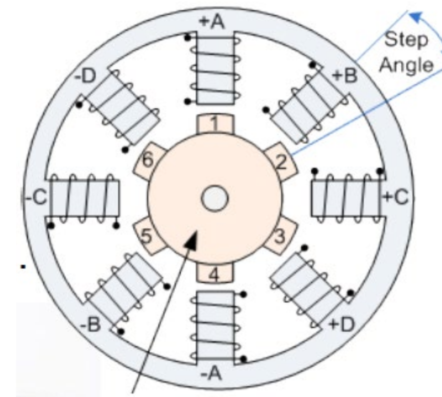
Digital Signals

Stepper Motors

→ CNC machine

→ we can use it in open Loop

- Provides rotation in the form of discrete angular displacement (step angles).
- Each step angle is actuated by a discrete electrical pulse.
- Are used in open loop control systems.



4 phases = 8 polar motor

راح اتحرك بمقدار ال step

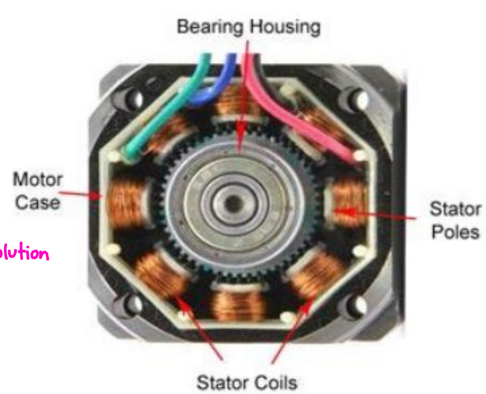
each step = 15°

4 steps = 4 x 15 = 60

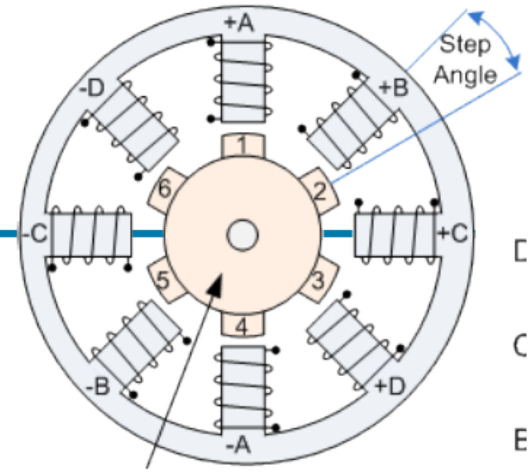
$\frac{360}{15}$ = 24 pulses to move one revolution

Steps ↑

Accuracy ↑



Stepper Motors



Step angle is given by: : $$\alpha = \frac{360}{n_s}$$

step angle

number of steps for the stepper motor

where n_s is the number of steps for the stepper motor (integer)

Total angle through which the motor rotates (A_m) is given by: $$A_m = n_p \alpha$$

where n_p = number of pulses received by the motor.

Total angle at which the motor rotates

number of pulses received by the motor

Angular velocity is given by: $$\omega = \frac{2\pi f_p}{n_s}$$

pulse frequency

Angular velocity

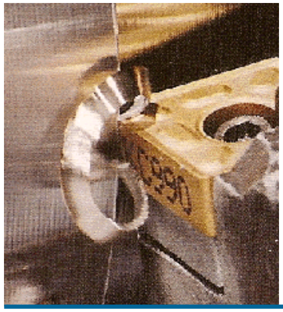
where f_p = pulse frequency

Speed of rotation is given by: $$N = \frac{60 f_p}{n_s}$$

to convert from rpm to $\frac{rev}{sec}$

speed of Rotation

$$\text{Stepper motor speed} = \frac{\text{Pulse rate of the stepper motor}}{\text{Motor step per revolution}}$$



Example

- A stepper motor has a step angle α = 3.6°.

  (1) How many pulses are required for the motor to rotate through ten complete revolutions?

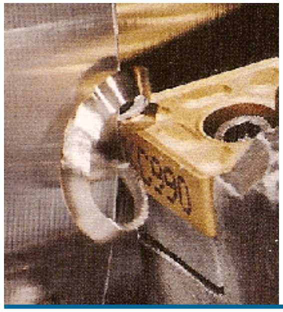
  n_p ??

  $A_m = 10 \times 360 = 3600$

  (2) What pulse frequency is required for the motor to rotate at a speed of 100 rpm (rev/min)?

  f_p ??

  $N = 100$ rev/min



Solution

$$\alpha = \frac{360}{n_s}$$

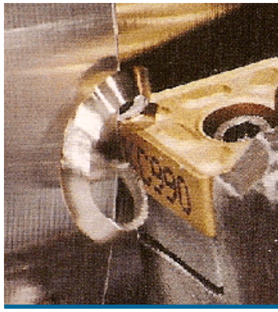
$$A_m = n_p \alpha$$

$$N = \frac{60 f_p}{n_s}$$

$3.6° = 360 / n_s$; $3.6° (n_s) = 360$; $n_s = 360 / 3.6 = 100$ step angles

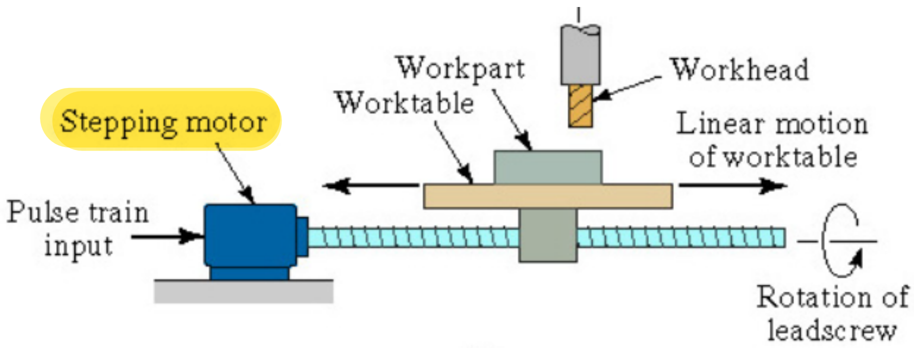
(1) Ten complete revolutions: $10(360°) = 3600° = A_m$
Therefore $n_p = 3600 / 3.6 = 1000$ pulses

(2) Where $N = 100$ rev/min:
$100 = 60 f_p / 100$
$10{,}000 = 60 f_p$
$f_p = 10{,}000 / 60 = 166.667 = 167$ Hz

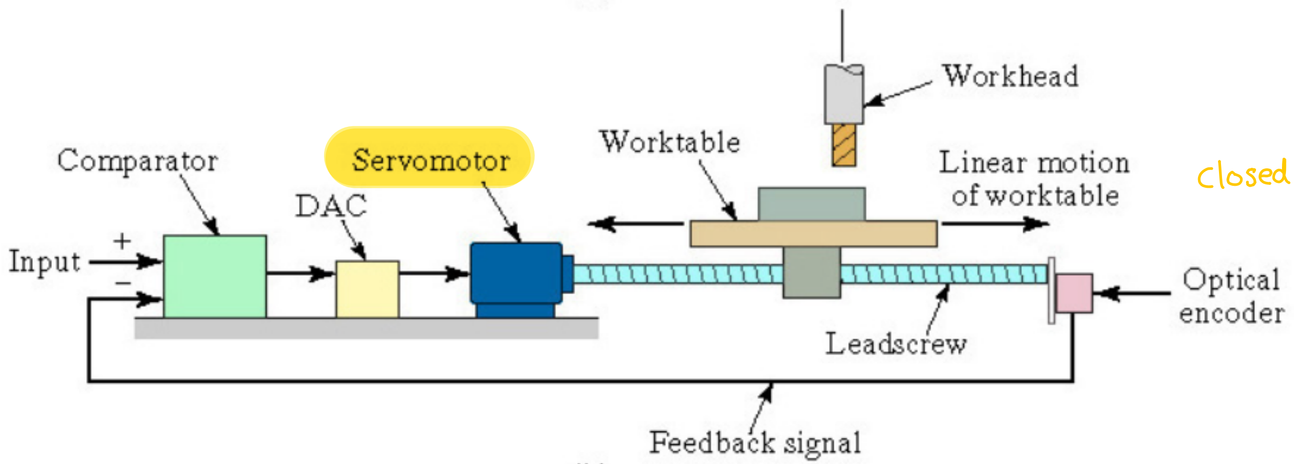


Stepper motor and Servomotor

closed Loop

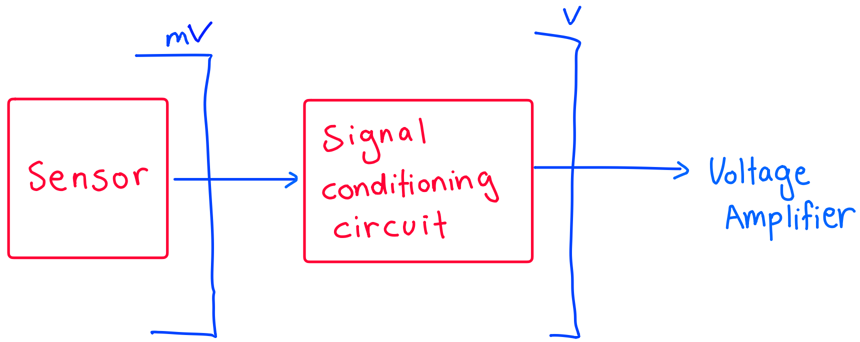


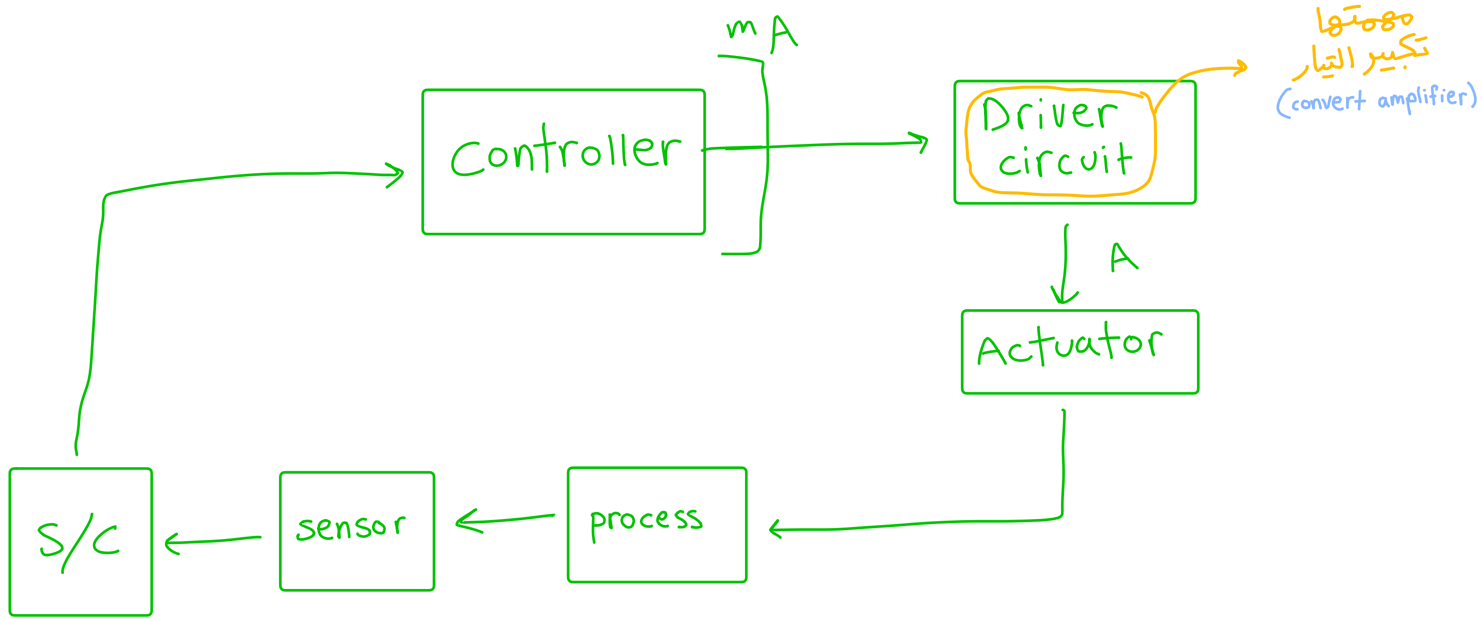
open loop

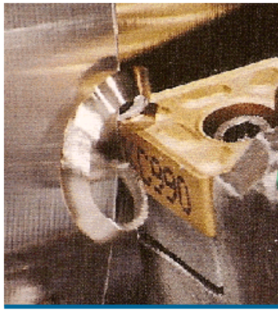


closed loop

أي device بيعطيني Torque

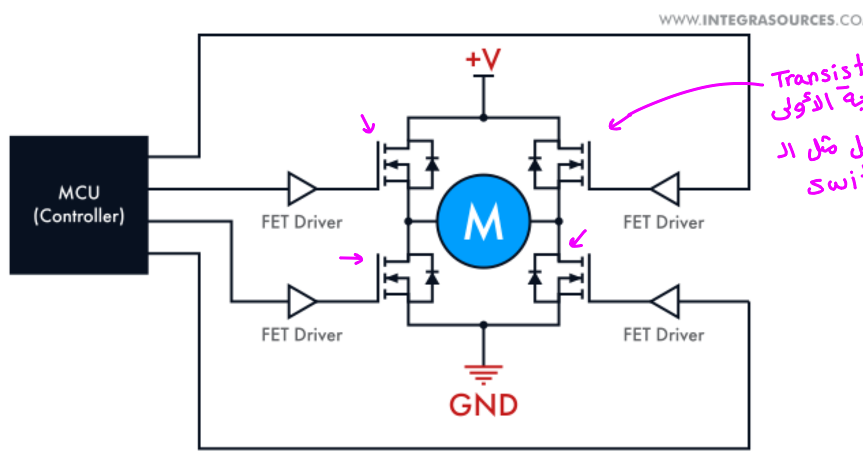






Driver Circuits for Actuators

- In electronics, a driver is a circuit or component used to control another circuit or component.
- يمكن أن يوفر ما يكفي
  Actuators need driver circuits that can furnish enough current to operate them.
- Example: H –bridge driver for DC motor.



Transistors
بالدرجة الأولى
و يستعمل مثل ال
switch

Electromagnitic Acctuation

Types
- Electrical
- Hydrolical
- Pneumatical

الملف اللولبي

Solenoid

Action: on / off

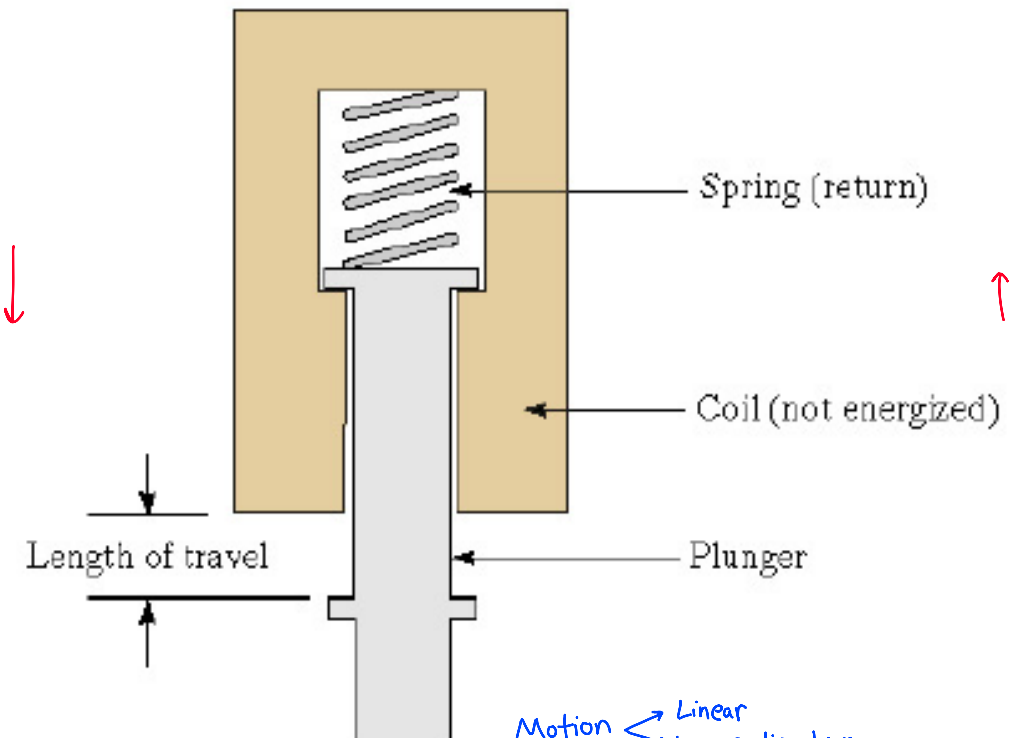
Digital Linear Acctuation

(Digital Actuator) Linear

⟹ Linear Actuator

Forword ↓

↑ backward



Motion: Linear, in one direction

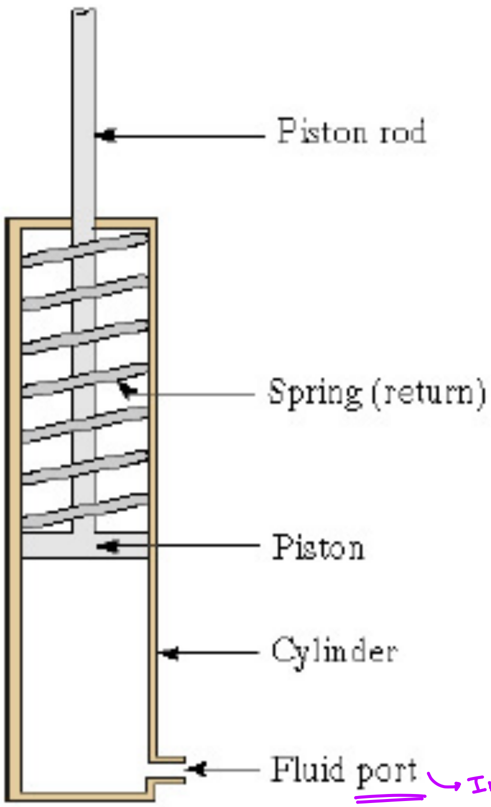
Cylinder and Piston: (a) Single-Acting and (b) Double-Acting

*safer

Linear Actuator

Compressed air

(a)



Input Output

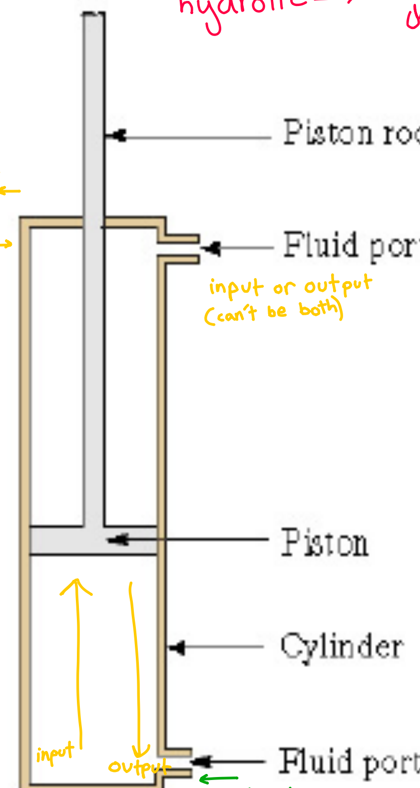
single at...

hydrolic → يمكن التحكم به بشكل أفضل

Hydrolic

(b)

⇐ سهم باتجاهين



input

output

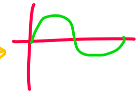
input or output (can't be both)

input

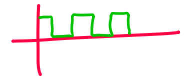
output

input or output (can't be both)

Hydrolic (more precise) I can control the way of the flow



اشارة اما positive و اما negative



[Sampling, Quantization, Encoding]

Analog-to-Digital Conversion

Sampling ↑
Charactarestics ↑

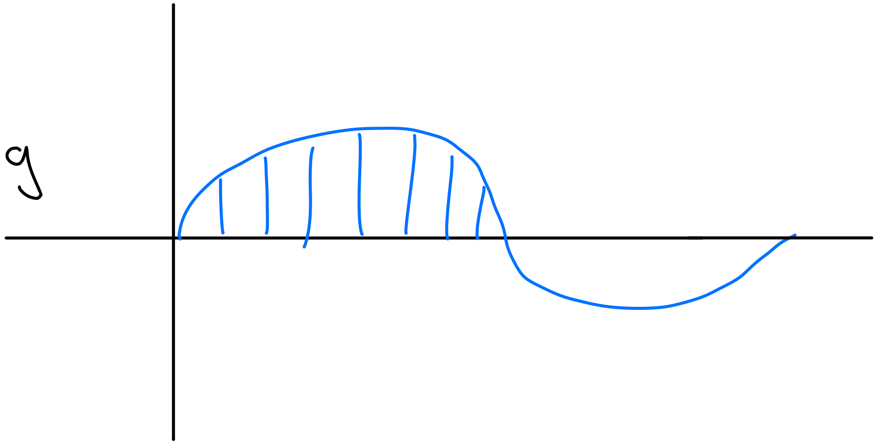
An ADC converts a continuous analog signal from transducer into digital code for use by computer

sometimes it is built in the device

- ADC consists of three phases:
  1. Sampling – converts the continuous signal into a series of discrete analog signals at periodic intervals
  2. Quantization – each discrete analog is converted into one of a finite number of (previously defined) discrete amplitude levels
  3. Encoding – discrete amplitude levels are converted into digital code

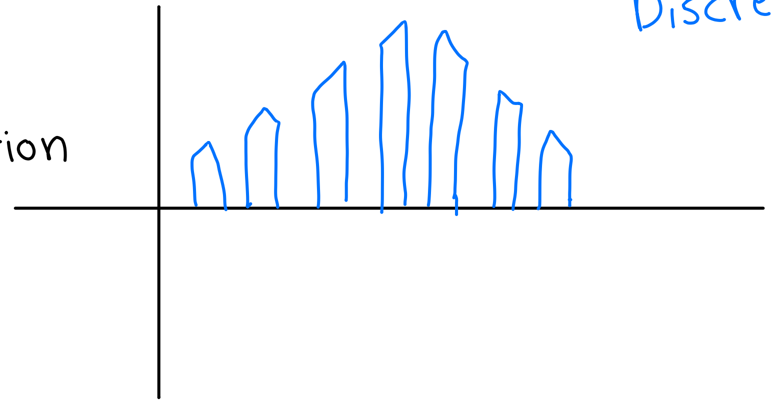
Discrete Signal

Sampling



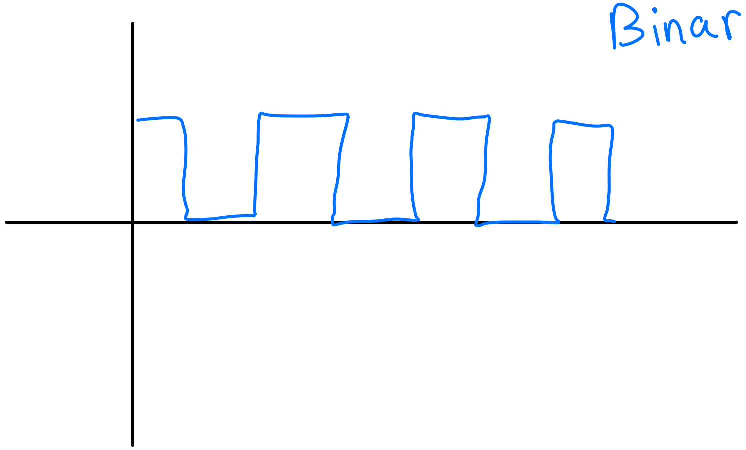
Quantization

Discrete



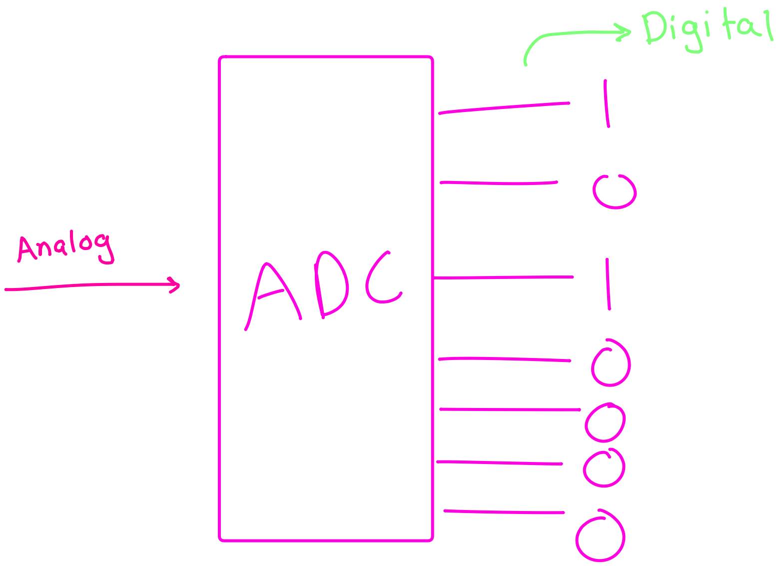
Encoding

Binary



$(5)_{10} \longrightarrow (00000101)_2$

LSB → Least Significant Bit



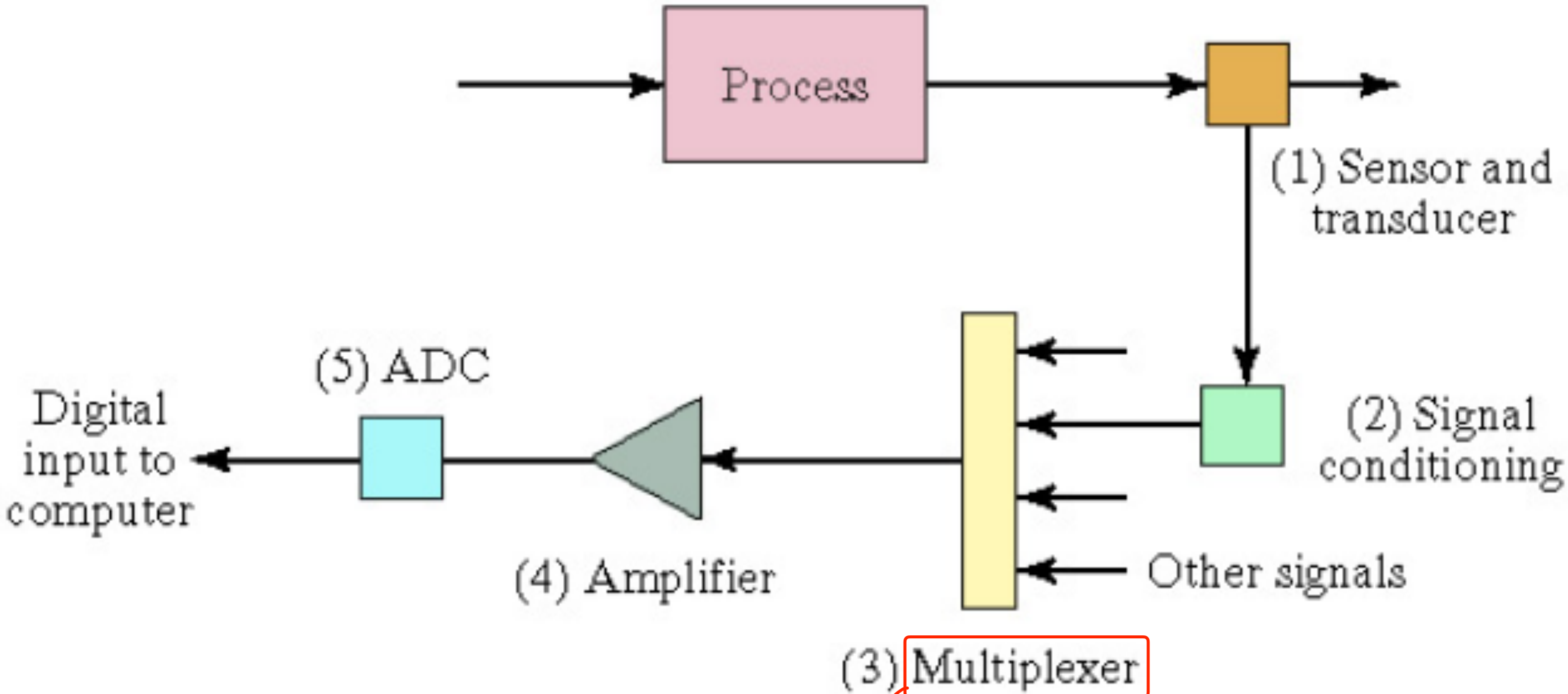
MSB → Most Significant Bit

$(5)V \longrightarrow 000000101$

$(9)V \longrightarrow 0001001$

$(15)V \longrightarrow 0001111$

Hardware Devices in Analog-to-Digital Conversion



multiple input and single output

Features of an ADC

- Sampling rate – rate at which continuous analog signal is polled

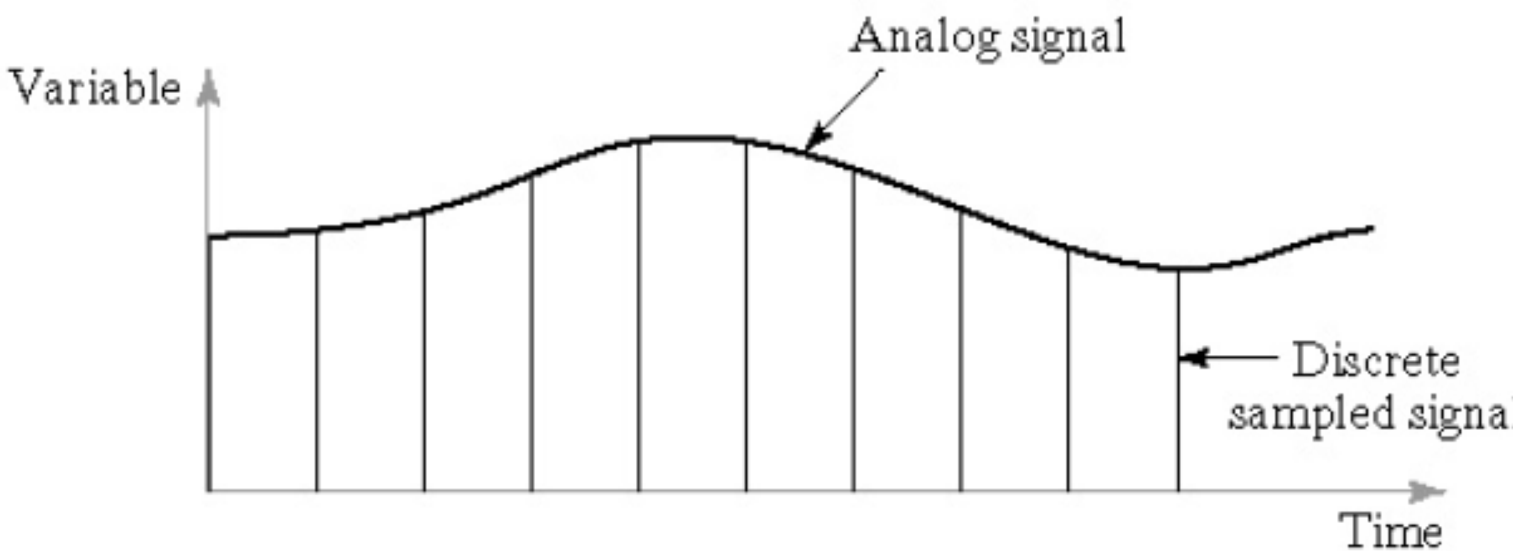
يعبر عن ال Sample frequence

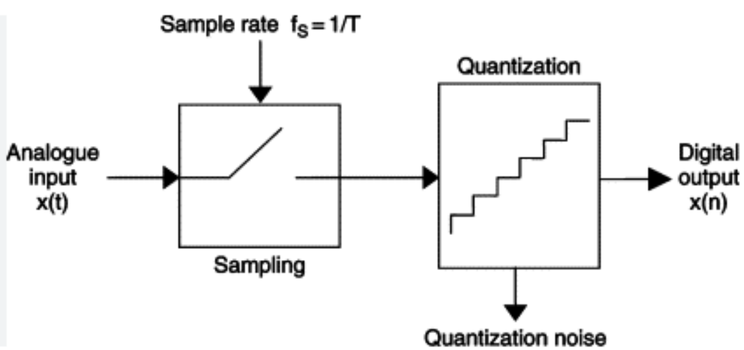
وفي علاقة

- Conversion time – how long it takes to convert the sampled signal to digital code
- Resolution – depends on number of quantization levels
- Conversion method – means by which analog signal is encoded into digital equivalent
  - Example – Successive approximation method

ADC Method

Analog Signal Converted into a Series of Discrete Data by A-to-D Converter





input voltage $>$ reference voltage $\Rightarrow$ 1
input voltage $<$ reference voltage (trial) $\Rightarrow$ 0

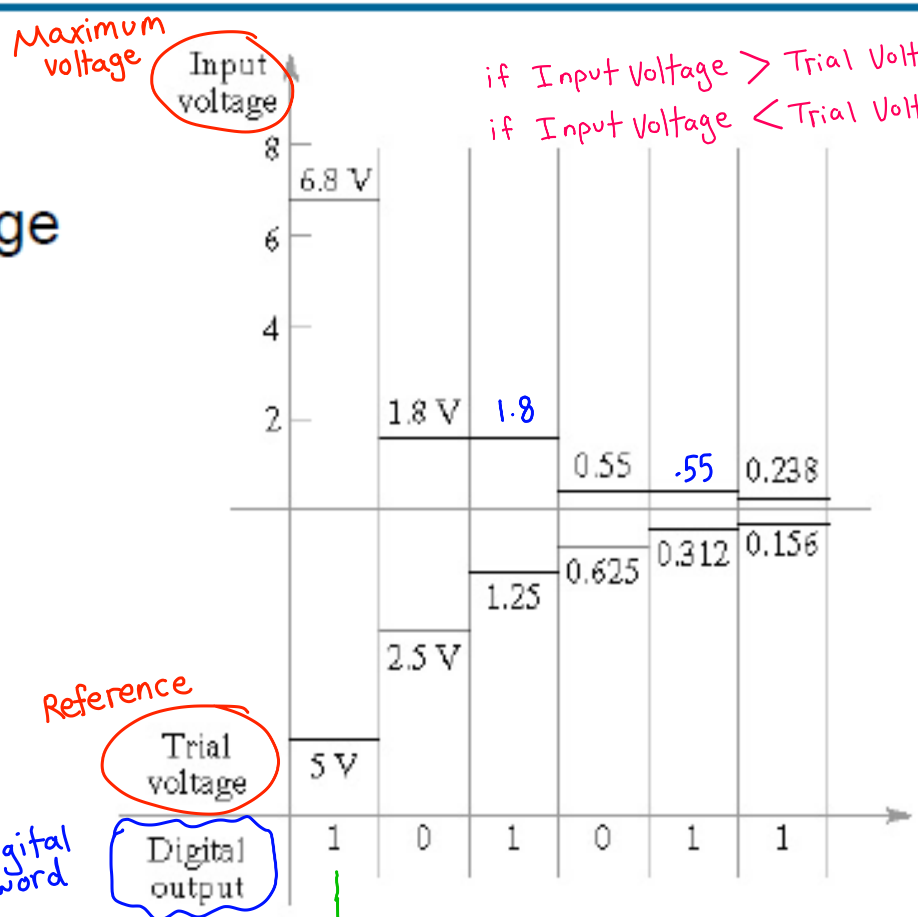
Successive Approximation Method

- A series of trial voltages are successively compared to the input signal whose value is unknown
- Number of trial voltages = number of bits used to encode the signal
- First trial voltage is 1/2 the full scale range of the ADC
- If the remainder of the input voltage exceeds the trial voltage, then a bit value of 1 is entered, if less than trial voltage then a bit value of zero is entered
- The successive bit values, multiplied by their respective trial voltages and added, becomes the encoded value of the input signal

Successive Approximation Method

Example for input voltage of 6.8 V

if Input Voltage > Trial Voltage ⟹ Digital output = 1
if Input Voltage < Trial Voltage ⟹ Digital output = 0

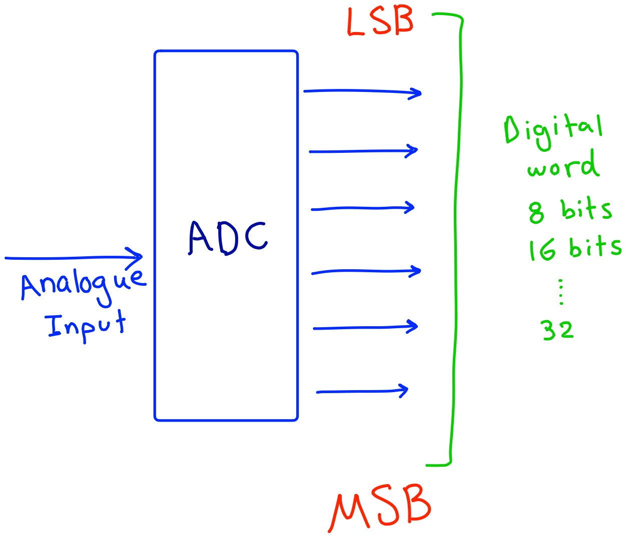


the wieght for it: 5x1

For six digit precision, the resulting binary digital value is 101011, which is interrupted as:

Trial voltage
1×5.0 V
0×2.5 V
1×1.25 V
0×0.625 V
1×0.312 V
1×0.156 V

Total = 6.718 V



كلما زاد عدد ال bits زادت ال Resolution
و الدقة

Digital word ↑

Resolution ↑

* (0000101)

DAC

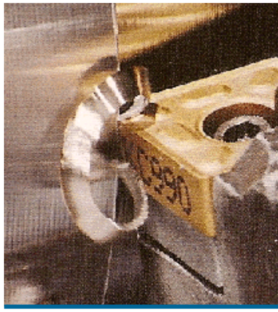
$2^2 + 2^0 = 4 + 1 = 5$

Maximum analog output → when all inputs are (1)

Digital-to-Analog Conversion

Converts the digital output of the computer into a continuous analog signal to drive an analog actuator (or other analog device)

- DAC consists of two steps:
  1. Decoding – digital output of computer is converted into a series of analog values at discrete moments in time
  2. Data holding – each successive value is changed into a continuous signal that lasts until the next sampling interval



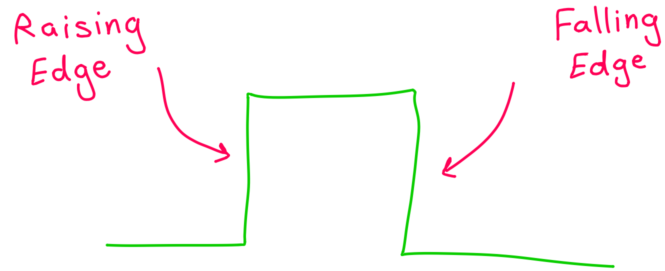
$(00000101)_2$ digital

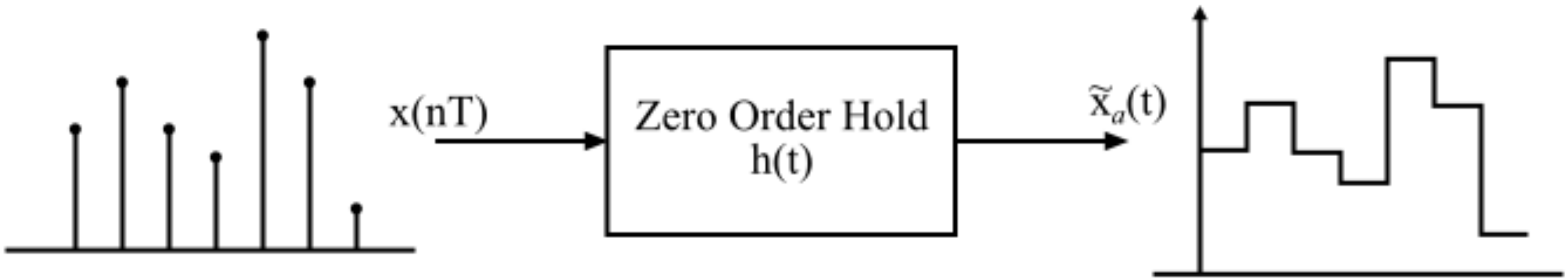
$\downarrow$

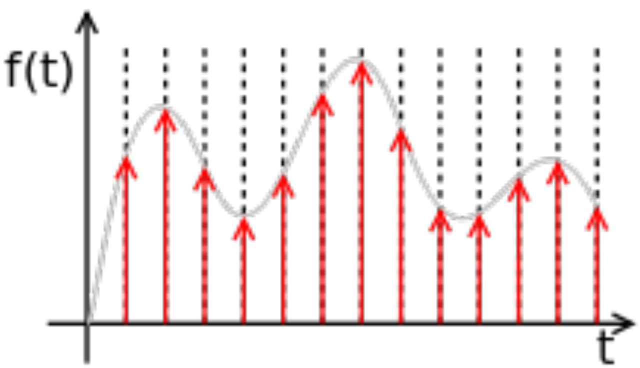
$+2^2+2^0 = 4+1 = (5)_{10}$ analog

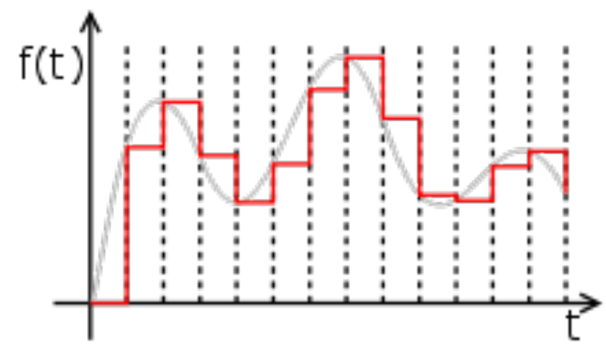
$V_{out} = VR(b_1 2^{-1} + b_2 2^{-2} + \ldots\ldots + b_n 2^{-n})$

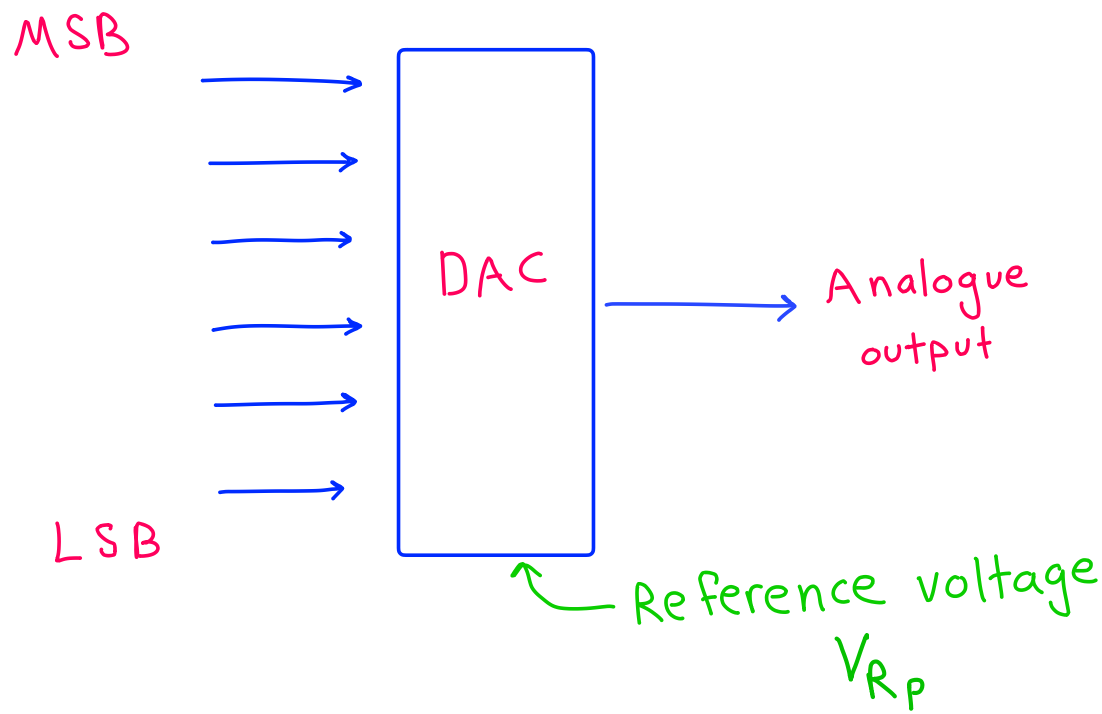
$n \rightarrow$ number of the bits










MSB
LSB
DAC
Analogue output
Reference voltage
V_{Rp}

* Example :-

Digital word 4 bits

$$V_{max} = V_R(2^{-1}+2^{-2}+2^{-3}+2^{-4})$$
$$= 0.9375\ V_R$$

* كلما زاد عدد ال bits
زاد ال Resolution
وقل ال weight لل bit الواحدة

Digital word = 8 bits

$$V_{max} = V_R(1\times2^{-1}+1\times2^{-3}+1\times2^{-4}+1\times2^{-5}+1\times2^{-6}+1\times2^{-6}+1\times2^{-7}+1\times2^{-8})$$
$$= 0.996\ V_R$$

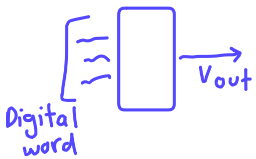
$$\boxed{V_{out} = \frac{N}{2^n} V_{ref}}$$

$(N)_{10}$ Decimal Value

$n \rightarrow$ number of the bits in the digital word

Vrefrence
بالعادة يساوي
ال Full scale

$(10100111)_2$



$V_{ref} = 5v$

$V_{out} = ???$

$\rightarrow$ 128 64 32 16 8 4 2 1

2 10

2 22

1 0 1 0 0 1 1 1

$N = (128\times1 + 32\times1 + 4\times1 + 2\times1 + 1\times1)$

$N = 167$

$V_{out} = \frac{167}{2^8} \times 5v = 3.2617\ V$

To Decimal

*from Past Papers

$\alpha = 1.5$

(9) A stepper motor has a step angle of 1.5 degree. Determine number of steps required for the shaft to make 10 revolutions.

(A) 3600.
$\boxed{\text{(B) 2400}}$
(C)1500
(D) Can't be determined.

$$\alpha = \frac{360}{n_s}$$

$$n_s = \frac{360}{1.5} = 240$$

$$240 \times \underset{\text{revolutions}}{10} = 2400$$

$N = 100\,rpm$

(10) In 9, what pulse frequency is required for the motor to rotate at a speed of 100 rpm (rev/min)?

$\boxed{\text{(A) 400 Hz.}}$
(B) 800 Hz.
(C) 200 Hz.
(D) 1200 Hz.

$$N = \frac{60 f_s}{n_s}$$

$$100 = \frac{60 \times f_s}{240}$$

$$f_s = \frac{24000}{60} = 400\ Hz$$

Automation

Chapter Nine:

Discrete Control Using Programmable Logic Controllers

Dr. Eng. Baha'eddin Alhaj Hasan
Department of Industrial Engineering

Chapter 9: Discrete Control

Sections:

1. Discrete Process Control
2. Ladder Logic Diagrams
3. Programmable Logic Controllers

PLC → (for discrete controllers)

2 States → 0 → ex: Low/off/.....
→ 1 → ex: High/on/.....

* غالباً -
0 → zero volt
1 → five volt

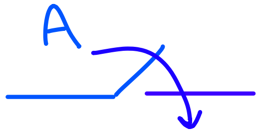
Sec 9.1: Discrete Process Control

- Continuous Control: deals with controlling continuous variables or parameters in the system.

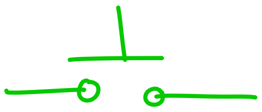
- Discrete Control: Control systems that operate on parameters and variables that change at discrete moments in time or at discrete events,
  - usually binary (0 or 1, off or on, open or closed, etc.)
  - Called also: switching systems.

Sensors and Actuators Used in Discrete Process Control

Sensors	Interpretation	Actuators	Interpretation
Limit switch	Contact/no contact	Motor ex: stepper motor	On/off
Photo-detector	On/off	Valve	Open/closed
Timer	On/off	Clutch	Engaged/not engaged
Push-button switch	On/off	Control relay	Contact/no contact
Control relay	Contact/no contact	Light	On/off
Circuit breaker	Contact/no contact	Solenoid	Energized/not energized



Normally Open switch (NO)

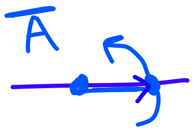


No pushbutton

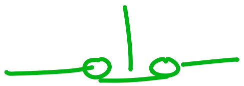
No switch

NO
normally open

Push button



Normally closed switch (NC)



NC push buttom switch

NC switch

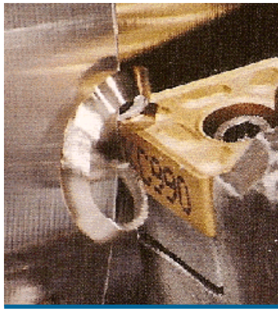
NC
normally closed

Push button

Categories of Discrete Control

- Logic control: event-driven changes
- Sequencing: time-driven changes

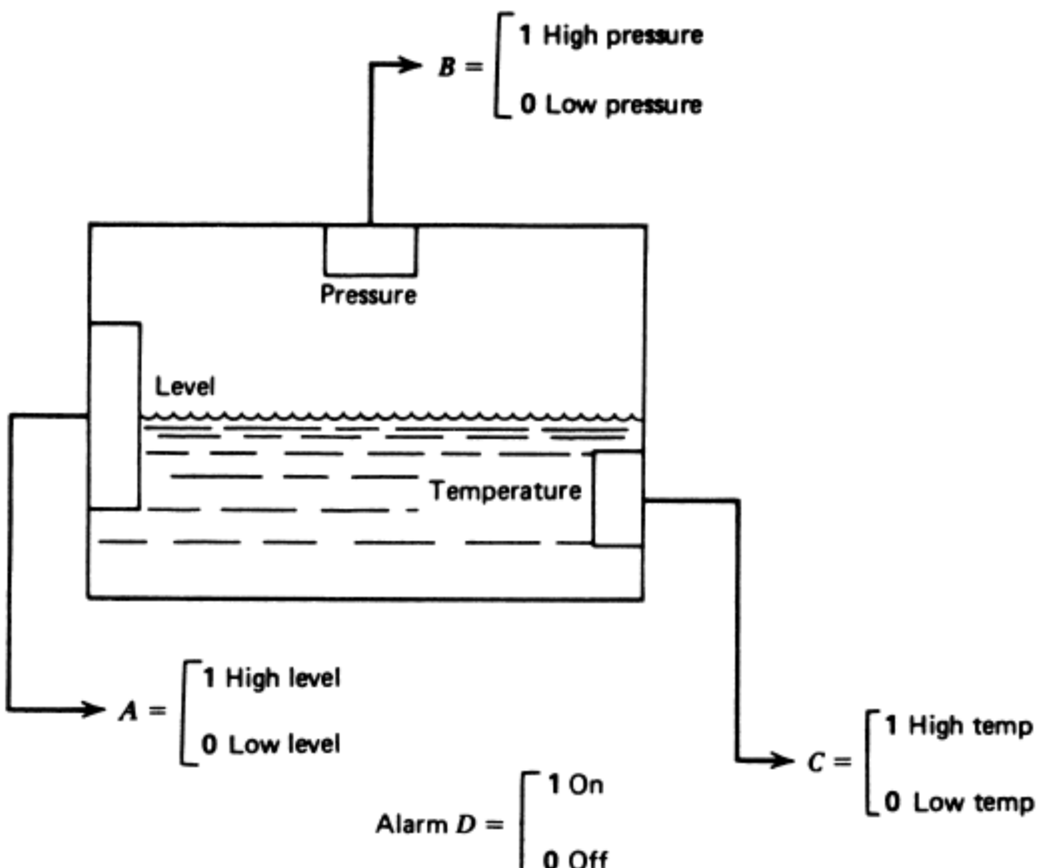
- **Logic Control:** a switching system whose output at any moment is determined exclusively by the values of inputs.
  - No memory
  - No operating characteristics that depend on time
  - Also called *combinational logic control*

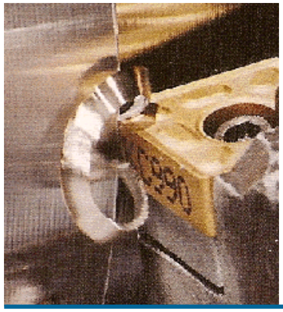


Digital Variables

2 States
0 → ex: Low/off/.....
1 → ex: High/on/.....

* غالباً :-
0 → zero volt
1 → five volt

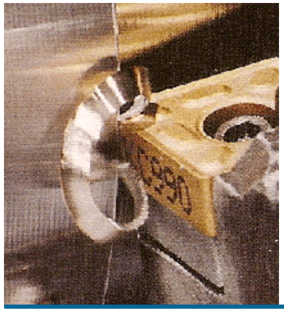




Boolean Algebra

The alarm will be triggered when the Boolean variable *D* goes to the logic true state. The alarm conditions are:

1. Low level with high pressure
2. High level with high temperature
3. High level with low temperature and high pressure



Boolean Algebra

A (Level)

B (Pressure)

C (Temperature)

D (Alarm)

We now define a Boolean expression with AND operations that will give a $D = \mathbf{1}$ for each condition:

1. $D = \overline{A} \cdot B$ will give $D = \mathbf{1}$ for condition 1.
2. $D = A \cdot C$ will give $D = \mathbf{1}$ for condition 2.
3. $D = A \cdot \overline{C} \cdot B$ will give $D = \mathbf{1}$ for condition 3.

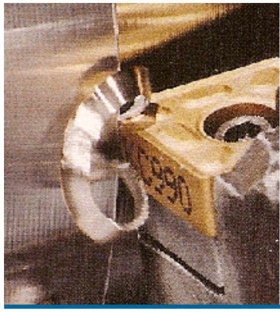
The alarm conditions are:

1. Low level with high pressure
2. High level with high temperature
3. High level with low temperature and high pressure

The final logic equation results from combining all three conditions so that if any is true, the alarm will sound ($D = \mathbf{1}$). This is accomplished with the OR operation

$$D = \overline{A} \cdot B + A \cdot C + A \cdot \overline{C} \cdot B \qquad (2)$$

This equation would now form the starting point for a design of electronic digital circuitry that would perform the indicated operations.



Boolean Algebra

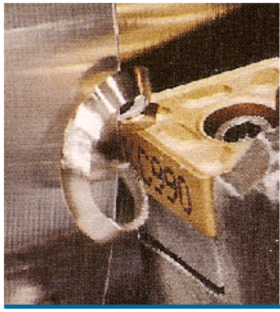
Develop a digital circuit using AND/OR gates that implements Equation (2).

Solution

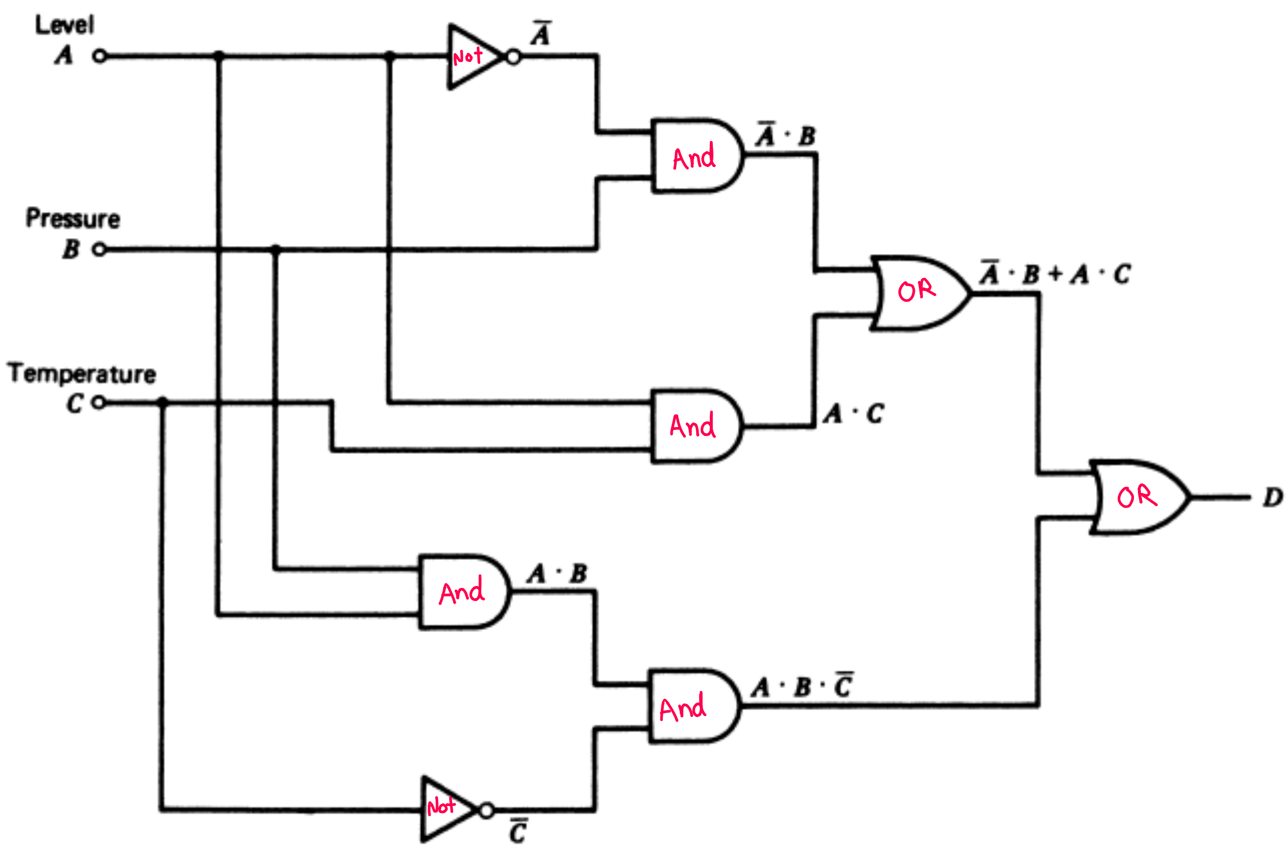
The problem posed in Section 2.3 (with Figure 1) has a Boolean equation solution of

$$D = \overline{A} \cdot B + A \cdot C + A \cdot \overline{C} \cdot B \qquad \textbf{(2)}$$

$$D = \overline{A} \cdot B + A \cdot C + A \cdot \overline{C} \cdot B$$



Boolean Algebra

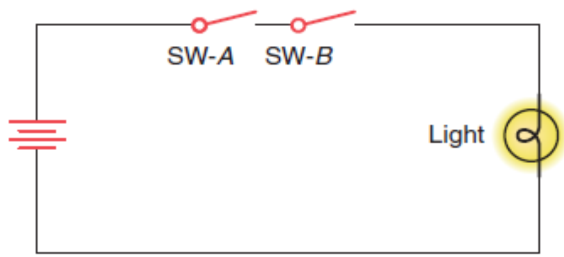


Fundamentals of Logic

- Single output < 0 / 1

- multiple input (ما عدا ال not)

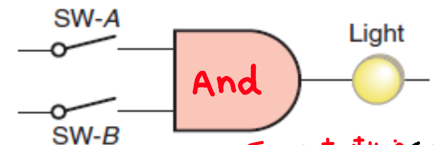
Hardwired circuit



Truth table

SW-A		SW-B		Light	
Open	(0)	Open	(0)	Off	(0)
Open	(0)	Closed	(1)	Off	(0)
Closed	(1)	Open	(0)	Off	(0)
Closed	(1)	Closed	(1)	On	(1)

Logic representation

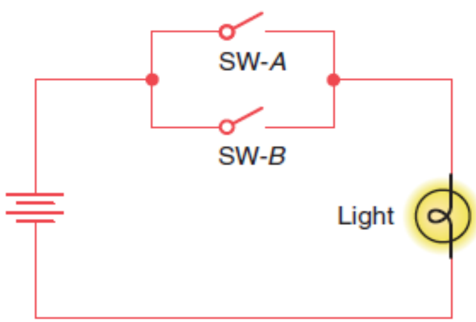


(And)

لو أي input ← 0 ← ف الoutput حيكون ← 0

لو كلهم شغالين يعني جميع الinput ← 1 ← حيكون الoutput ← 1

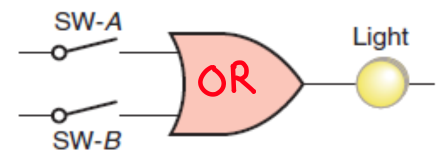
Hardwired circuit



Truth table

SW-A		SW-B		Light	
Open	(0)	Open	(0)	Off	(0)
Open	(0)	Closed	(1)	On	(1)
Closed	(1)	Open	(0)	On	(1)
Closed	(1)	Closed	(1)	On	(1)

Logic representation

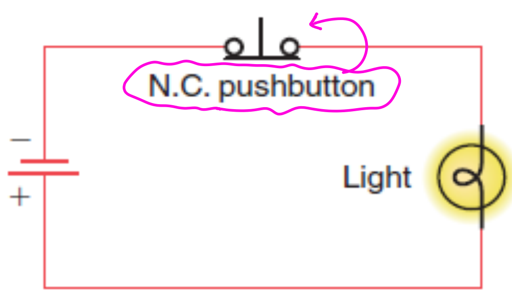


(OR)

اي input ← 1

راح يعطيني output ← 1

Hardwired circuit

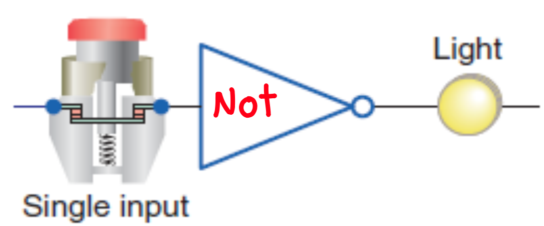


N.C A normally closed pushbutton.

Truth table

Pushbutton		Light	
Not pressed	(0)	On	(1)
Pressed	(1)	Off	(0)

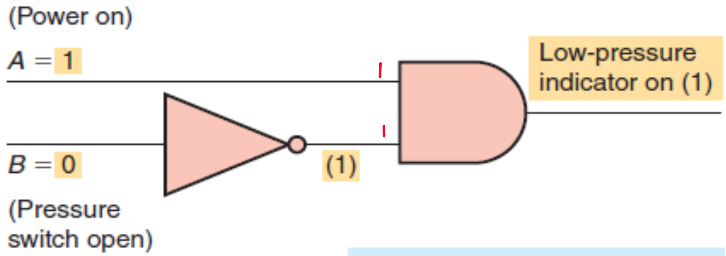
Logic representation



(Not)

عكس ال input

Fundamentals of Logic



Truth table		
Pressure switch	Power	Pressure indicator
0	1	1
1	1	0

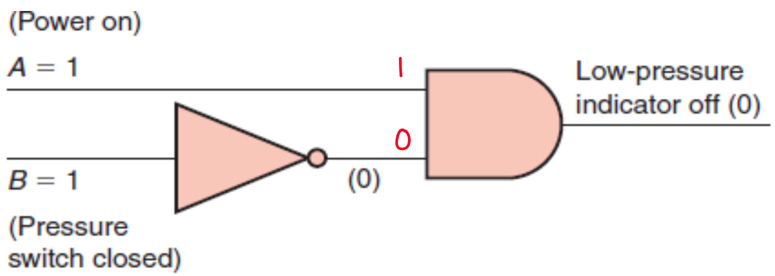
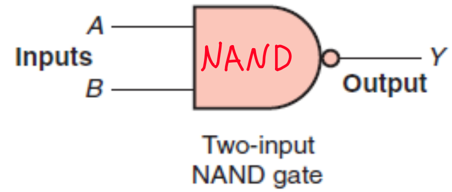


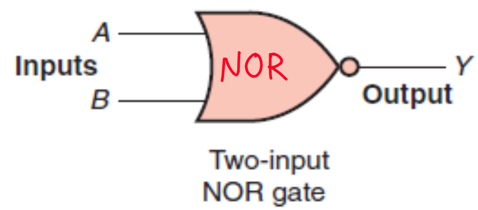
Figure 4-11 NOT function is most often used in conjunction with an AND gate.



NAND truth table

Inputs		Output
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

Figure 4-12 NAND gate symbol and truth table.



NOR truth table

Inputs		Output
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

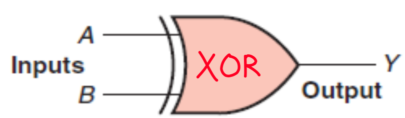
Figure 4-13 NOR gate symbol and truth table.

(XOR)

(XNOR)
هي عكسها

input متشابه → output zero

input مختلف → output one

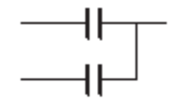
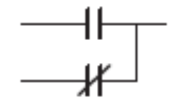
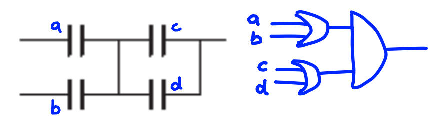
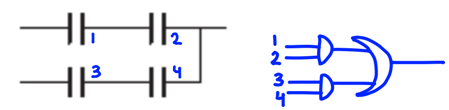
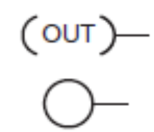
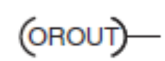
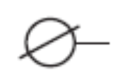


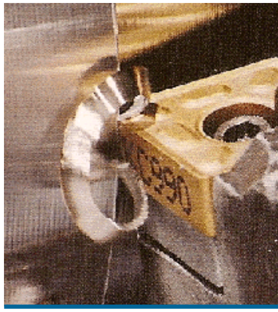
Truth table

Inputs		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

Figure 4.14 The XOR gate symbol and truth table.

Table 4-1 Typical Boolean Instruction or Statement List

Boolean Instruction and Function	Graphic Symbol
Store (STR)–Load (LD) → output Begins a new rung or an additional branch in a rung with a normally open contact.	
Store Not (STR NOT)–Load Not (LD NOT) Begins a new rung or an additional branch in a rung with a normally closed contact.	
Or (OR) Logically ORs a normally open contact in parallel with another contact in a rung.	
Or Not (OR NOT) Logically ORs a normally closed contact in parallel with another contact in a rung.	
And (AND) Logically ANDs a normally open contact in series with another contact in a rung.	
And Not (AND NOT) Logically ANDs a normally closed contact in series with another contact in a rung.	
And Store (AND STR)–And Load (AND LD) Logically ANDs two branches of a rung in series.	
Or Store (OR STR)–Or Load (OR LOAD) Logically ORs two branches of a rung in parallel.	
Out (OUT) Reflects the status of the rung (on/off) and outputs the discrete (ON/OFF) state to the specified image register point or memory location.	
Or Out (OR OUT) Reflects the status of the rung and outputs the discrete (ON/OFF) state to the image register. Multiple OR OUT instructions referencing the same discrete point can be used in the program.	
Output Not (OUT NOT) Reflects the status of the rung and turns the output OFF for an ON execution condition; turns the output ON for an OFF execution condition.	



Fundamentals of Logic

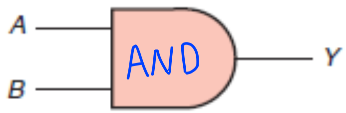
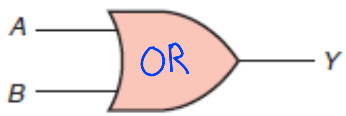
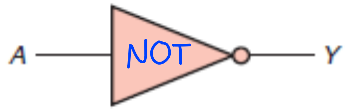
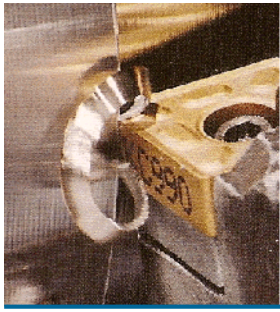
Logic symbol	Logic statement	Boolean equation	Boolean notations
	*Y* is 1 if *A* and *B* are 1	$Y = A \bullet B$ or $Y = AB$	Symbol — Meaning $\bullet$ — and $+$ — or $-$ — not $\circ$ — invert $=$ — result in
	*Y* is 1 if *A* or *B* is 1	$Y = A + B$	
	*Y* is 1 if *A* is 0 *Y* is 0 if *A* is 1	$Y = \overline{A}$	

Figure 4-15 Boolean algebra as related to AND, OR, and NOT functions.



Fundamentals of Logic

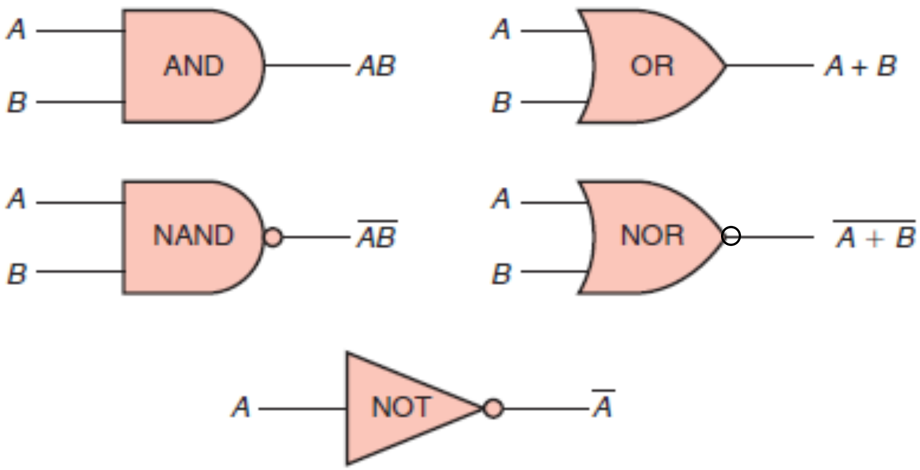
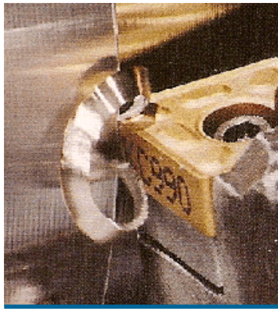


Figure 4-16 Logic operators used singly to form logical statements.



Fundamentals of Logic

As a Lader diagram

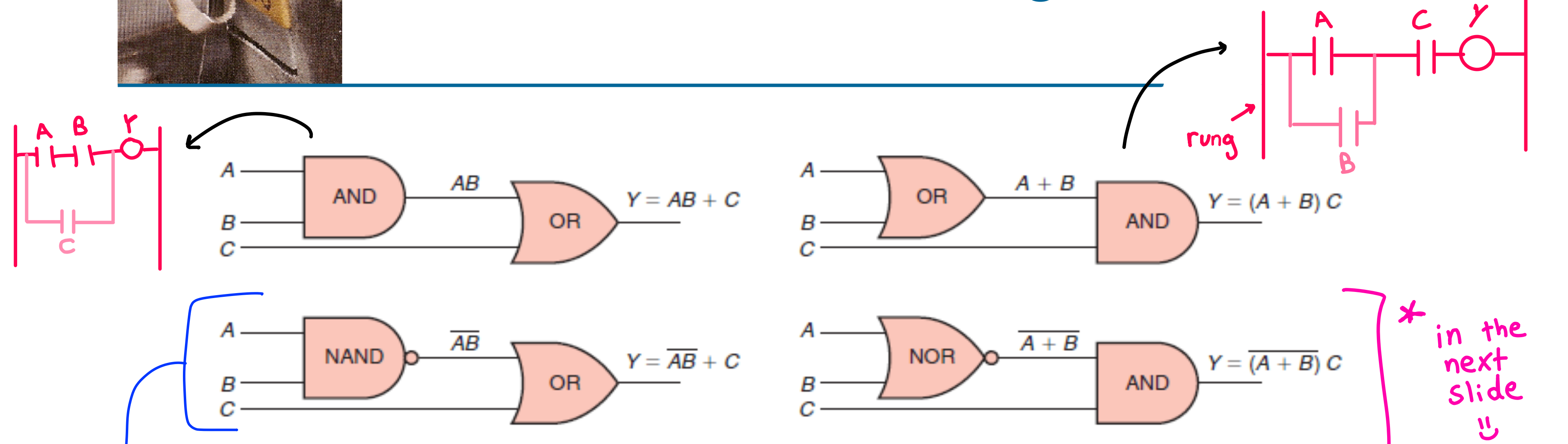
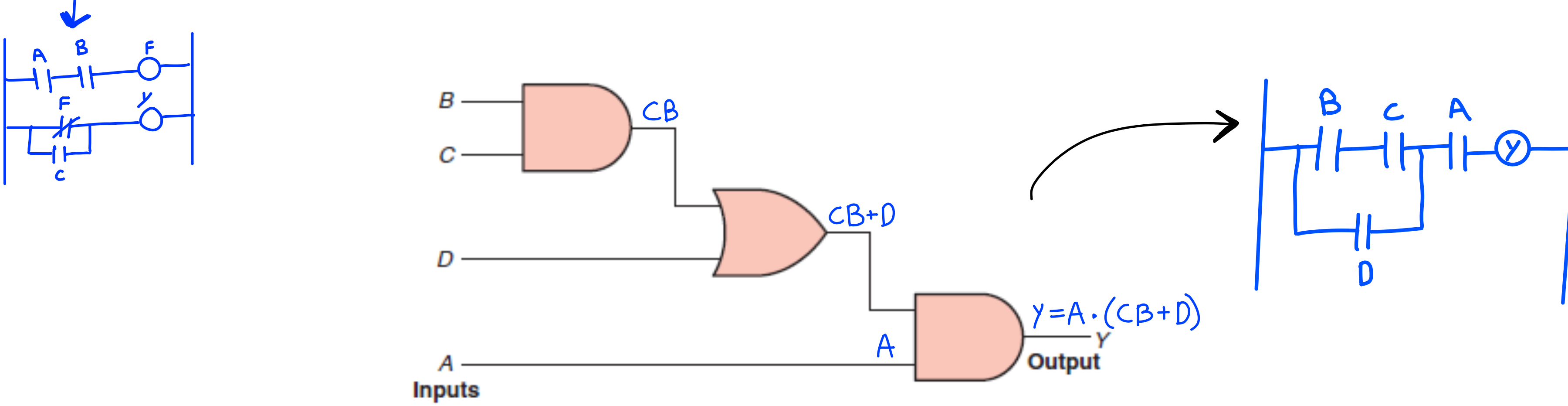
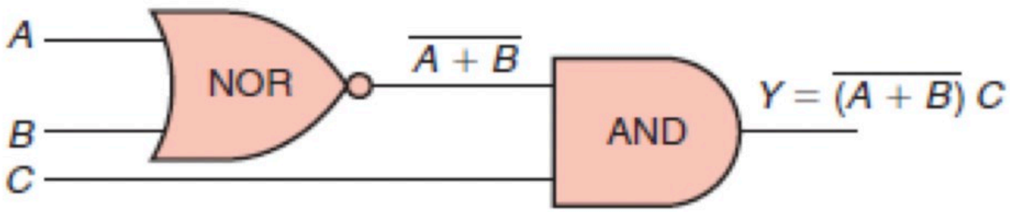
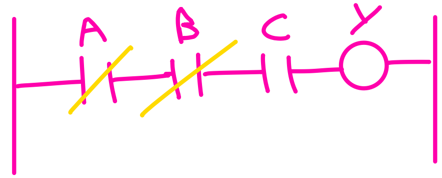


Figure 4-17 Logic operators used in combination to form Boolean equations.





* first method



Demorgon's Theory

$Y = \overline{(A+B)}.C$

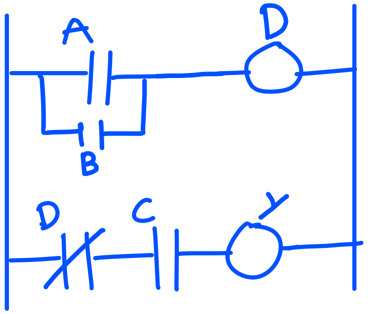
$= \bar{A}.\bar{B}.C$

* Second Method

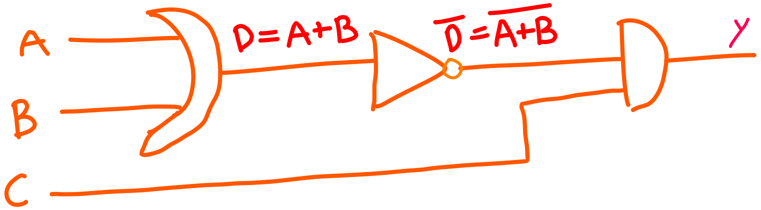
$Y = \overline{(A+B)}C$

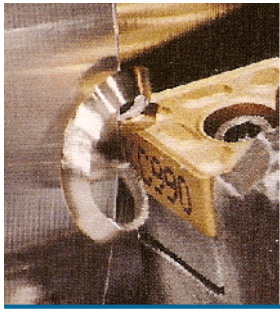
$A+B = D$

$Y = \bar{D}C$



$Y = \overline{(A+B)}C$





Fundamentals of Logic

COMMUTATIVE LAW

$A + B = B + A$

$A \cdot B = B \cdot A$

ASSOCIATIVE LAW

$(A + B) + C = A + (B + C)$

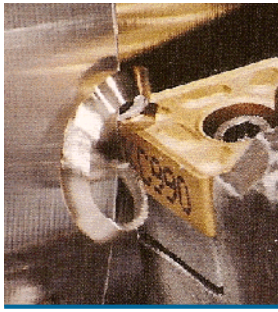
$(A \cdot B) \cdot C = A \cdot (B \cdot C)$

DISTRIBUTIVE LAW

$A \cdot (B + C) = (A \cdot B) + (A \cdot C)$

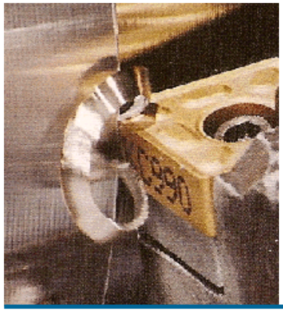
$A + (B \cdot C) = (A + B) \cdot (A + C)$

This law holds true only in Boolean algebra.

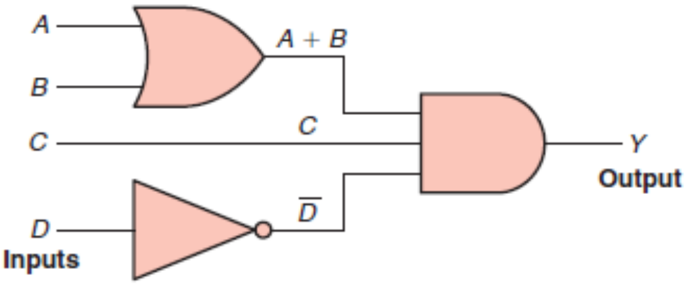


Fundamentals of Logic

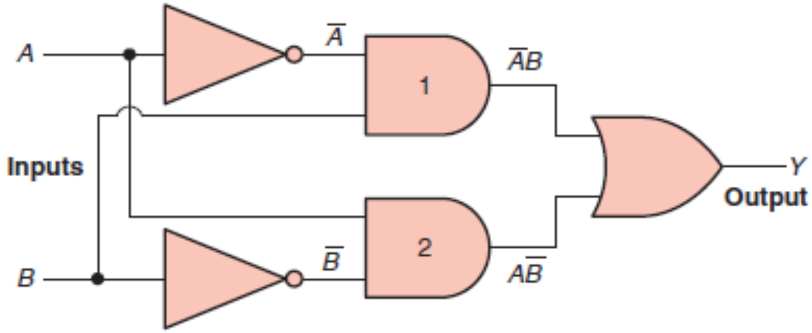
Name	AND form	OR form
Identity law	$1A = A$	$0 + A = A$
Null law	$0A = 0$	$1 + A = 1$
Idempotent law	$AA = A$	$A + A = A$
Inverse law	$A\bar{A} = 0$	$A + \bar{A} = 1$
Commutative law	$AB = BA$	$A + B = B + A$
Associative law	$(AB)C = A(BC)$	$(A + B) + C = A + (B + C)$
Distributive law	$A + BC = (A + B)(A + C)$	$A(B + C) = AB + AC$
Absorption law	$A(A + B) = A$	$A + AB = A$
De Morgan's law	$\overline{AB} = \bar{A} + \bar{B}$	$\overline{A + B} = \bar{A}\bar{B}$



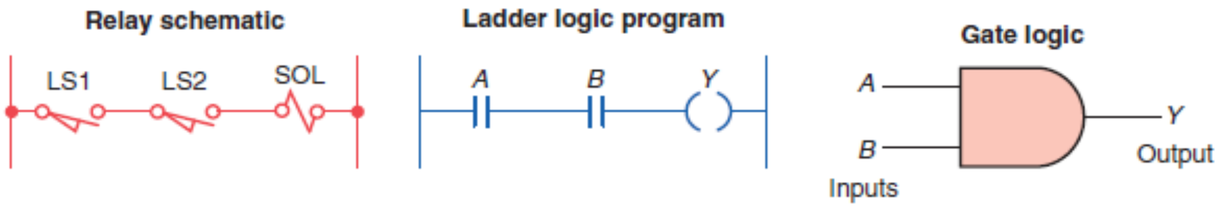
Fundamentals of Logic



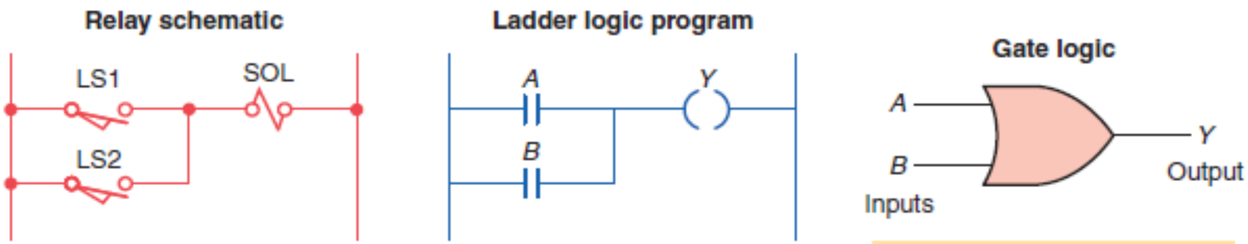
$Y = (A+B) . C . \overline{D}$



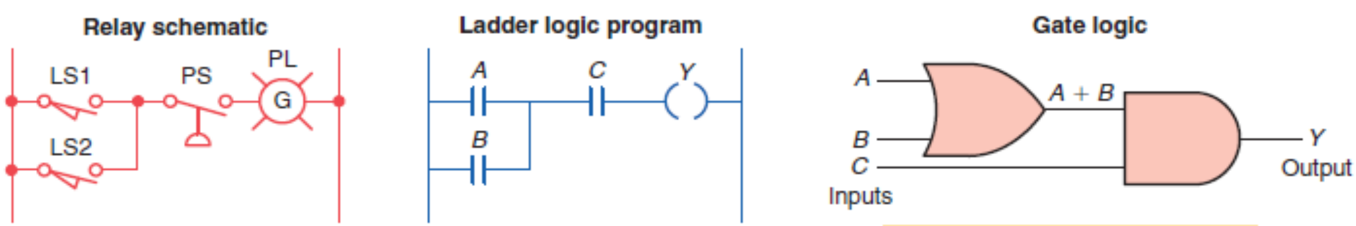
$Y = \overline{A}B + A\overline{B}$



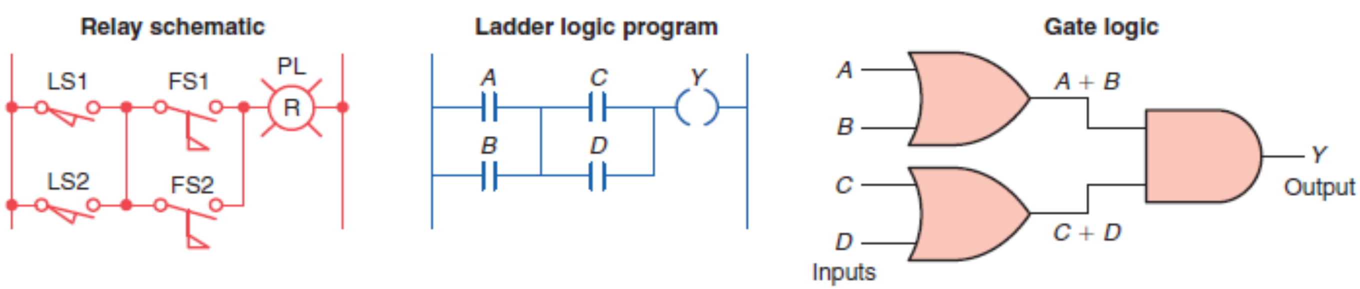
Boolean equation: $AB = Y$



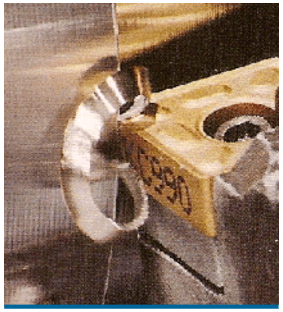
Boolean equation: $A + B = Y$

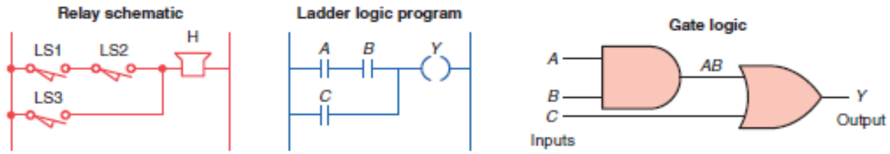


Boolean equation: $(A + B)C = Y$



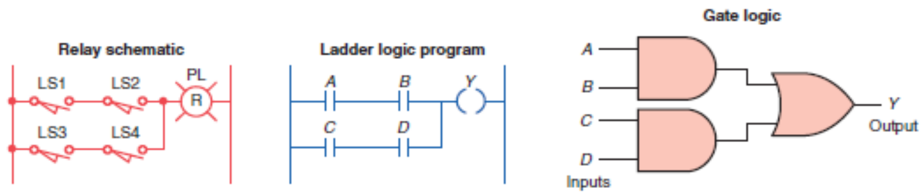
Boolean equation: $(A + B)\,(C + D) = Y$





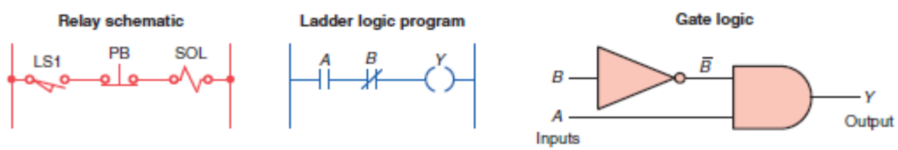
Boolean equation: $(AB) + C = Y$

Example 4-5 Two limit switches connected in series with each other and in parallel with a third limit switch, and used to control a warning horn.



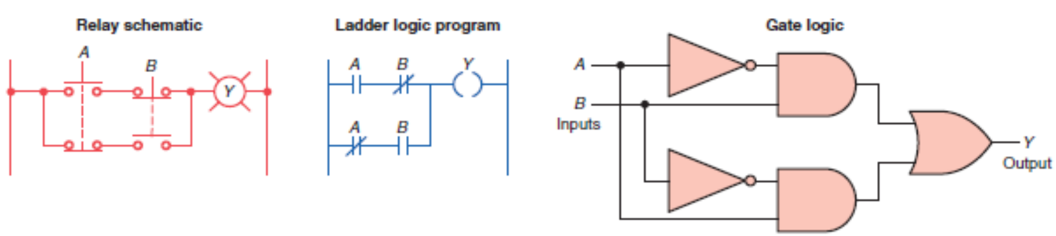
Boolean equation: $(AB) + (CD) = Y$

Example 4-6 Two limit switches connected in series with each other and in parallel with two other limit switches (that are connected in series with each other), and used to control a pilot light.



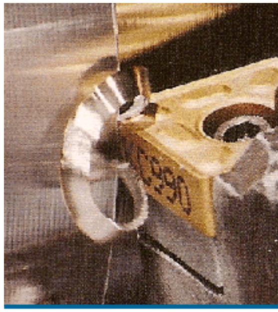
Boolean equation: $A\overline{B} = Y$

Example 4-7 One limit switch connected in series with a normally closed pushbutton and used to control a solenoid valve. This circuit is programmed so that the output solenoid will be turned on when the limit switch is closed and the pushbutton is *not pushed*.



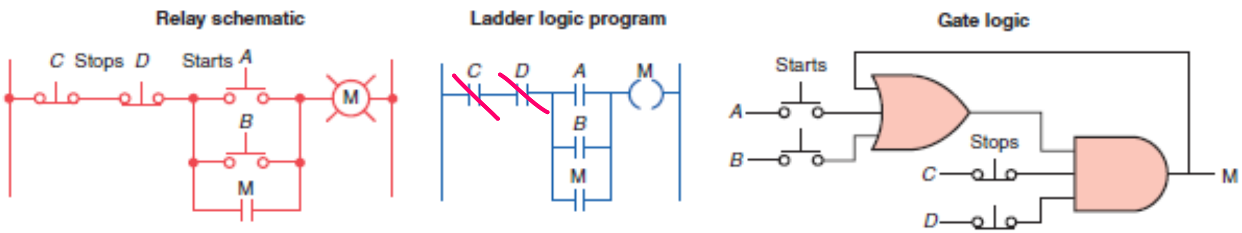
Boolean equation: $\overline{A}B + A\overline{B} = Y$
$A \oplus B = Y$

Example 4-8 Exclusive-OR circuit. The output lamp of this circuit is ON only when pushbutton A or B is pressed, but not both. This circuit has been programmed using only the normally open A and B pushbutton contacts as the inputs to the program.



Fundamentals of Logic

دوائر فيها اغلاط بدنا نصلحها



Example 4-9 A motor control circuit with two start/stop buttons. When either start button is depressed, the motor runs. By use of a seal-in contact, it continues to run when the start button is released. Either stop button stops the motor when it is depressed.

Example :-

$$Z = \bar{A}C\left(\overline{\bar{A}BD}\right) + \bar{A}B\bar{C}\bar{D} + A\bar{B}C$$

$$= \bar{A}C\left(\overset{A}{\cancel{\bar{\bar{A}}}} + \bar{B} + \bar{D}\right) + \bar{A}B\bar{C}\bar{D} + A\bar{B}C$$

$$= \overset{0}{\cancel{\bar{A}C.A}} + \bar{A}\bar{B}C + \bar{A}C\bar{D} + \bar{A}B\bar{C}\bar{D} + A\bar{B}C$$

$$= \bar{A}\bar{B}C + A\bar{B}C + \bar{A}C\bar{D} + \bar{A}B\bar{C}\bar{D}$$

$$= \bar{B}C\underbrace{(A + \bar{A})}_{1} + \bar{A}\bar{D}\underbrace{(C + B\bar{C})}_{C+B}$$

$$= \bar{B}C + \bar{A}\bar{D}(C + B)$$

$$\overline{A+B} = \bar{A}.\bar{B}$$

$$\overline{A.B} = \bar{A} + \bar{B}$$

$$\bar{\bar{A}} = A$$

$$A.\bar{A} = 0$$

$$A + A = A$$

$$A + \bar{A} = 1$$

$$\bar{A} + AB = \bar{A} + B$$

$$A + \bar{A}B = A + B$$

Example :-

$$\bar{A}\bar{B}C + \bar{A}C\bar{D} + \bar{A}B\bar{C}\bar{D} + A\bar{B}C$$

$$= \bar{A}\bar{B}C + \overbrace{(\bar{A}C\bar{D} + \bar{A}C\bar{D})}^{\bar{A}C\bar{D}} + \bar{A}B\bar{C}\bar{D} + A\bar{B}C$$

$$= \bar{A}C(\bar{B} + \bar{D}) + (\bar{A}\bar{D}\,\overbrace{(C + B\bar{C})}^{C+B} + A\bar{B}C$$

$$= \bar{A}C(\bar{B} + \bar{D}) + \bar{A}\bar{D}(C + B) + A\bar{B}C$$

$$= \bar{A}\bar{B}C + \underbrace{\bar{A}C\bar{D} + \bar{A}C\bar{D}}_{\bar{A}C\bar{D}} + \bar{A}B\bar{D} + A\bar{B}C$$

$$+ \bar{B}C\underbrace{(A + \bar{A})}_{1} + \bar{A}B\bar{D}$$

$$= \bar{A}C\bar{D} + \bar{B}C + \bar{A}B\bar{D}$$

$$= \bar{A}\bar{D}(C + B) + \bar{B}C$$

Boolean Simplification Algebra

$$A(\bar B + A + \bar B\bar C(A + \bar B\bar C))$$

$$= A(\bar B + A + \bar B\bar C A + \underbrace{\bar B\bar C\bar B\bar C}_{\bar B\bar C})$$

عامل مشترك

$$= A(\bar B + A + \bar B\bar C\underbrace{(A+1)}_{1})$$

$$= A(\bar B\underbrace{(\bar C+1)}_{1} + A)$$

$$= A(\bar B + A)$$

$$= A\bar B + AA$$

$$= A\underbrace{(\bar B+1)}_{1}$$

$$= A$$

$$(A\bar B(C + BD) + \bar A\bar B)C$$

$$= (A\bar B C + \cancel{A\underbrace{\bar B BD}_{\bar B B = 0}}) + \bar A\bar B)C$$

$CC = C$

$$= A\bar B C + \bar A\bar B C$$

$$= \bar B C\underbrace{(A + \bar A)}_{1}$$

$$= \bar B C$$

$$Z = ABC + A\bar B\cdot(\overline{\bar A\cdot\bar C})$$

$$= ABC + A\bar B\cdot(\underbrace{\bar{\bar A}}_{A} + \underbrace{\bar{\bar C}}_{C})$$

$$= ABC + A\bar B A + A\bar B C$$

$$= AC(B + \bar B) + A\bar B$$

$$= A(C + \bar B)$$

$$\bar X YZ + (\overline{XY\bar Z})$$

$$= \bar X YZ + (\bar X + \bar Y + \underbrace{\bar{\bar Z}}_{Z})$$

$$= \bar X YZ + (\bar X + \bar Y + Z)$$

عامل مشترك

$$= Z\underbrace{(\bar X Y + 1)}_{1} + \bar X + \bar Y$$

$$= \bar X + \bar Y + Z$$

$$XY + X(Y+Z) + Y(Y+Z)$$

$$= XY + XY + XZ + \underbrace{YY}_{Y} + YZ$$

$$= Y\underbrace{(X+1)}_{1} + XZ + YZ$$

$$= Y(1+Z) + XZ$$

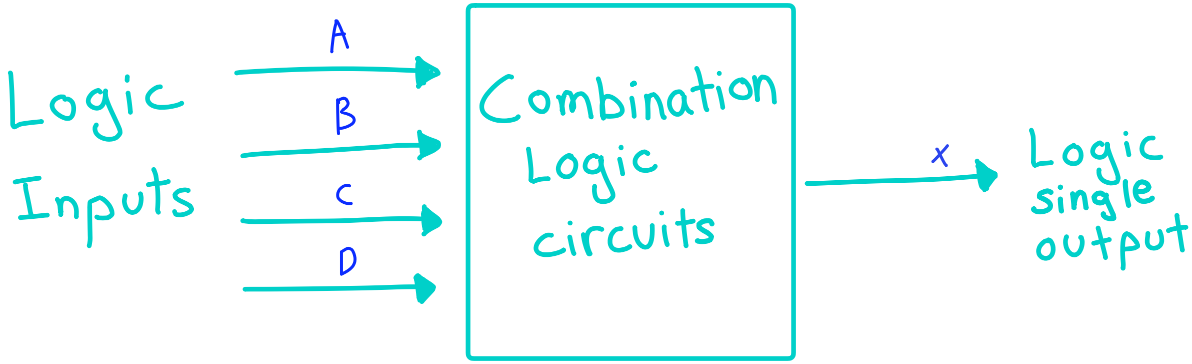
$$= Y + XZ$$

$$Z = A\bar B\bar C + A\bar B C + ABC$$

$$= A\bar B\bar C + AC\underbrace{(\bar B + B)}_{1}$$

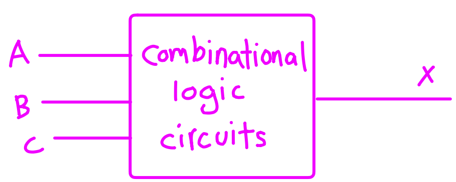
$$= A(\bar B\bar C + C)$$

$$= A(C + \bar B)$$



* based on Logic statments that converts Logic inputs into output

*example



في هذا المثال

Logic statment

[X is high when two or more of the inputs are high]

* Combinational Logic Circut Design

1 Truth Table

to connect all combinational possibilities of inputs to output

↳ ※of them $= 2^{\text{inputs}} = 2^3 = 8$

	C	B	A	X
0	0	0	0	0
1	0	0	1	0
2	0	1	0	0
3	0	1	1	1
4	1	0	0	0
5	1	0	1	1
6	1	1	0	1
7	1	1	1	1

في هذا المثال

Logic statment

[X is high when two or more of the inputs are high]

2 write the output as a boolean expression based on the Truth table

$$X = AB\bar{C} + A\bar{B}C + \bar{A}BC + ABC$$

$A + A = A$

$ABC + ABC = ABC$

$A + \bar{A} = 1$

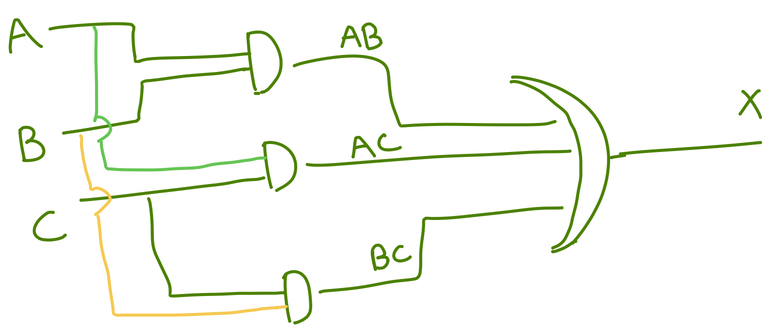
3 Simplify :-

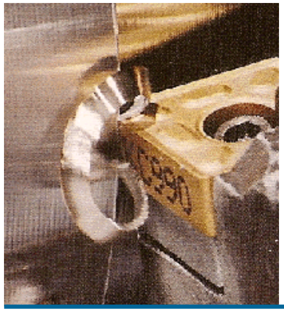
$$X = AB\bar{C} + A\bar{B}C + \bar{A}BC + ABC + ABC + ABC$$

$$= AB(C+\bar{C}) + AC(\bar{B}+B) + BC(A+\bar{A})$$

$$= AB + AC + BC$$

4 Draw the Combinational Logic circuit :-





Fundamentals of Logic

Develop a $\boxed{\text{logic gate circuit}}$ for each of the following Boolean expressions using AND, OR, and NOT gates:

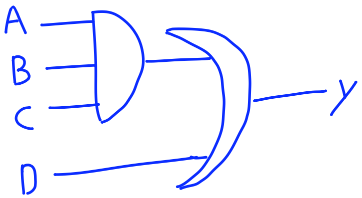
a. $Y = ABC + D$
b. $Y = AB + CD$
c. $Y = (A + B)(\overline{C} + D)$

d. $Y = \overline{A}(B + CD)$
e. $Y = \overline{A}B + C$
f. $Y = (ABC + D)(E\overline{F})$

* Develop a Logic Gate circuit :-

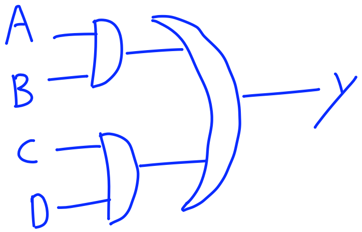
(a)

$$Y = ABC + D$$



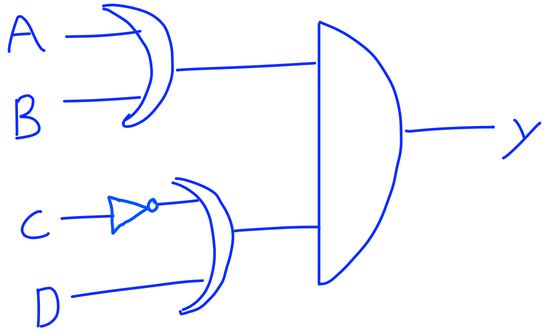
(b)

$$Y = AB + CD$$



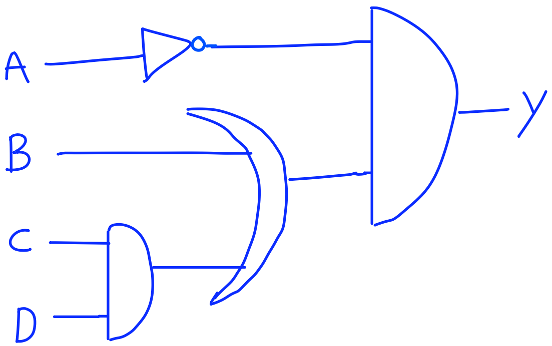
(c)

$$Y = (A+B)(\overline{C} + D)$$



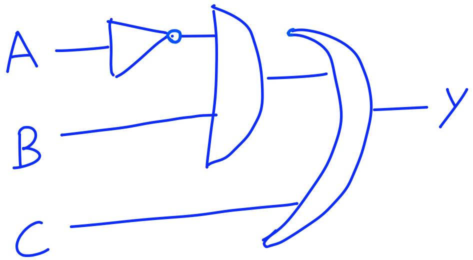
(d)

$$Y = \overline{A}(B + CD)$$



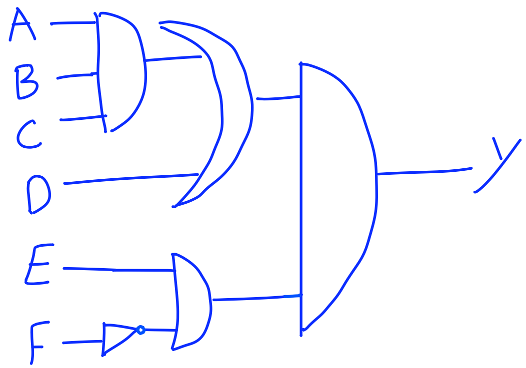
(e)

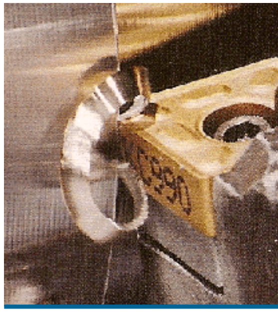
$$Y = \overline{A}B + C$$



(f)

$$Y = (ABC + D)(E\overline{F})$$





Fundamentals of Logic

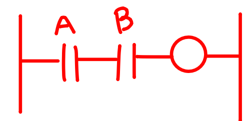
Ladder diagram :-

* single output
* multiple input
* no feedback

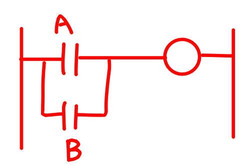
4. Express each of the following equations as a ladder logic program:
   a. $Y = (A + B)CD$
   b. $Y = A\bar{B}C + \bar{D} + E$
   c. $Y = [(\bar{A} + \bar{B})C] + DE$
   d. $Y = (\bar{A}B\bar{C}) + (D\bar{E}F)$

$\boxed{\text{* Gates in Ladder Diagram}}$

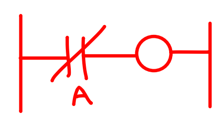
AND Gate
(توالي)
(A.B)



OR Gate
(توازي)
(A+B)



Inverter
$\bar{A}$



(Always start from inside the brackets)

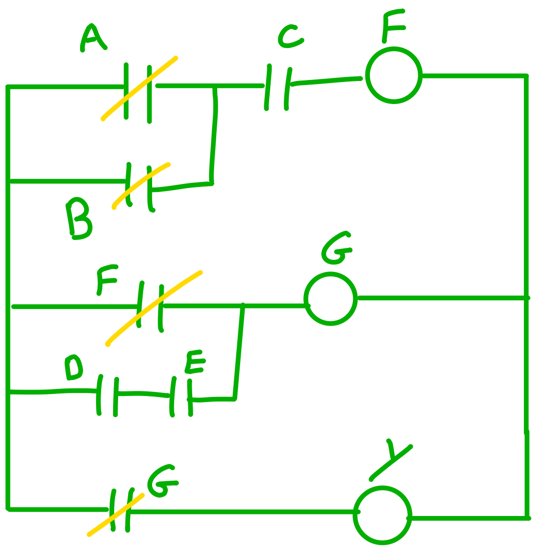
* Express each of the following equation as a Ladder

$$Y = \overline{\overline{(\bar{A} + \bar{B}) \cdot C} + DE}$$

F $\bar{F}$ G

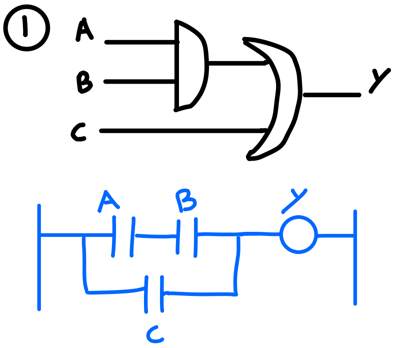
$$Y = \overline{\overline{(\bar{A} + \bar{B}) \cdot C} + DE}$$

يبدأ دائماً بالجزء الداخل الاقواس

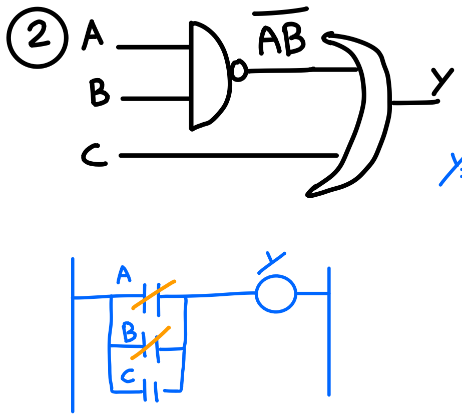


* Convert from (combinational Logic circuit) to (Ladder Diagram)

①



②

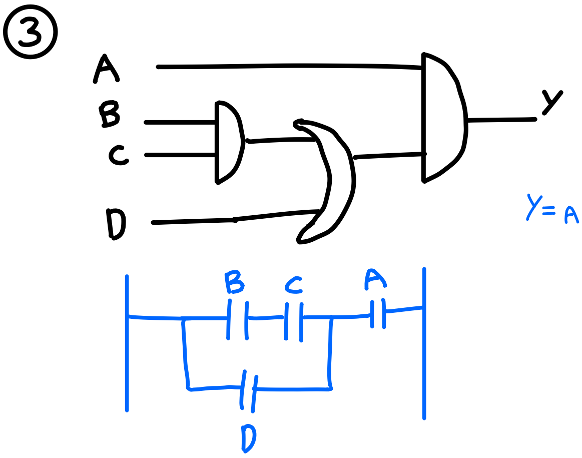


$Y=\overline{AB}+C$

↳ Demorgan's Theory

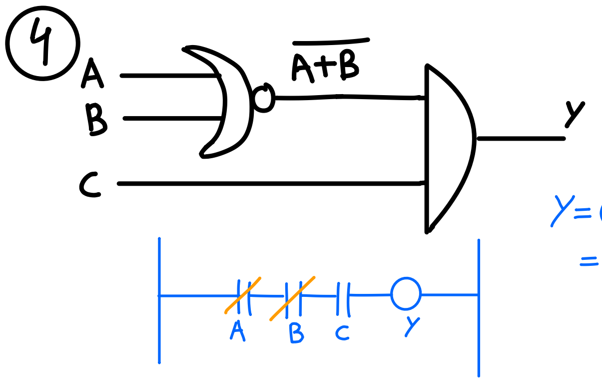
$\boxed{\bar{A}+\bar{B}+C}$

③



$Y=A(BC+D)$

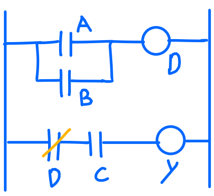
④



$Y=(\overline{A+B})C$

$=\bar{A}.\bar{B}.C$

أو

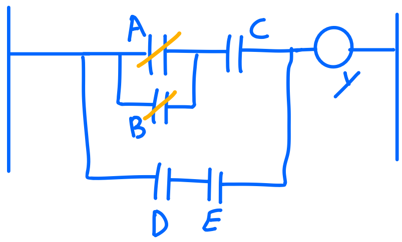


***Note:**

D and Y are outputs so we should draw them above each others

⑤

$Y=[(\bar{A}+\bar{B})C]+DE$

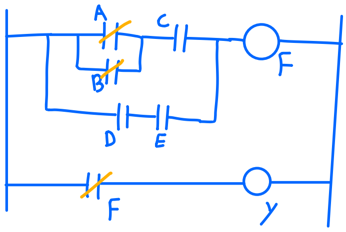


⑥

$Y=\overline{[(\bar{A}+\bar{B})C]+DE}$

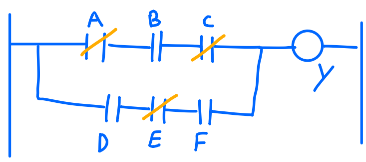
$[(\bar{A}+\bar{B})C]+DE \rightarrow F$

$\overline{[(\bar{A}+\bar{B})C]+DE} \rightarrow \bar{F}$

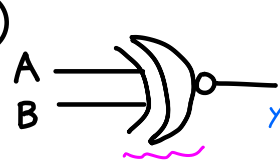


⑦

$Y=(\bar{A}B\bar{C})+(D\bar{E}F)$

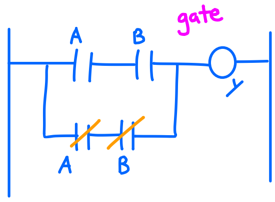


⑧

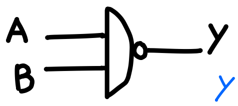


$Y=AB+\bar{A}\bar{B}$

XNOR gate

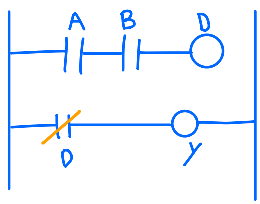


⑨



$Y=\overline{AB}$

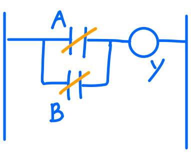
NAND gate



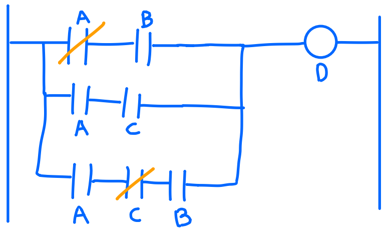
أو

with simplification

$Y=\bar{A}+\bar{B}$



⑩ $D = \bar{A}.B + A.C + A.\bar{C}.B$



أو

with simplification

$$D = \bar{A}.B + \underbrace{A.C + A.\bar{C}.B}_{\text{عامل مشترك}}$$

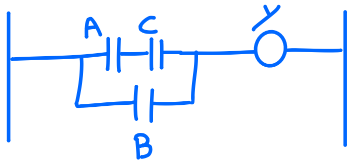
$$= \bar{A}B + A(C + \bar{C}B)$$

$$= \bar{A}B + A(C + B)$$

$$= \bar{A}B + AC + AB$$

$$= B(\bar{A} + A) + AC$$

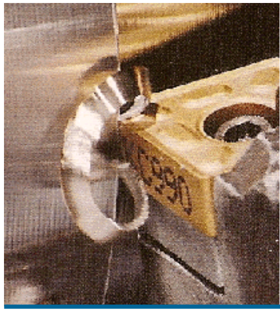
$$= B + AC$$



Note:-

يا برسم ال Ladder diagram من البداية

يا بسوي simplifications بعدين برسمه

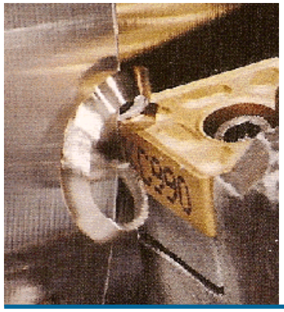


Example 1:

- On a particular piece of operator-controlled production equipment, the production process may only be performed by the operator activating two safety switches, located at some distance from each other. This is to prevent the equipment from accidentally starting whilst the operator is loading or unloading the machine. The switches have to be depressed together by the operator using both hands.

That means (AND gate)

- (a) What is the truth table for this operation?
- (b) What is the Boolean logic expression for this operation?
- (c) What is the logic network diagram for the operation?



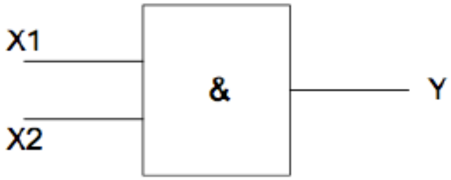
Example 1 solution:

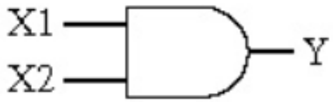
- (a) Where X1 is first switch, and X2 is second switch, and Y is the output of switch activation.

Inputs		Output
X1	X2	Y
0	0	0
0	1	0
1	0	0
1	1	1

- (b) Y = X1*X2
- (c)

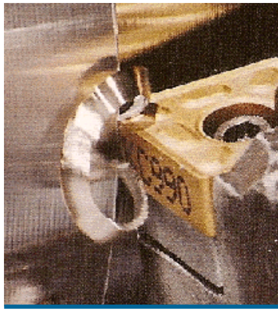
logic network diagram





No push button

NC push button



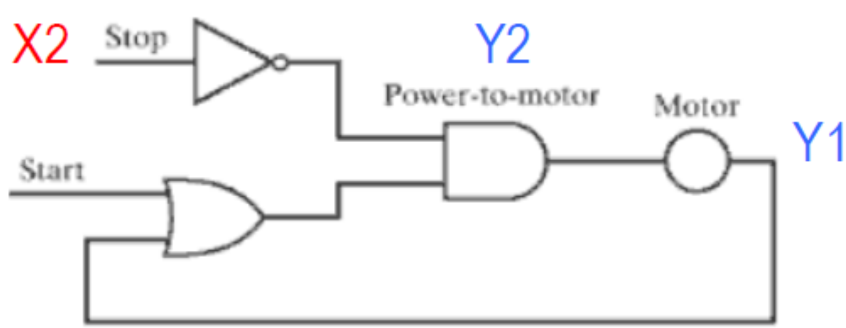
Example 2:

Write the Boolean logic expression for the pushbutton switch system below using the following symbols:

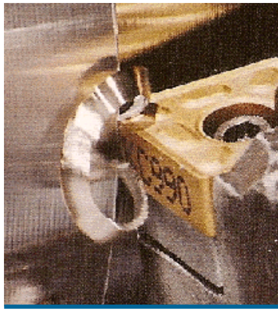
X1 = START, X2 = STOP, Y1 = MOTOR, and Y2 = POWER-TO-MOTOR.

بتطفي الـ system بس ما بتشغله ← X2

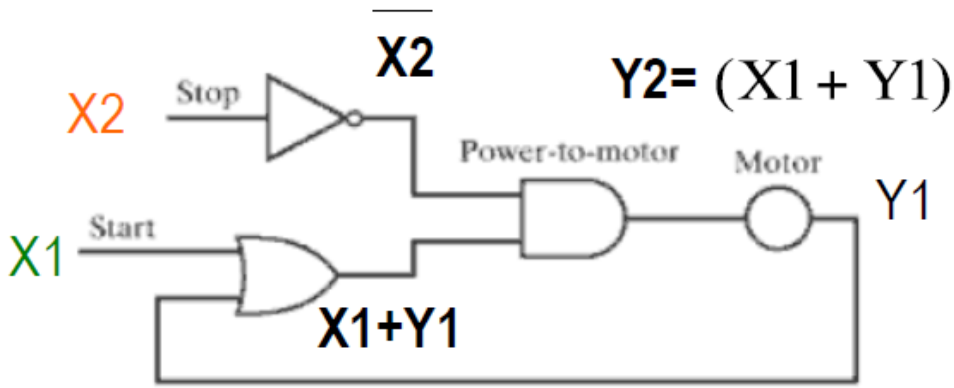
بتشغل الـ system بس ما بتطفيه ← X1



logic network diagram



Example 2 Solution:



$$Y2 = (X1 + Y1) \cdot \overline{X2}$$

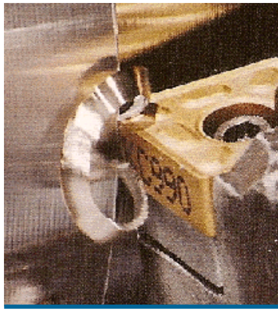
Truth Table

$= \overline{X_2}(X_1 + Y_1)$

	Start	Stop	Motor	Power-to-Motor
	0	0	0	0
	0	1	0	0
	1	0	0	1
x	1	1	0	0
	0	0	1	1
	0	1	1	0
	1	0	1	1
x	1	1	1	0

This Truth table :-
→ Logically is correct
→ but in Reality it is not correct

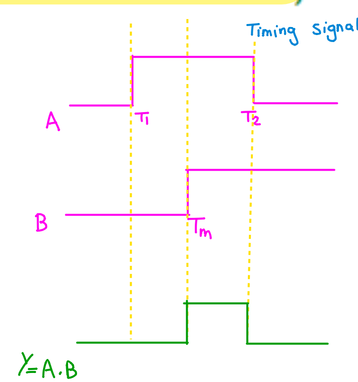
the Automation is sequencing Logic events

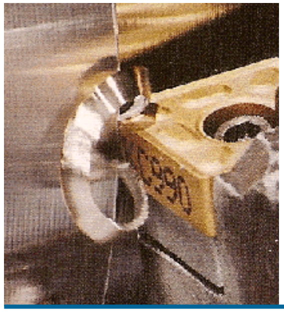


Sequencing

A switching system that uses internal timing devices to determine when to initiate changes in output variables

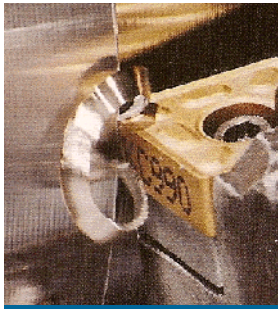
- Examples: Washing machines, dryers, dishwashers, Traffic light.





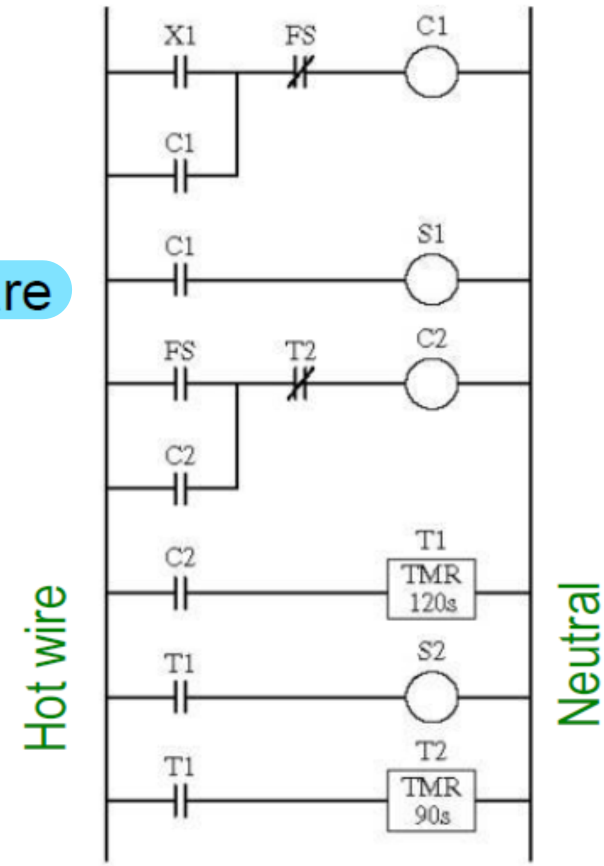
Sequencing

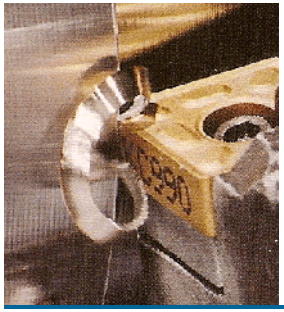
- Outputs are usually generated "open loop"
  - No feedback that control function is executed
- Sequence of output signals is usually cyclical, as in a high production work cycle
  - The signals occur in the same repeated pattern within each regular cycle
- Common sequencing devices:
  - Timer – output switches on/off at preset times
  - Counter – counts electrical pulses and stores them



Ladder Logic Diagrams

- Another way for drawing Logic Network Diagrams.
- A diagram where logic elements are displayed along horizontal lines (rungs) connecting two rails.
- Combines both: logic and sequencing control.

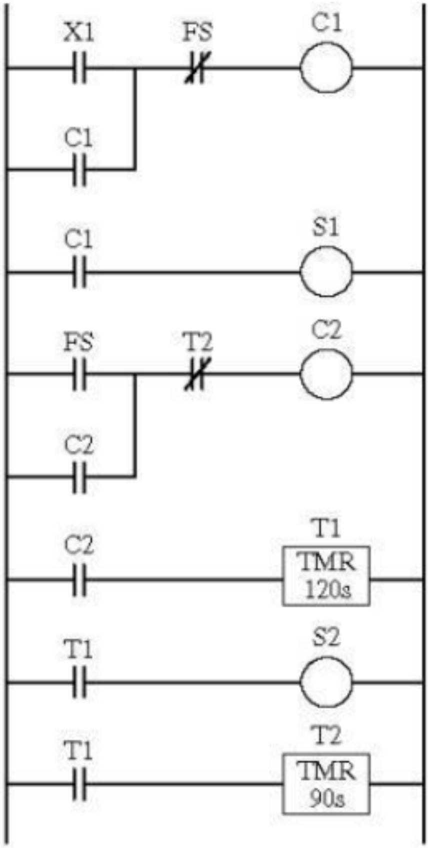


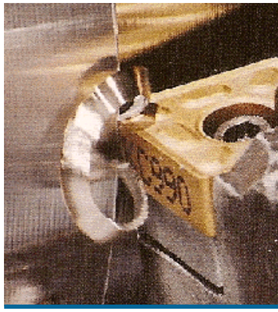


Ladder Logic Diagrams

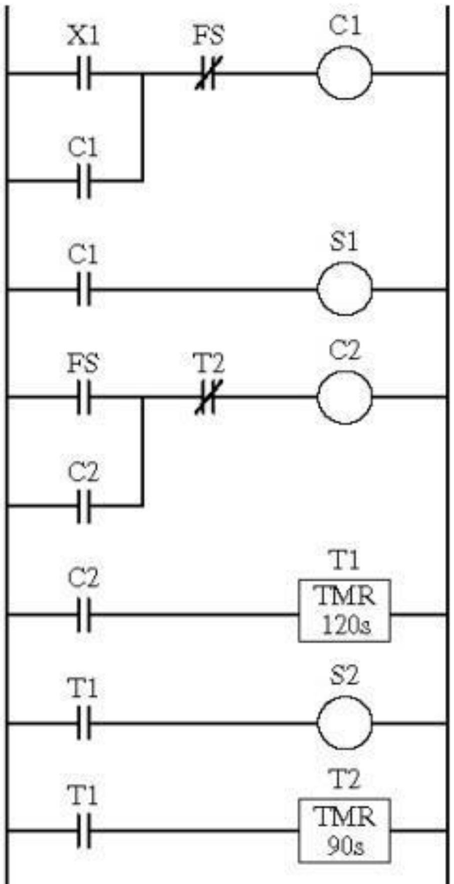
- Components of Ladder Diagrams:

1. Contacts - logical inputs, e.g., limit switches, photo-detector.
2. Loads (coils) - outputs, e.g., motors, lights, alarms, solenoids.
3. Timers - to specify length of delay.
4. Counters - to count pulses received

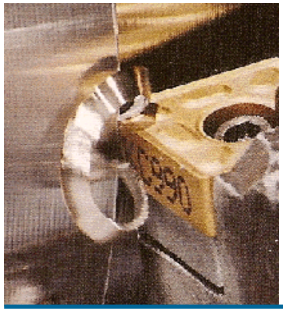




Components of Ladder Logic Diagram



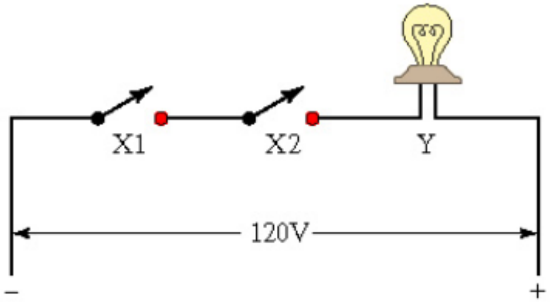
Ladder symbol	Hardware component
(a)	Normally open contacts (switch, relay, other ON/OFF devices)
(b)	Normally closed contacts (switch, relay, etc.)
(c)	Output loads (motor, lamp, solenoid, alarm, etc.)
(d) TMR 3s	Timer
(e) CTR	Counter

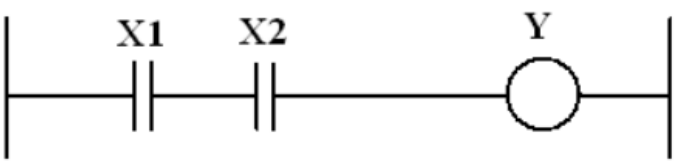


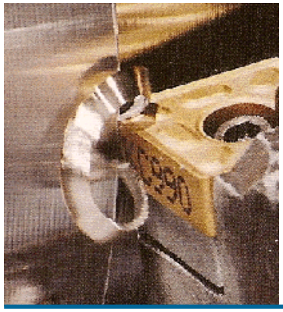
Example 1

- Construct the ladder logic diagrams for the AND gate.
  (series)

- Solution:





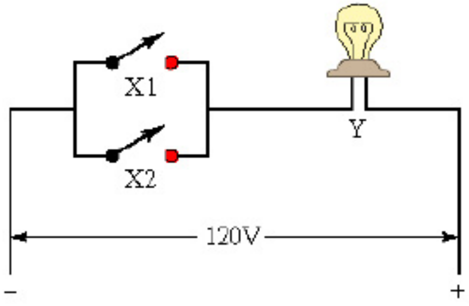


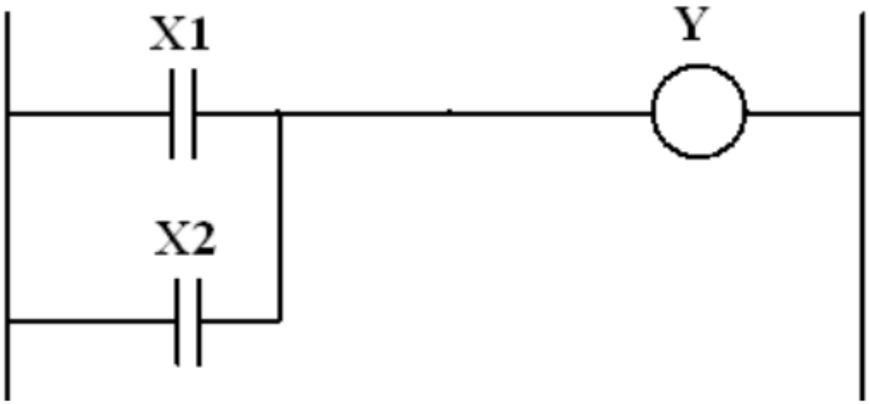
Example 2

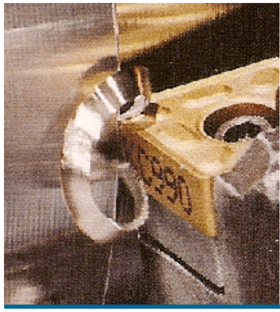
- Construct the ladder logic diagrams for the OR gate.

(parrallel)

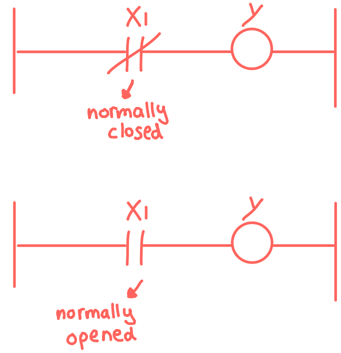
- Solution:





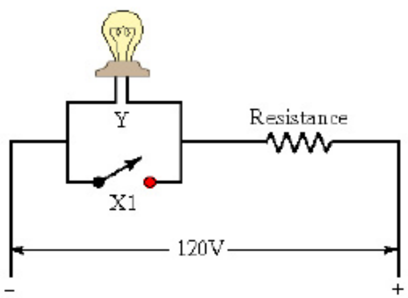


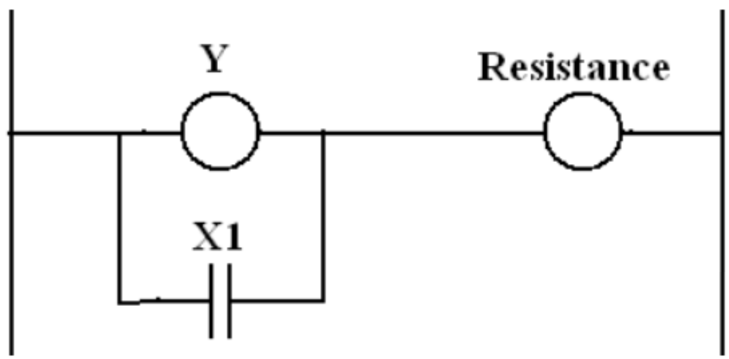
Example 3



- Construct the ladder logic diagrams for the NOT gate.

- Solution:

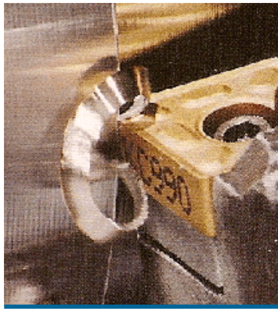




التيار سوف يمر ب X1 لما نسكر ال switch لأنها short circuit ف ال LED سوف ينطفيء

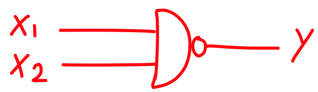
$X_1: 0 \longrightarrow Y: 1$

$X_1: 1 \longrightarrow Y: 0$



Example 4

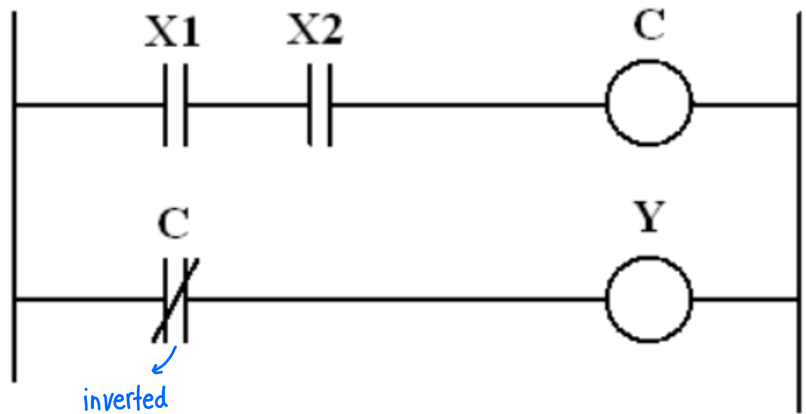
- Construct the ladder logic diagrams for the NAND gate.
- Solution:



we can simplify

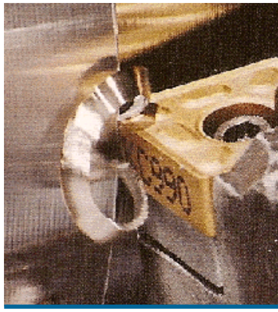
$Y = \overline{X_1 . X_2} \longrightarrow \overline{X_1} + \overline{X_2}$

(a) NAND		
Inputs		Output
X1	X2	$Y = \overline{X1 \cdot X2}$
0	0	1
0	1	1
1	0	1
1	1	0



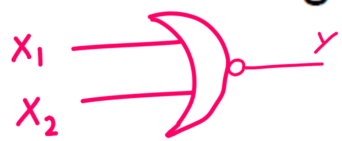
- If X1 or X2 remain open then C coil is unexcited and C contact remains closed, therefore Y is on.
- If X1 and X2 are closed then C coil is excited and C contact is opened and Y is off

C عكس Y



Example 5

- Construct the ladder logic diagrams for the NOR gate.
- Solution:

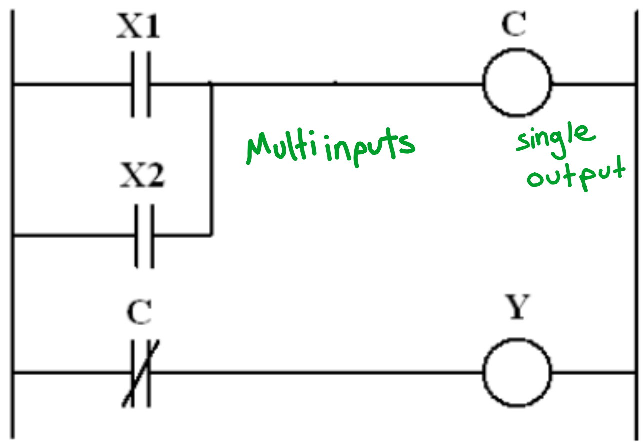


we can simplify

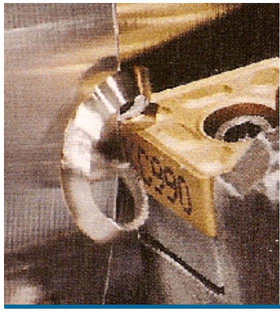
$Y = \overline{X_1 + X_2} \rightarrow \overline{X_1} \cdot \overline{X_2}$

(b) NOR

Inputs		*Output*
X1	X2	$Y = \overline{X1 + X2}$
0	0	1
0	1	0
1	0	0
1	1	0



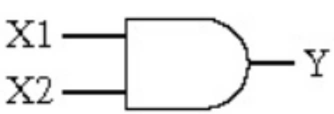
- If X1 and X2 remain open then C coil is unexcited and C contact remains closed, therefore Y is on.
- If X1 or X2 are closed then C coil is excited and C contact is opened and Y is off

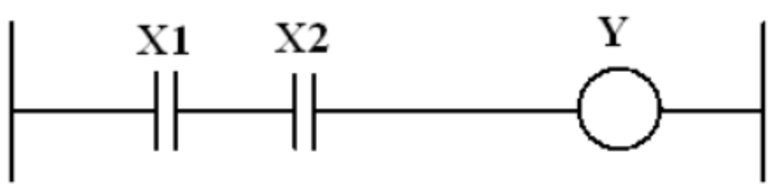


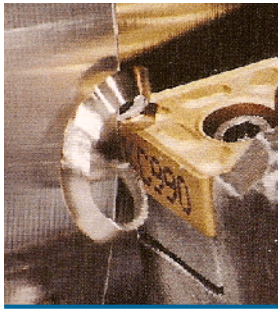
Example 6: Safety switches

- The production process may only be performed when the operator activates two spring activated safety switches. The switches have to be depressed and held closed together by the operator using both hands.

AND





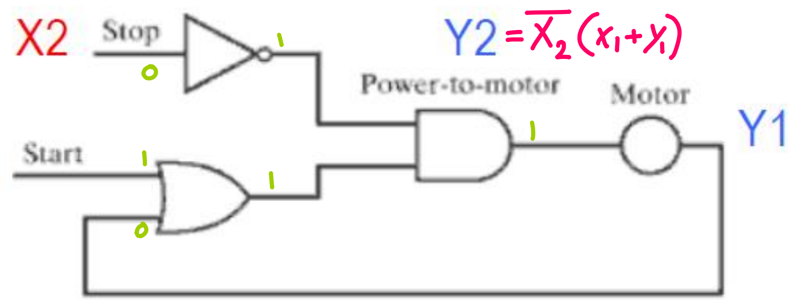


Example 7: Push Button

- Create ladder logic diagram for Push Button switch.

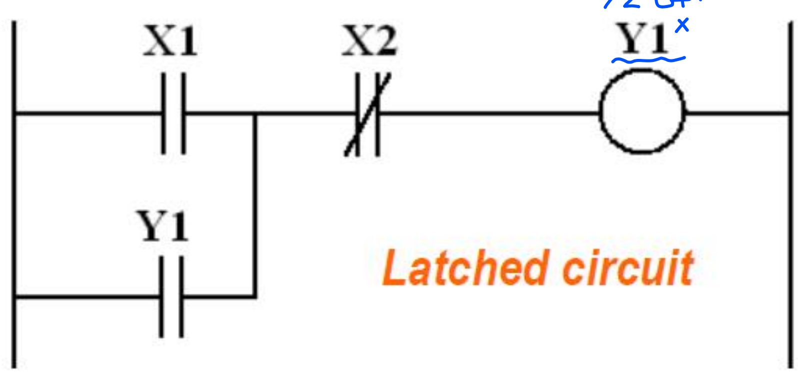
مهم

فقط لتشغيل الـ motor

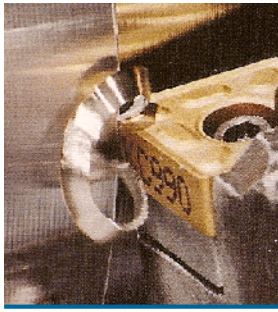


(X1 OR Y1) AND (NOT X2)

$$(X1 + Y1) \cdot \overline{X2}$$



* لا يوجد Feedback في ال Ladder Diagram



Example 8

- A motor controlled by stop and start push button switches.
- One signal light must be illuminated when the power is applied to the motor and another when it is not applied.

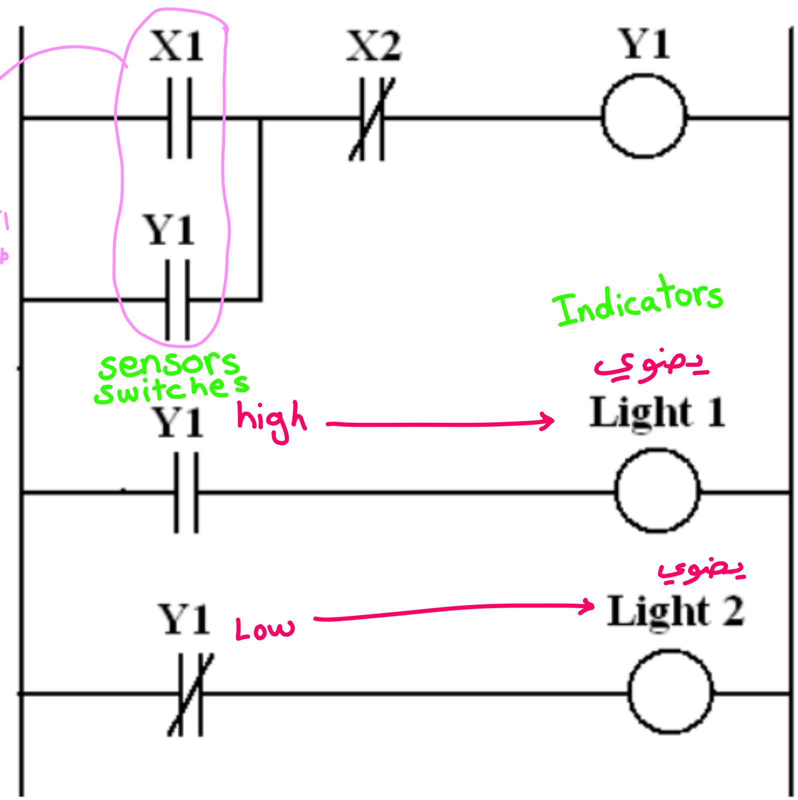
X_1 → ON only
X_2 → OFF only

X_1 oring with Y_1

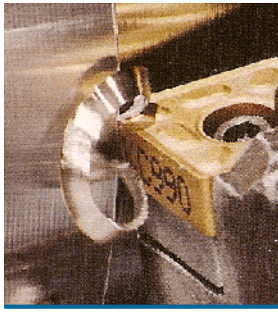
عشان بس اكبس X_1 اكتر من مرة يضل شغال طبيعي و بس اكبس X_2 يسكر

Multi inputs

Single output



كل Rung عبارة عن one event



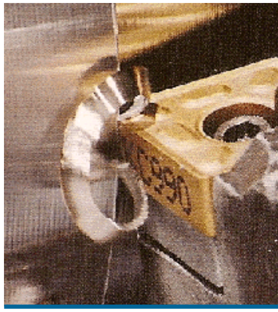
Example 9.5 Control Relay

C

electro magnitic device

يتحكم

- A control relay can be used to control on/off actuation of a powered device at some remote location. It can also be used to define alternative decisions in logic control. Construct the ladder logic diagram of a control relay.

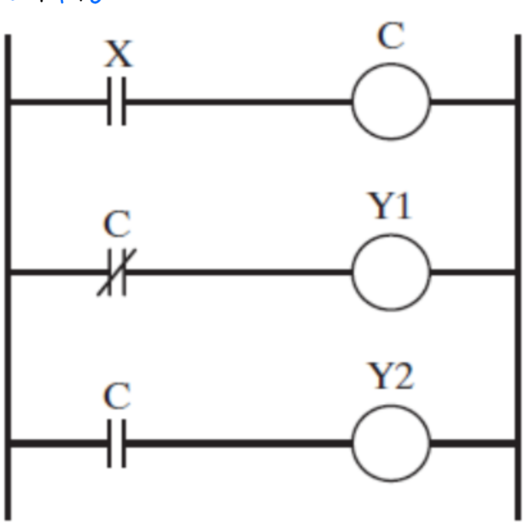


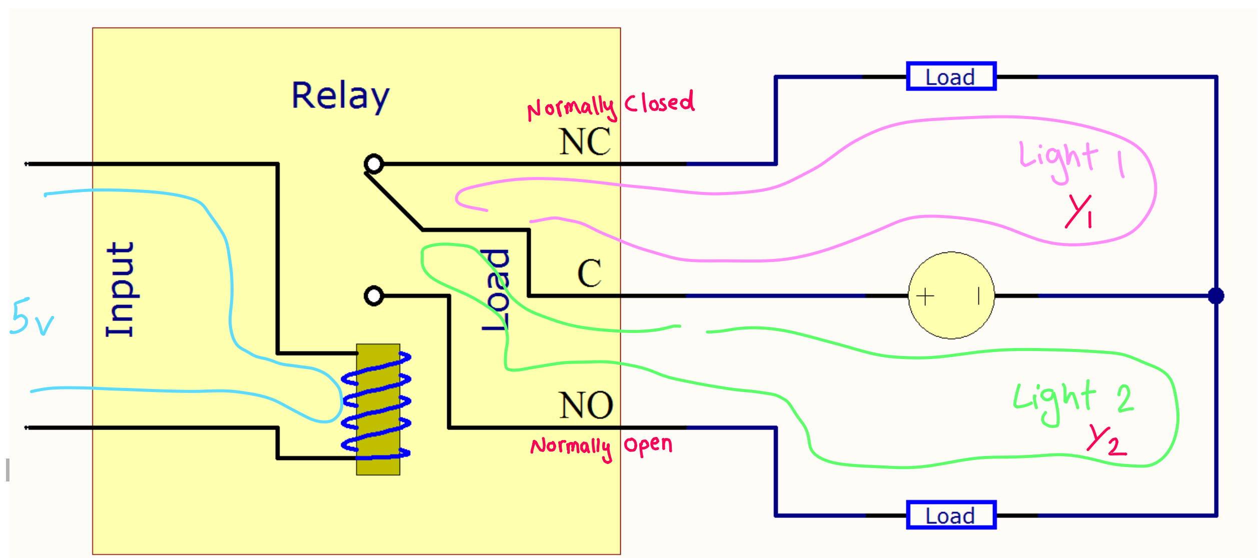
Example 9.5 Control Relay

important

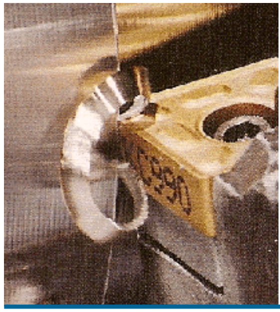
- Electromagnetic relay is an electronic control device. It has a control system (also called an input loop) and a controlled system (also called an output loop). It is usually used in automatic control circuits. It actually a kind of "automatic switch" that uses a smaller current and a lower current to control a larger current and a higher voltage.

X_1	C_1	Y_1	Y_2
1	1	0	1
0	0	1	0





في البداية نحدد ال inputs وال outputs



Example 9.6 Fluid Storage Tank

هدف هذا المثال دراسة ال dependencies between inputs and outputs

- Consider the fluid storage tank illustrated in Figure 9.10.
- When the start button X1 is depressed, this closes the control relay C1, which energizes solenoid S1, which opens a valve allowing fluid to flow into the tank.

يشغل ال system لكن ما بطفيه

- When the tank becomes full, the float switch FS closes, which opens relay C1, causing the solenoid S1 to be de-energized, thus turning off the in-flow.
- Switch FS also activates timer T1, which provides a 120-sec delay for a certain chemical reaction to occur in the tank.

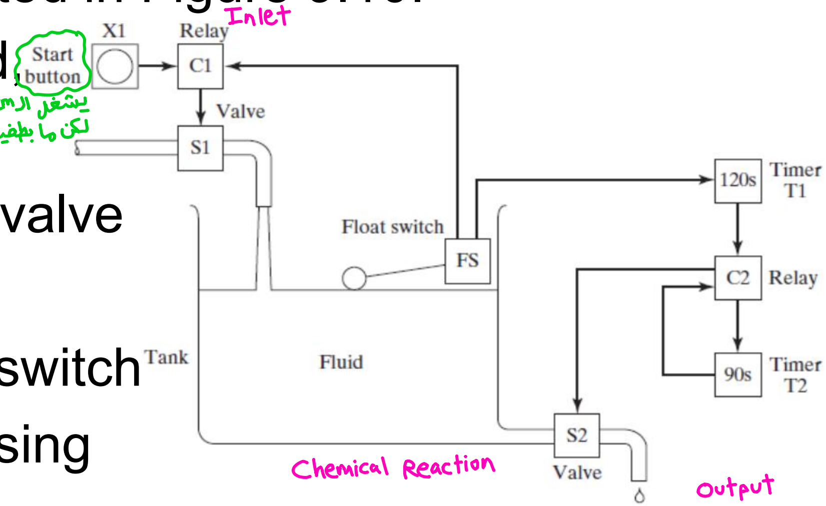
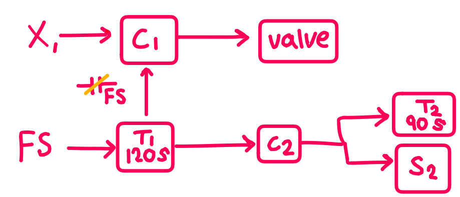
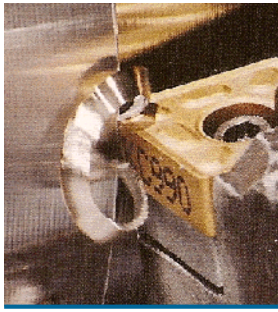


Figure 9.10 Fluid filling operation of Example 9.6.



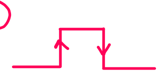


Example 9.6 Fluid Storage Tank

- At the end of the delay time, the timer energizes a second relay C2, which controls two devices: (1) It initiates timer T2, which
- waits 90 sec to allow the contents of the tank to be drained, and (2) it energizes solenoid S2, which opens a valve to allow the fluid to flow out of the tank.
- At the end of the 90 sec, the timer breaks the current and de-energizes solenoid S2, thus closing the out-flow valve.
- Depressing the start button X1 resets the timers and opens their respective contacts.

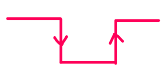
two types of timers

1



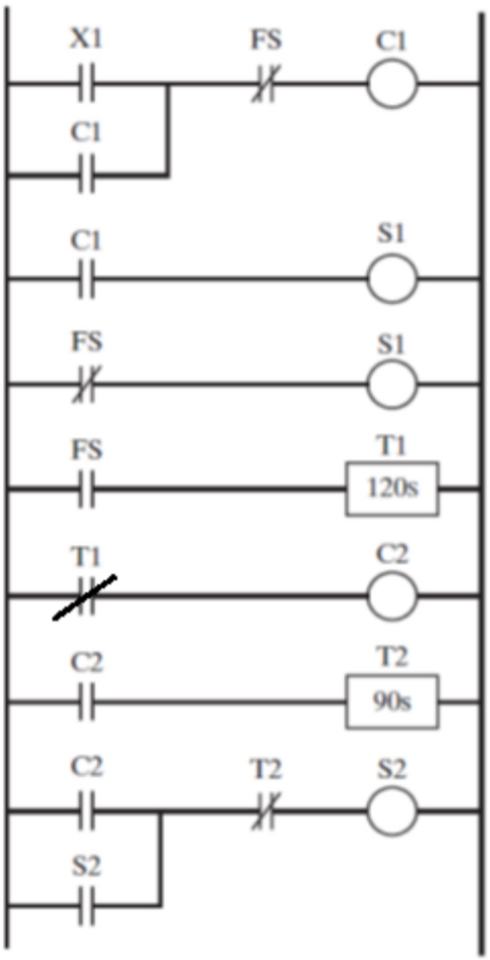
edge high → (لما يبدأ ال time
تبعه بكون High
(logic 1))

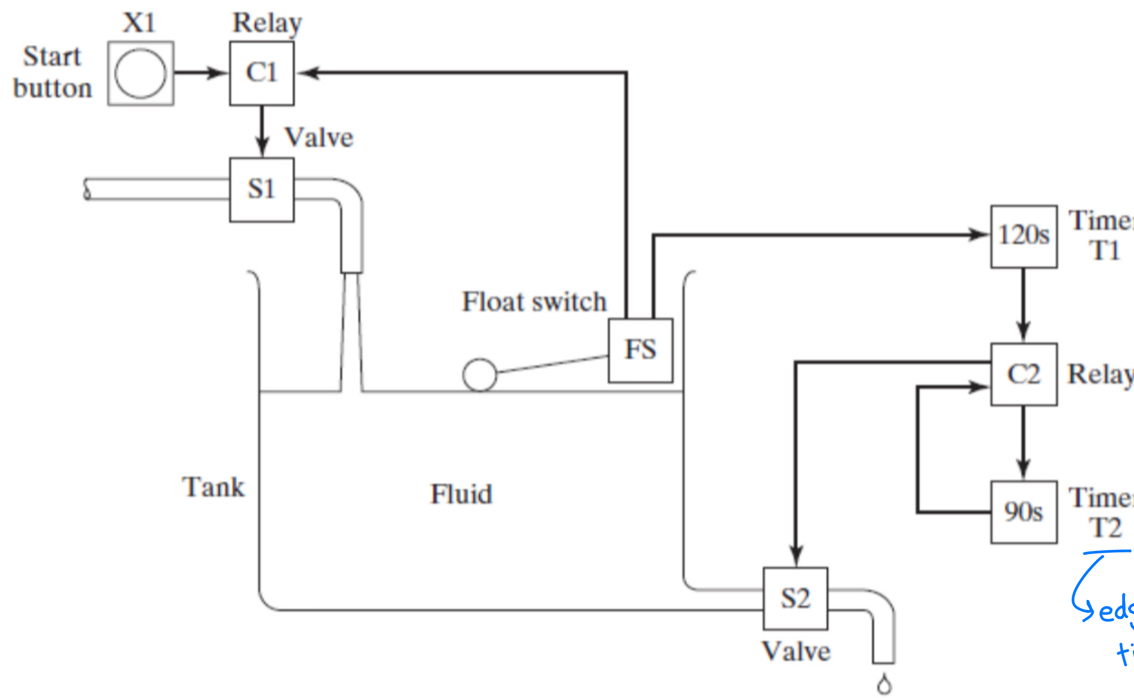
2



edge low

Example 9.6 Fluid Storage Tank

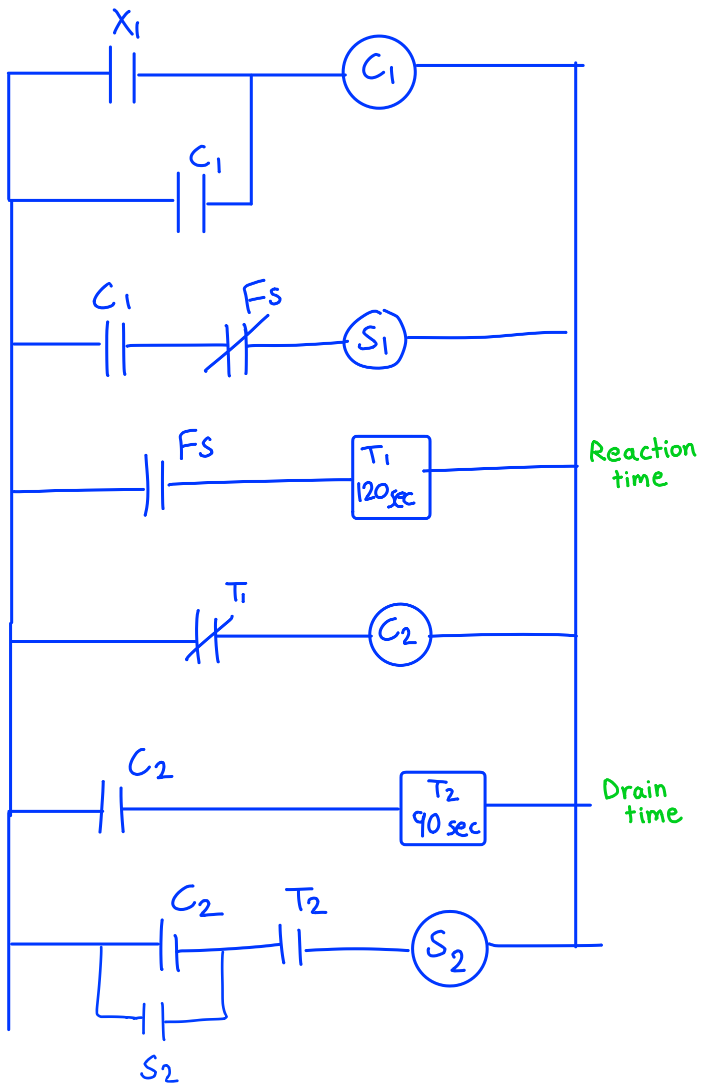


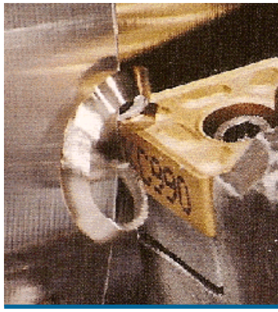


edge low
timer

Figure 9.10 Fluid filling operation of Example 9.6.

Timer will be logic 1 when it’s time is expired.


X1
C1
C1
C1
FS
S1
FS
T1
120 sec
Reaction time
T1
C2
C2
T2
90 sec
Drain time
C2
T2
S2
S2



Question

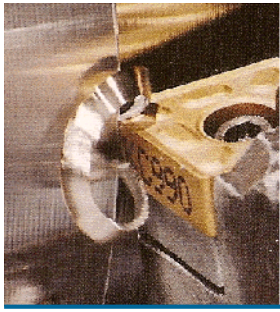
- An industrial robot performs a machine loading and unloading operation. A PLC is used as the cell controller. The cell operates as follows:

(1) a human worker places a part into a nest,

(2) the robot reaches over and picks up the part and places it into an induction heating coil,

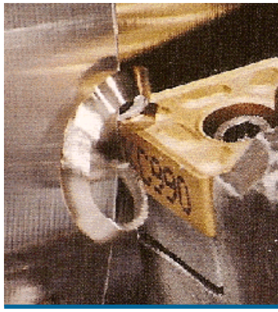
(3) a time of 10 sec is allowed for the heating operation, and (

4) the robot reaches into the coil, retrieves the part, and places it on an outgoing conveyor.



Question

- A limit switch X1 (normally open) is used to indicate that the part is in the nest in step (1). This energizes output contact Y1 to signal the robot to execute step (2) of the work cycle (this is an output contact for
- the PLC, but an input interlock signal for the robot controller).
- A photocell X2 is used to indicate that the part has been placed into the induction heating coil C1.
- Timer T1 is used to provide the 10-sec heating cycle in step (3), at the end of which, output contact Y2 is used to signal the robot to execute step (4).
- Construct the ladder logic diagram for the system



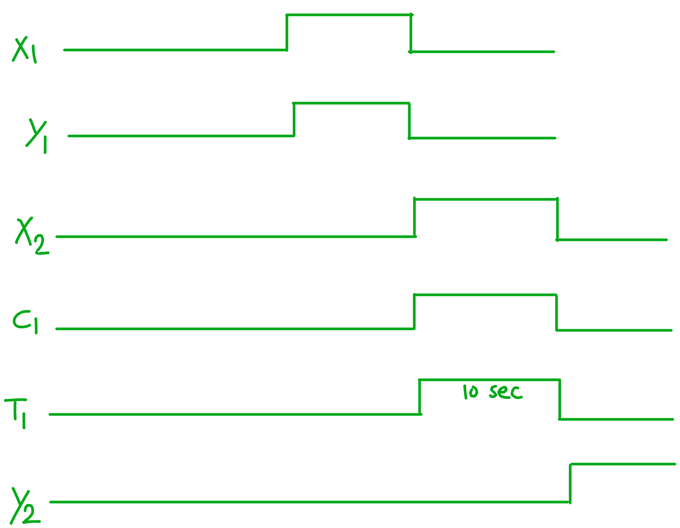
Answer :

→ c_1 is on if the timer is on and there is a part on heating coil

inputs → x_1, x_2

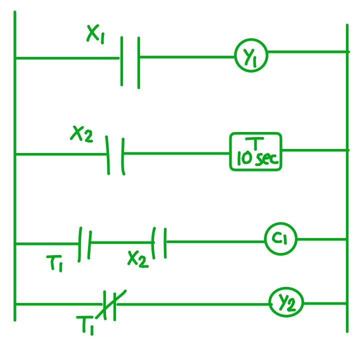
Timers → T_1

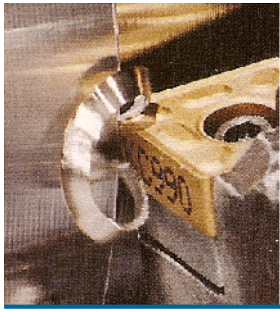
outputs → Y_1 robot signal nest → heating coil
→ c_1 heating coil
→ Y_2 robot signal



⇒

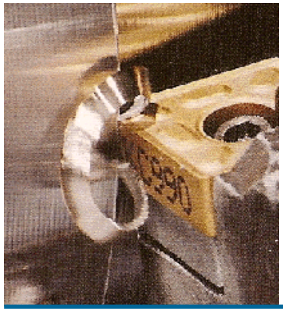
Ladder diagram





Another Question:

- An emergency stop system is to be designed for a certain automatic production machine.
- A single “start” button is used to turn on the power to the machine at the beginning of the day.
- In addition, there are two “stop” buttons located at two locations on the machine, either of which can be pressed to immediately turn off power to the machine.
- Let X1 = start buttom (normally open), X2 = stop button 1 (normally closed), X3 = stop button 2 (normally
- closed), and Y = power to the machine.

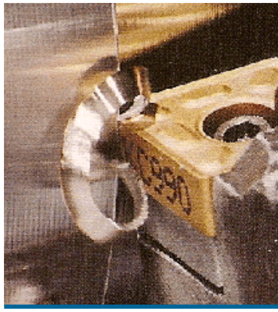


Another Question:

(a) Construct the truth table for this system.

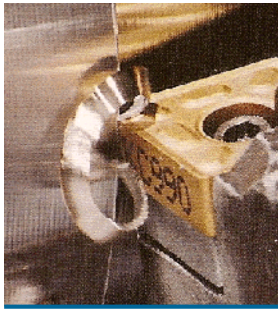
(b) (b) Write the Boolean logic expression for the system.

(c) (c) Construct the ladder logic diagram for the system.



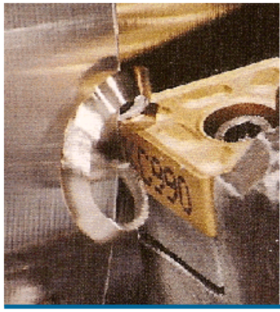
Sec 9.3: Programmable Logic Controller (PLC)

- https://www.youtube.com/watch?v=PbAGI_mv5XI
- https://www.youtube.com/watch?v=pPUnihpL6UI
- https://www.youtube.com/watch?v=wICG8d2iQ5c



Sec 9.3: Programmable Logic Controller (PLC)

- A microcomputer-based controller that uses stored instructions in programmable memory to implement logic, sequencing, timing, counting, and arithmetic functions through digital or analog modules, for controlling machines and processes.



Components of a PLC

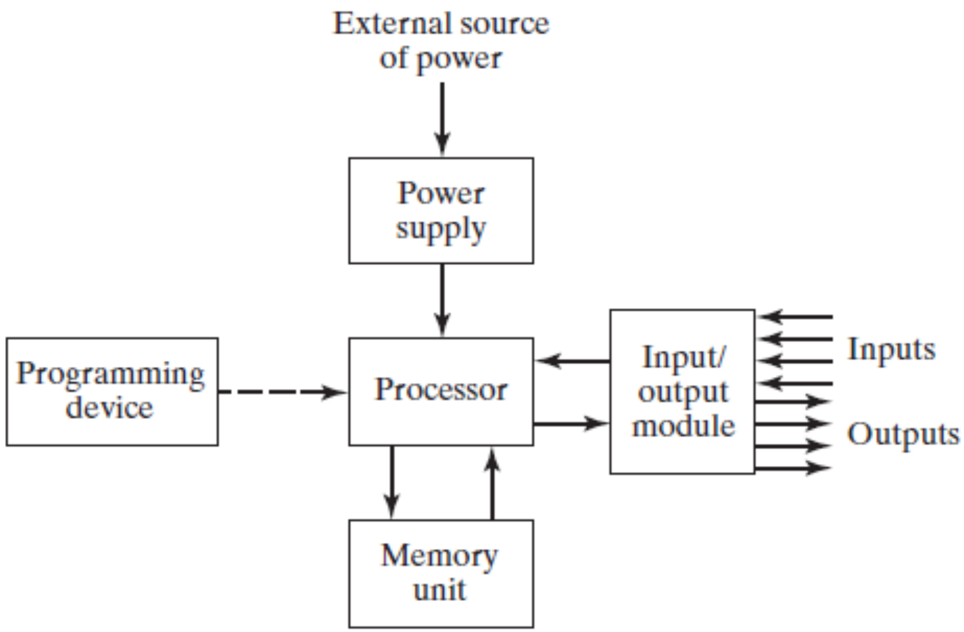
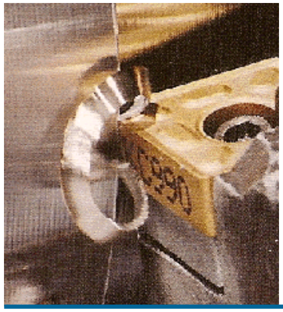
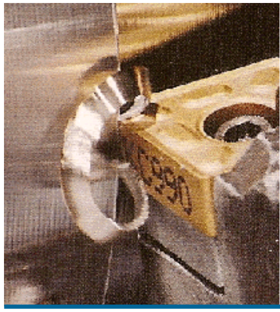


Figure 9.11 Components of a PLC.



Advantages of PLCs Compared to Relay Control Panels

- Programming a PLC is easier than wiring a relay control
- panel
- PLC can be reprogrammed
- PLCs take less floor space
- Greater reliability, easier maintenance
- PLC can be connected to computer systems (CIM)
- PLCs can perform a greater variety of control functions



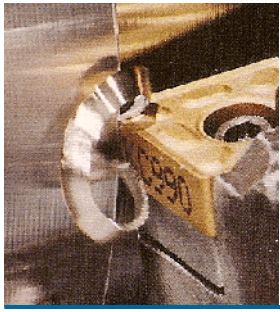
Typical PLC Operating Cycle

1. Input scan – inputs are read by processor and stored in memory
2. Program scan – control program is executed

- Input values stored in memory are used in the control
- logic calculations to determine values of outputs

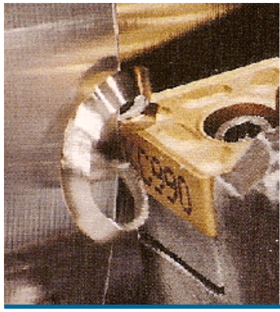
3. Output scan – output values are updated to agree with

- calculated values
- Time to perform the three steps (scan time) varies between 1 and 25 msec

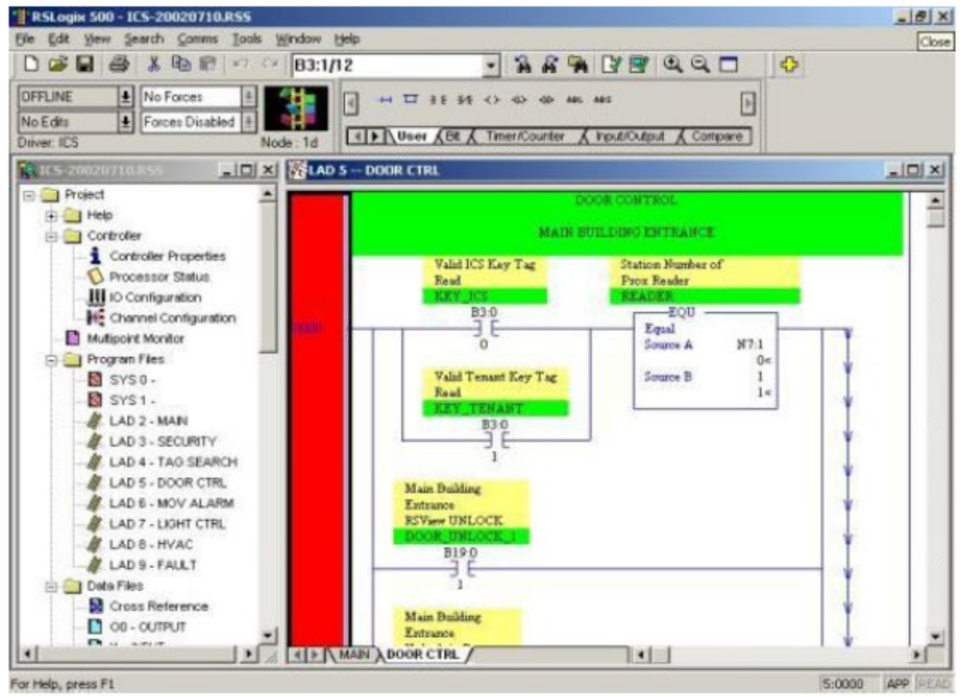


PLC Programming

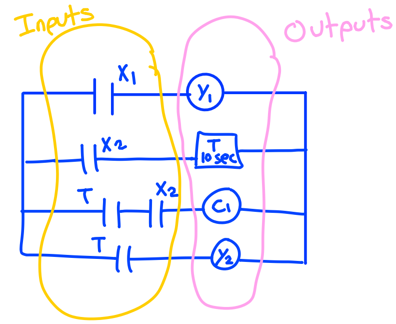
- Graphical languages:
  1. Ladder logic diagrams – most widely used
  2. Function block diagrams – instructions composed of operation blocks that transform input signals
  3. Sequential function charts – series of steps and transitions from one state to the next (Europe)
- Text-based languages:
  1. Instruction list - low-level computer language
  2. Structured text – high-level computer language



PLC Programming



inputs
outputs
كيف يرتبطو مع بعض
أهم اشي تحديد



PLC Questions

An Industrial Robot

An industrial robot performs a machine loading and unloading operation. A PLC is used as the cell controller. The cell operates as follows:

(1) a human worker places a part into a nest,

(2) the robot reaches over and picks up the part and places it into an induction heating coil,

(3) a time of 10 sec is allowed for the heating operation, and (

4) the robot reaches into the coil, retrieves the part, and places it on an outgoing conveyor.

A limit switch X1 (normally open) is used to indicate that the part is in the nest in step (1). This energizes output contact Y1 to signal the robot to execute step (2) of the work cycle (this is an output contact for the PLC, but an input interlock signal for the robot controller).

A photocell X2 is used to indicate that the part has been placed into the induction heating coil C1.

Timer T1 is used to provide the 10-sec heating cycle in step (3), at the end of which, output contact Y2 is used to signal the robot to execute step (4).

Construct the ladder logic diagram for the system

*** Inputs**

X_1 : limit switch
part on the nest

X_2 : photo cell
part on heating coil

*** Timer**

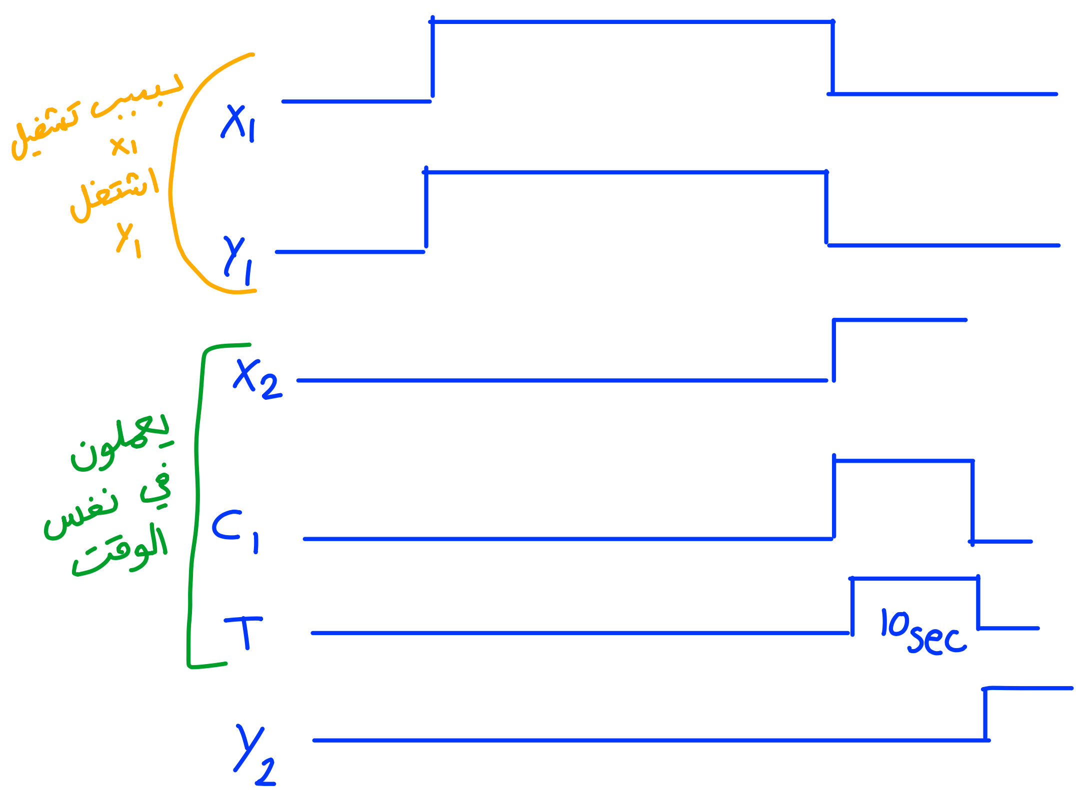
T : 10 sec

*** outputs**

Y_1 : Robot signal
nest ⟶ heating coil

Y_2 : Robot signal
heating coil ⟶ conuyer

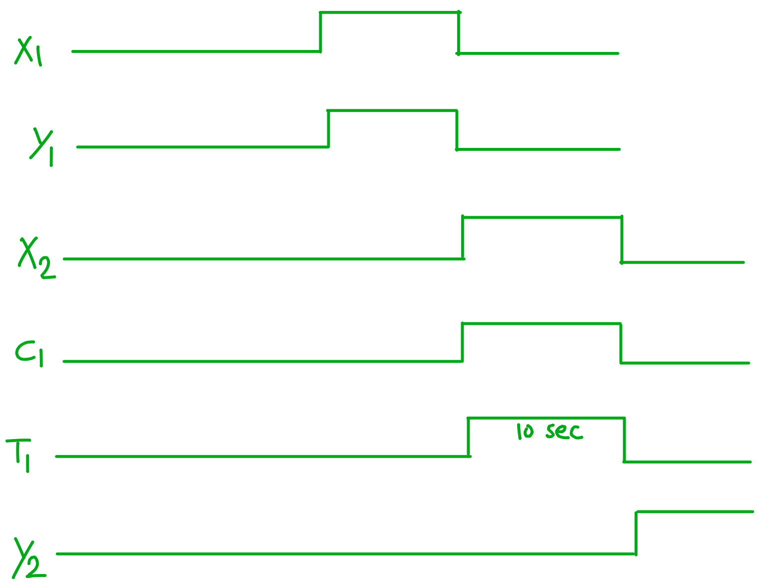
C_1 : heating coil



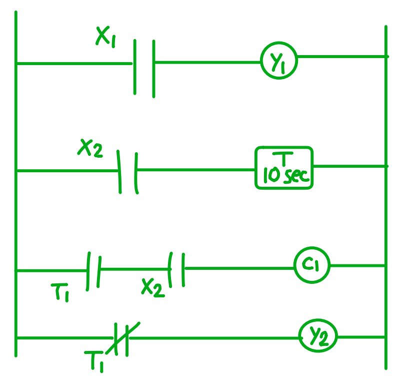
inputs → X_1, X_2

Timers → T_1

Outputs → Y_1 robot signal nest → heating coil
→ C_1 heating coil
→ Y_2 robot signal



Ladder diagram



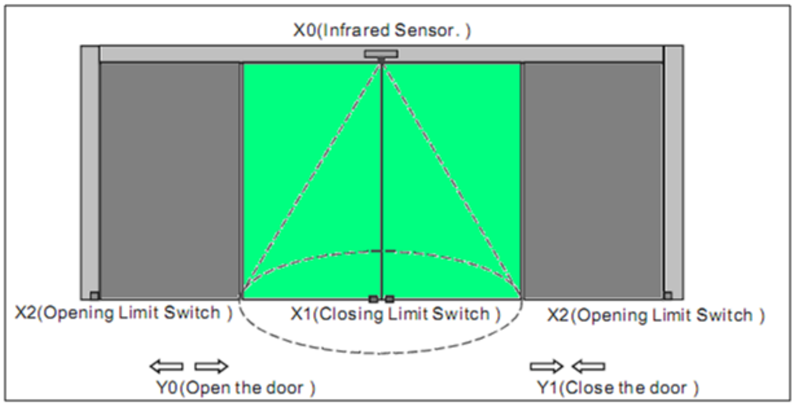
Inputs: Xo
X2 open limit switch
X1 close limit switch

Time: T : 7 seconds

outputs: Y0 open the door
Y1 close the door

يفتح الباب motor
يغلق الباب motor
sensor
ينتظر و هو فاتح 7 seconds الا اذا حداجي time

Automatic opening closing Door PLC Program



When someone enters the infrared sensing field, opening motor starts working to open the door automatically till the door touches the opening limit switch If the door touches the opening limit switch for 7 sec and nobody

enters the sensing field, the closing motor starts working to close the door automatically till the closing limit switch touched together. Stop the closing action immediately if someone enters the sensing field during the door closing process.

Number of PLC Inputs Required

X0 – X0 = ON when someone enters the sensing field.

X1 – Closing limit switch. X1 = ON when 2 switches touched together.

X2 – Opening limit switch. X2 = ON when the door touched the switches.

Number of PLC Outputs Required

Y0 -Opening motor

Y1 – Closing motor

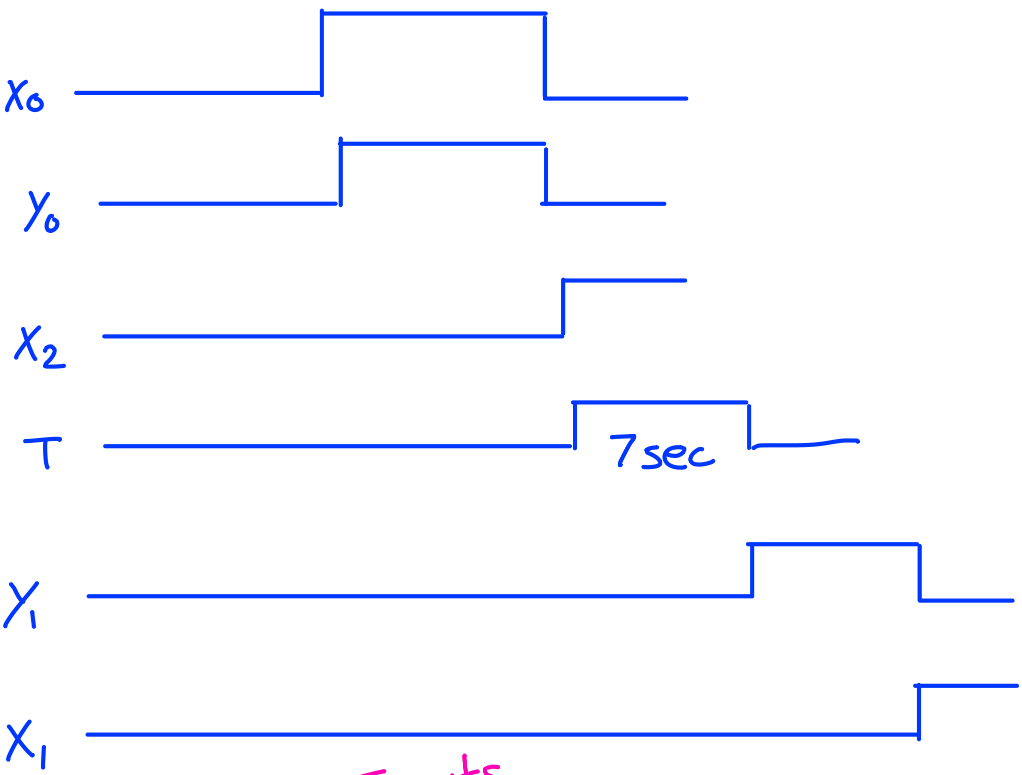
Number of PLC Timers Required

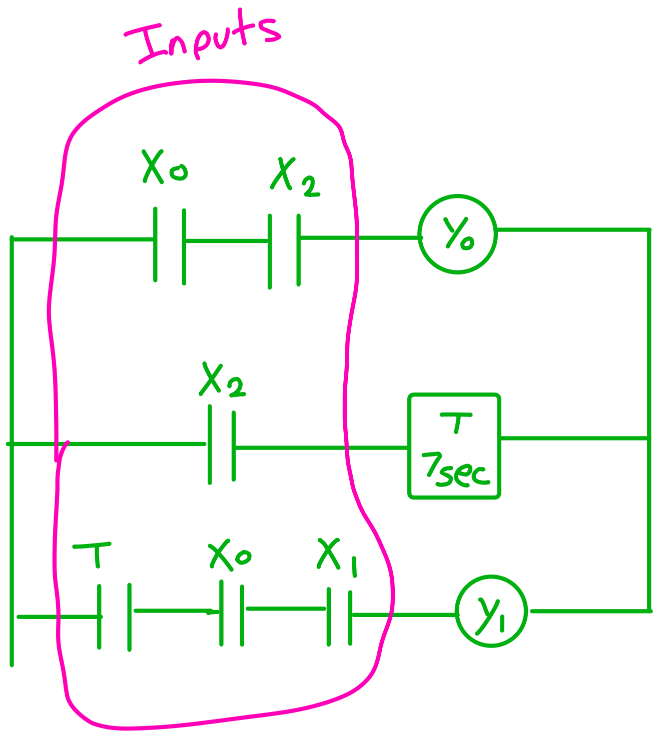
T0 – 7 sec timer.

Inputs:
X_0, X_2 open limit switch
X_1 close limit switch

Time: T : 7 seconds

outputs: Y_0 open the door
Y_1 close the door





Consider the Automatic coffee maker as illustrated in Figure 1:

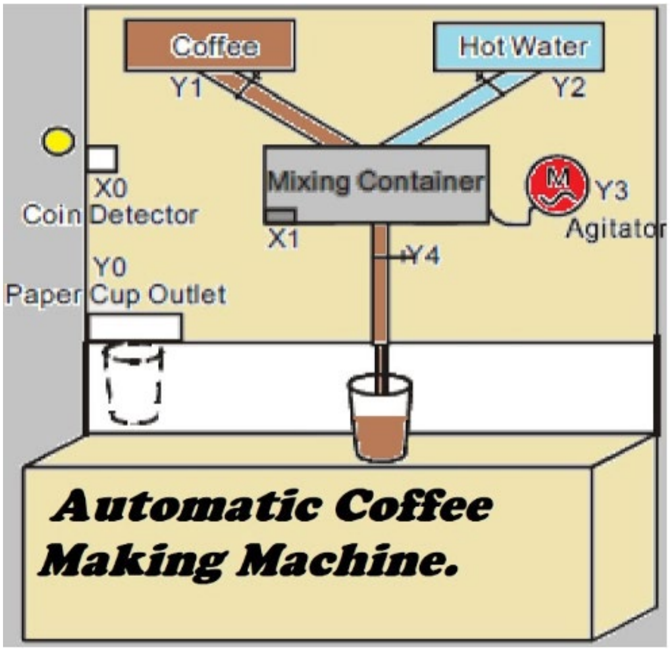
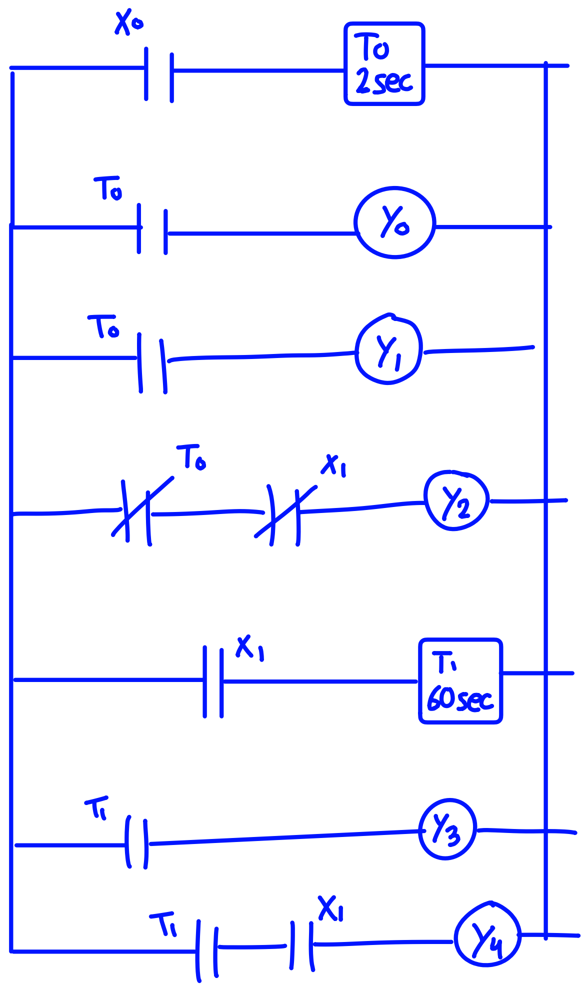


Fig.1 Automatic coffee maker

1. When a coin is inserted, ~~X1~~ اظن X0 is HIGH (ON) and the following outputs will be activated at the same time:
   - A timer T0 will be activated for 2 sec
   - Y0 (paper cup outlet) will be HIGH (ON) and latched (a paper cup will be sent out)
   - Y1 (coffee powder outlet) will be HIGH (ON) and latched (a certain amount of coffee will be poured into the container).
   - Y0 and Y1 will be HIGH (ON) for 2 sec, which is the set value of the timer T0.

2. After 2 sec, Y2 (hot water outlet) will be activated HIGH (ON), and the hot water will be poured in the container. At the same time, Y0 and Y1 will be closed LOW (OFF).
3. When the liquid in the container reaches a certain amount of pressure:
   - A pressure sensor X1 will be activated HIGH (ON).
   - Y2 will be reset LOW (OFF)
   - Timer T1 will be activated HIGH (ON) for 60 sec.
   - The agitator Y3 will be HIGH (ON) for 60 sec, which is the set value of Timer T1.
4. After 60 sec, the agitator Y3 will be Low (OFF) and Y4 (the ready – made coffee outlet) will be HIGH (ON) and latched and the ready –made coffee will be pouring out from the Y4 outlet.
5. When the coffee is poured into the paper cup completely, X1 will be LOW (OFF) and Y4 will be reset LOW (OFF) the ready-made coffee outlet will be closed.

Draw the PLC ladder diagram for the infusing container system above.



X0
T0 2sec
T0
Y0
T0
Y1
T0
X1
Y2
X1
T1 60sec
T1
Y3
T1
X1
Y4

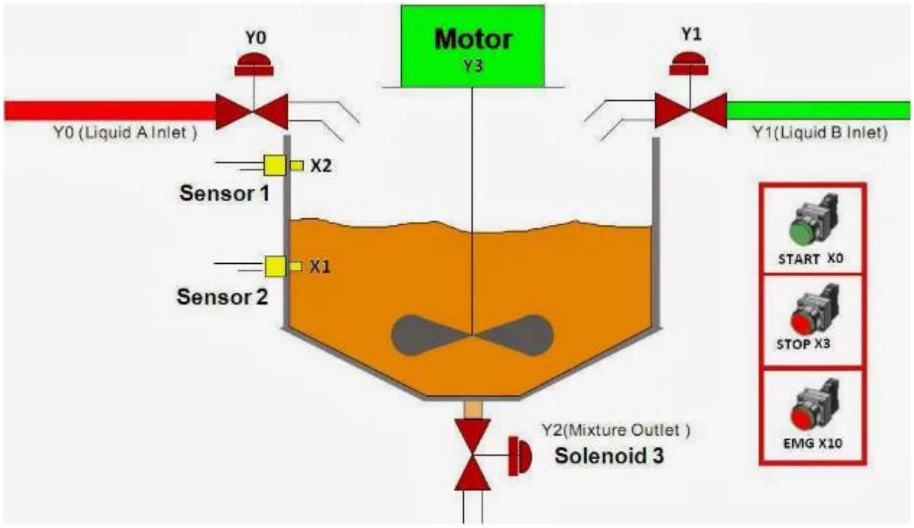
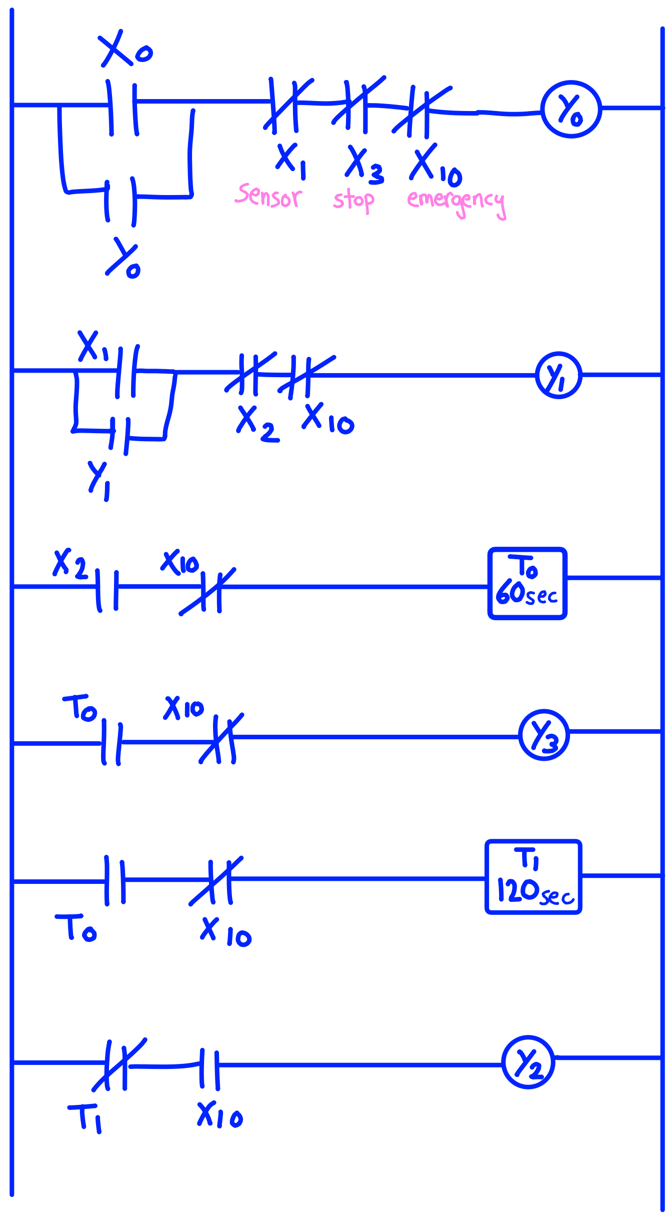


Fig.2

Consider the automatically infusing container with liquids A and B as illustrated in Figure 2:

1. When X0 (start button) will be ON when START is pressed. Y0 will be ON and latched, and the valve will be opened for infusing liquid A until the level reaches the low-level set point indicated by float sensor X1.
2. X1 will be ON when the level reaches the low-level float sensor. Y1 will be ON and latched, and the valve will be opened for infusing liquid B until the level reaches the high-level float sensor X2.
3. X2 will be ON when the level reaches the high-level float sensor. Y3 will be ON and activates the motor of the mixer. Also, timer T0 will be activated and start to count for 60 sec (mixing period).
4. After 60 sec, T0 will be OFF, and the mixer motor Y3 will stop working. Y2 will be ON , and the mixture will drain out of the container.
5. When Y2 = ON, timer T1 will be activated and start to count for 120 sec. After 120 sec, T1 will be Off and Y2 will be OFF. The draining process will be stopped.
6. When an error occurs, press EMERGENCY STOP button X10. The NC contact X10 will be ON to disable all the outputs. The system will then stop running.

Draw the PLC ladder diagram for the infusing container system above.



X0
X1
X3
X10
Y0
Sensor
stop
emergency
Y0
X1
X2
X10
Y1
Y1
X2
X10
T0
60sec
T0
X10
Y3
T1
120sec
T0
X10
T1
X10
Y2

Automation

There is a high connection between Automation and Manufacturing

Chapter Seven:
Computer Numerical Control (CNC)

Subtractive Manufacturing (Material Removal)

Dr. Eng. Baha'eddin Alhaj Hasan
Department of Industrial Engineering

CNC $\rightarrow$ Computer Controlled for machining and manufacturing (not handling not assembly)

Unit 7 Computer Numerical Control

Learning Objectives:

- ❑ Explain what NC is
- ❑ Explain what CNC is
- ❑ Outline how CNC work (Control system, Controller…)
- ❑ Explain the fundamentals of motion control in CNC
- ❑ Perform basic NC programming

- https://www.youtube.com/watch?v=FNYEXjRmDtI

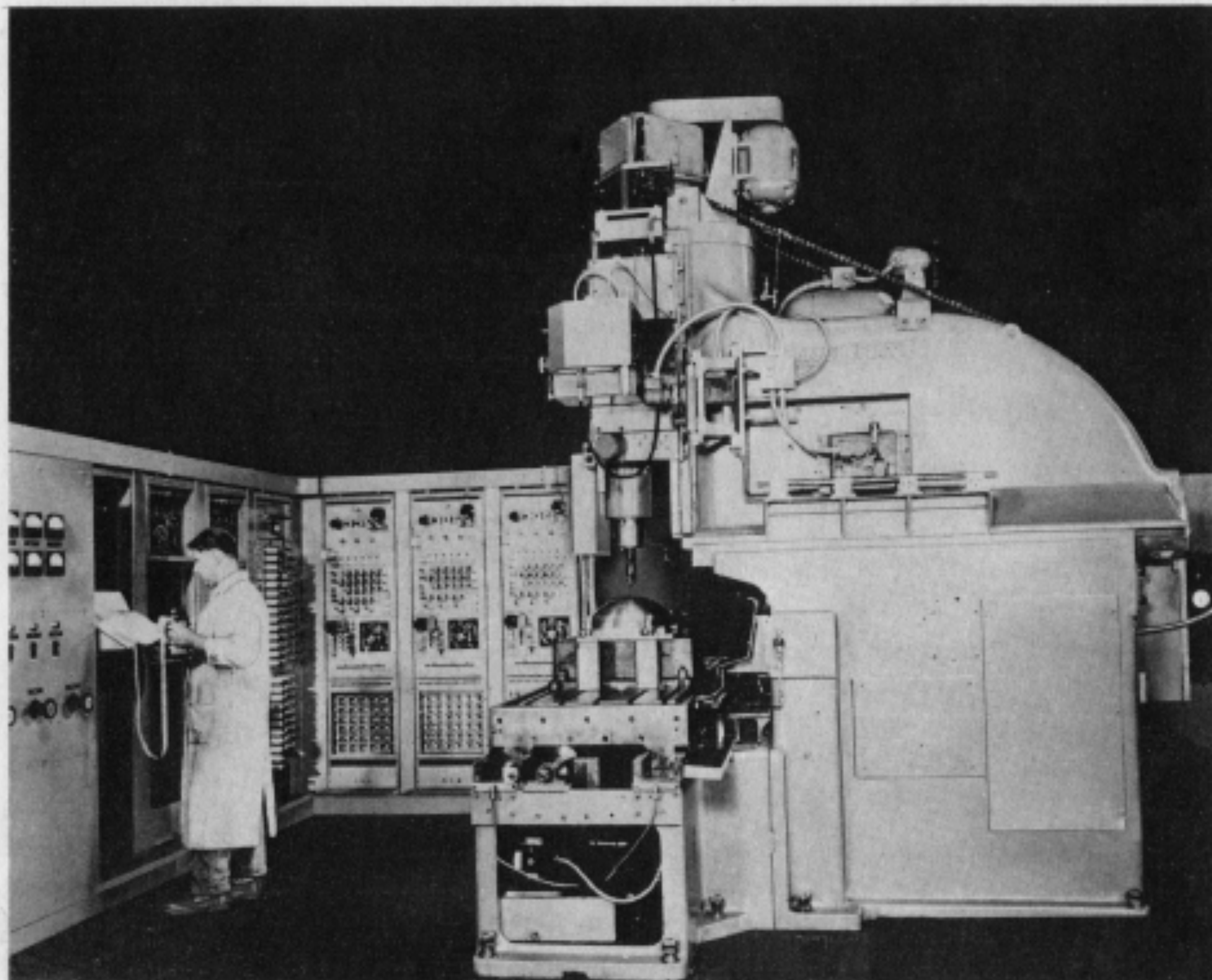
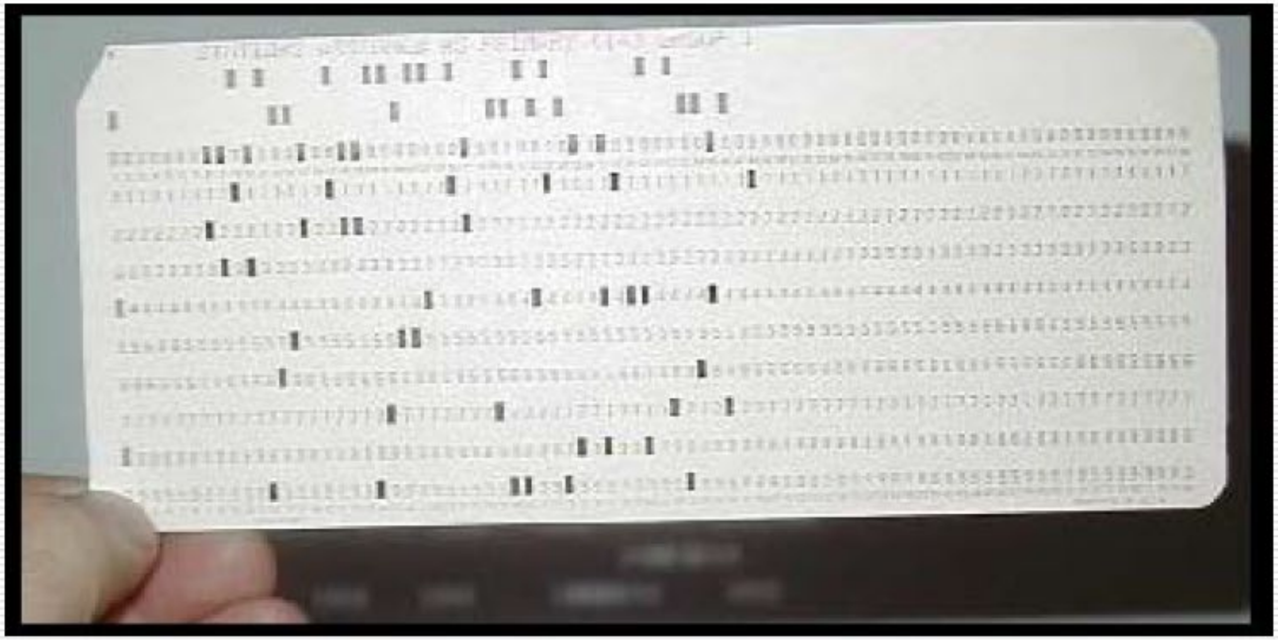
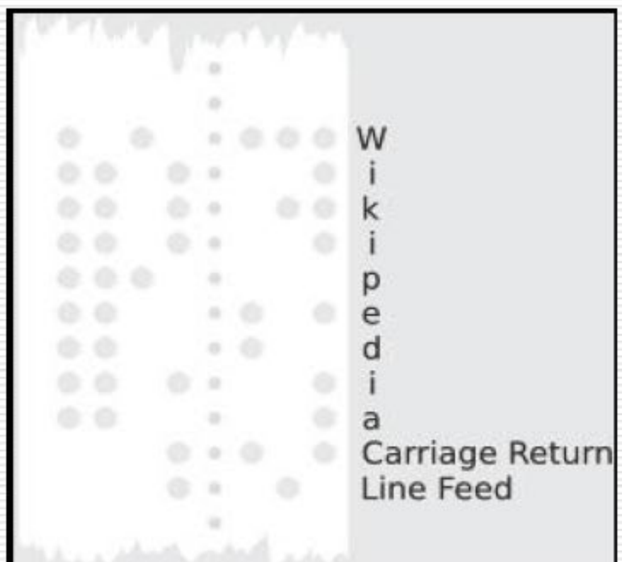
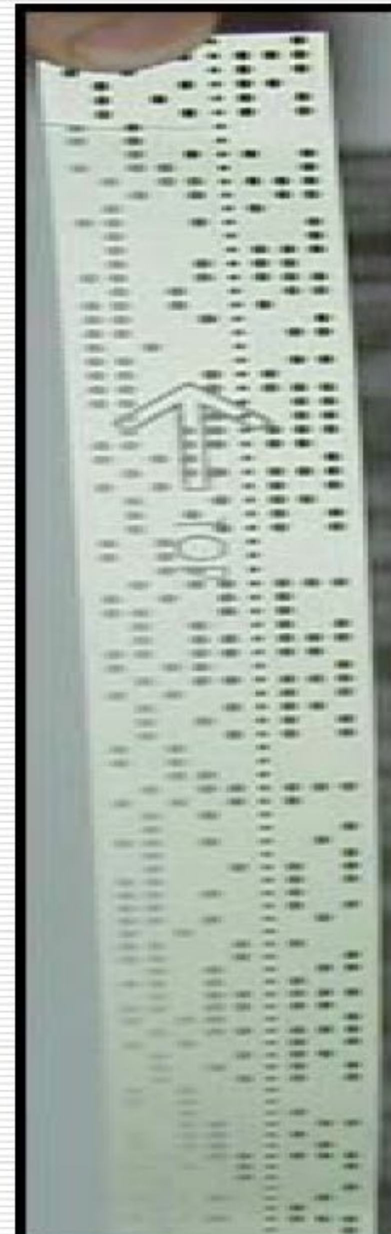


FIG. 1–8. Believed to be the first NC machine, the one shown above was successfully demonstrated at MIT in 1952.







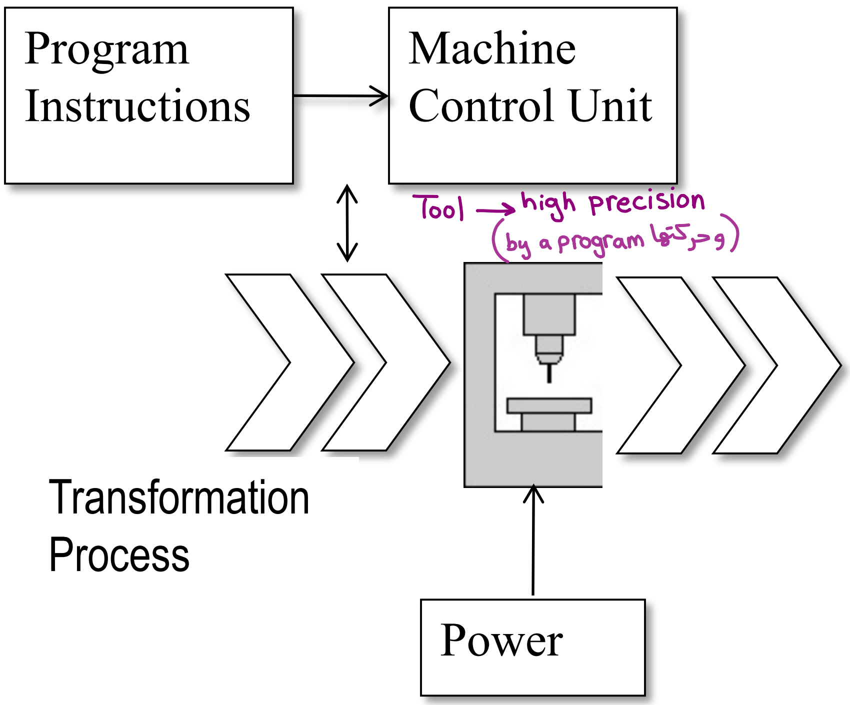
Source: Wikipedia

if I have a Computer base
then I have a (CPU)

Numerical Control (NC) Defined

- Programmable automation in which the mechanical actions of a 'machine tool' are controlled by a program containing coded alphanumeric data that represents relative positions between a work head (e.g., cutting tool) and a work part.

- Basic Components of NC:
  1. Program of instructions
     - Part program in machining
  2. Machine control unit
     - Controls the process
  3. Processing equipment
     - Performs the process

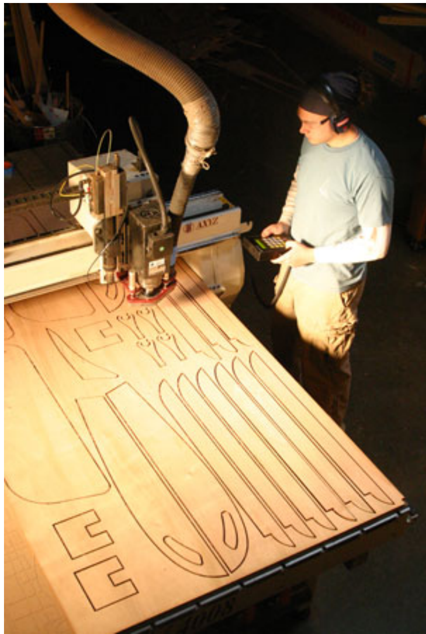


the Product is becoming more difficult

حجم ال Product يناسب مع حجم ال Machine

Turning Machine
(Tool ثابت
Product متحرك)

CNC Laser Cutting Machine, Capacity upto 28 mm Thickness.

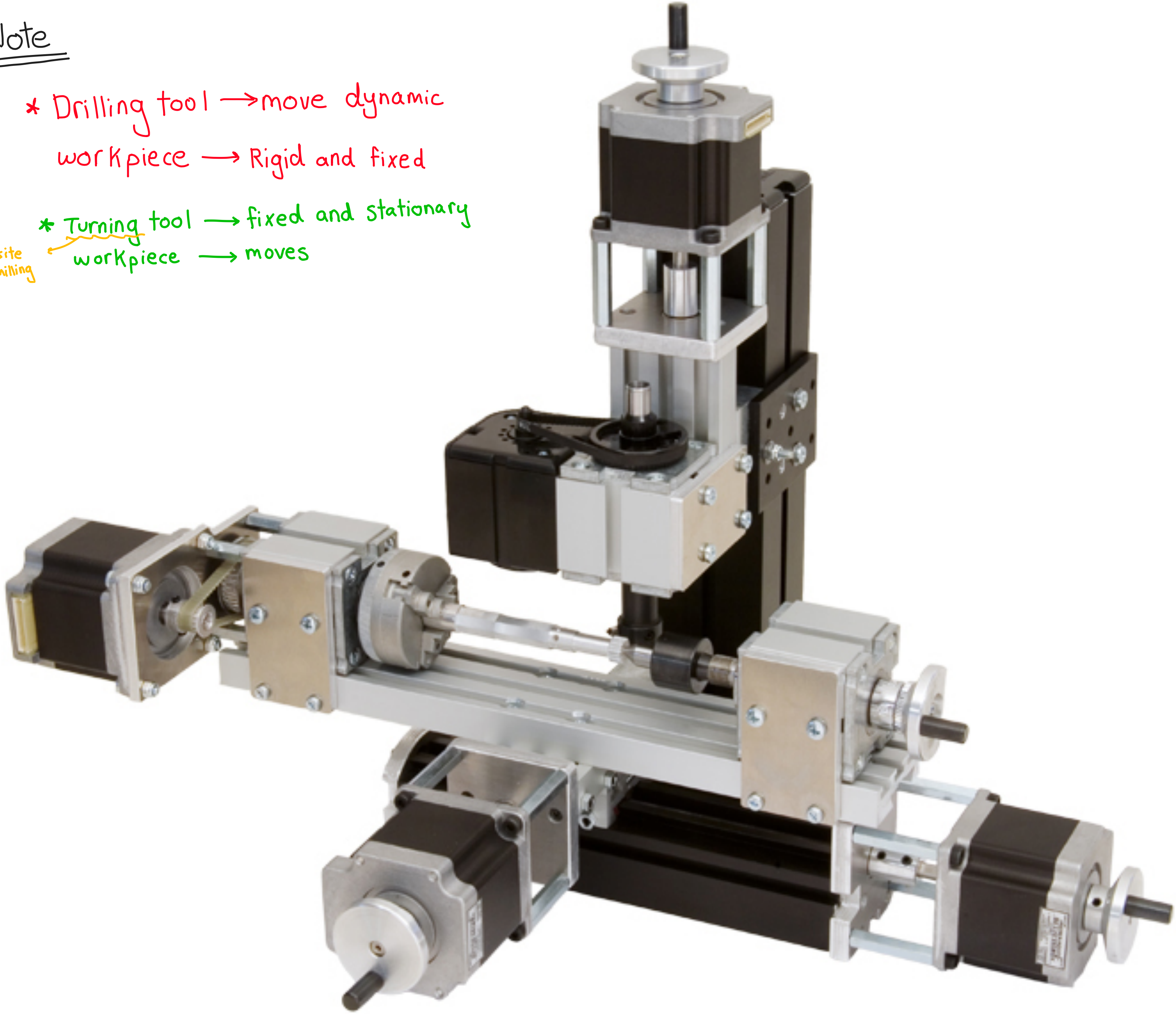


Note

* Drilling tool → move dynamic
workpiece → Rigid and fixed

* Turning tool → fixed and stationary
workpiece → moves

opposite for milling



كل CNC machine بكون عندها على الأقل (2-axis)

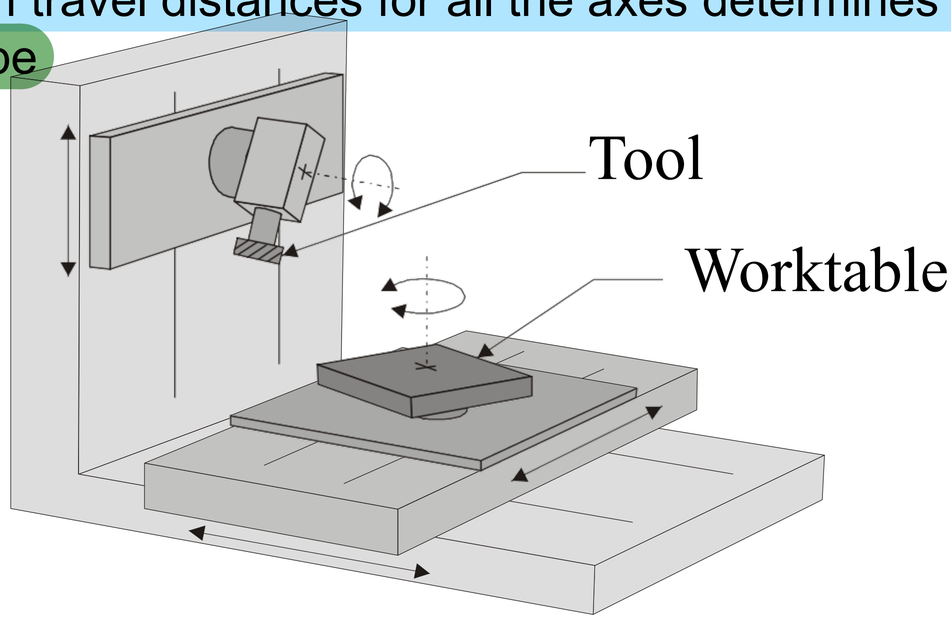
Machining using NC

- Machining refers to cutting operations that are based on the removal of material from a rough-shaped workpiece via turning, milling, drilling, etc:
- Example: Up to 5 motion axes may need to be controlled simultaneously.
- Each linear axis has a maximum travel distance. The combination of the maximum travel distances for all the axes determines a machine's work envelope

كل axis له Range معين

مهم

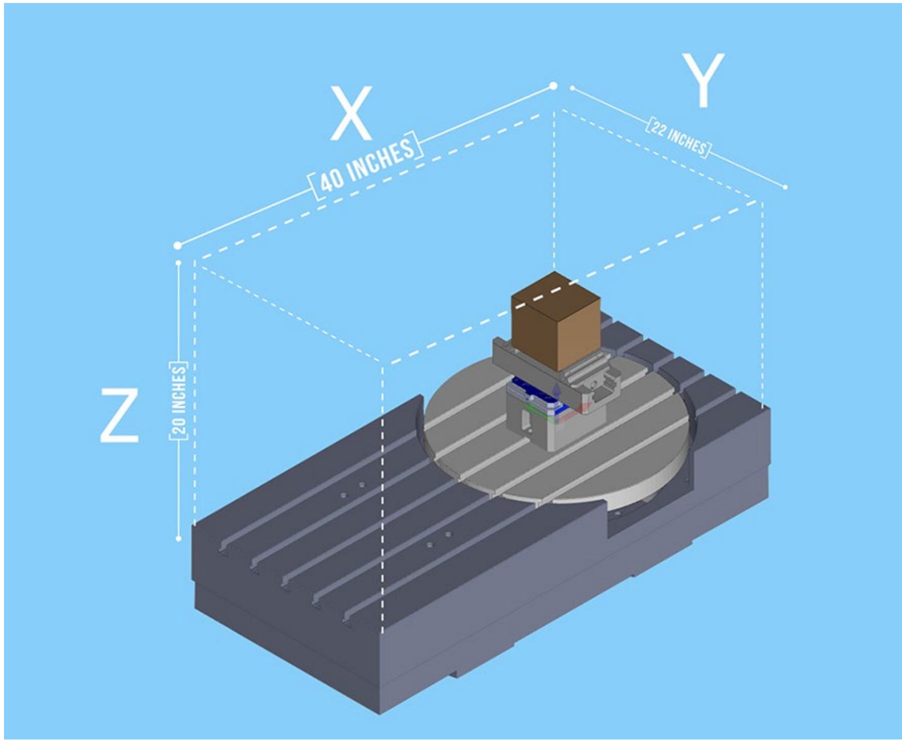
in Milling Machines



machine's work envelope

The Machine Tool Envelope is the physical zone that the machine tool can reach.

The Product dimensions should be compatable with the work envelop



There is difference between CNC machine and robots

CNC machine

1. specalized in machining
2. used for machining operations (removing materials)

robots

1. the working area is Larger
2. used for assembly operations

كلما زاد تعقيد الـ Product ↑

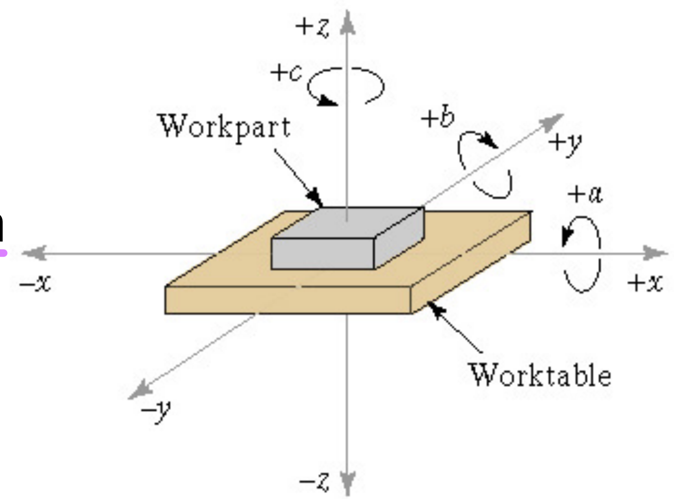
زاد مدى تعقيد الـ CNC machine ↑

Milling Machines are usually with flat surfaces

NC Coordinate Systems

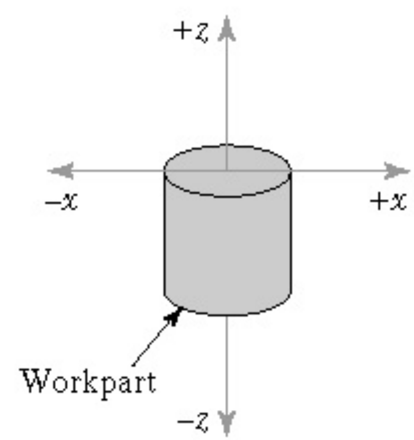
For flat and prismatic (block-like) parts:

- Milling and drilling operations
- Conventional Cartesian coordinate system
- Rotational axes about each linear axis



For rotational parts:

- Turning operations
- Only *x*- and *z*-axes



Computer Numerical Control $\boxed{\text{(CNC)}}$

مميزات الـ (CNC)

١) دقة عالية

٢) الـProgramming يكون مرة وبعدين اما بعدل عليه

بعيده من الصفر

- Computer Numerical Control (CNC) has one microcomputer at the machine tool to control the NC functions
- CNC machines thus provide a high level of:
  - Accuracy
  - Repeatability
  - Programming capability
- CNC advantages
- Program entry only once, stored in memory to □ errors
- Program can be edited at the machine site
- Therefore - more flexible
- Integrated with the manufacturing information system

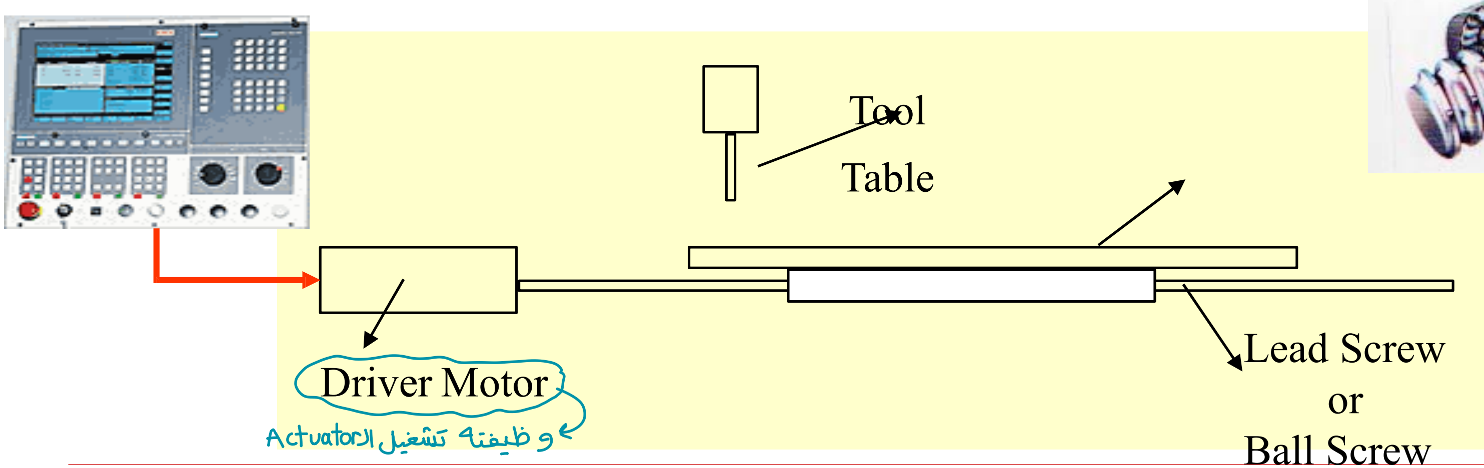
Motors in CNC machines :-
1. Stepper Motor → High precision with low Torque → (open Loop)
2. Servo Motor → feedback already connected → (closed Loop)

العملية مرتبطة بال coordinate axises *

نقص

How CNC Work?

- Each CNC machine has a CNC controller which can be programmed to drive the machine through a series of motions
- Axis: Each direction of motion of a CNC machine is called an axis. It is simply a direction of motion under the influence of the CNC controller. It can either be linear or rotary.
- Ball (lead) screw transfer rotation to linear motion of the mechanical device. The drive motor is the link between the ball screw and the CNC control. The motor can be either a stepper motor or a servo motor.



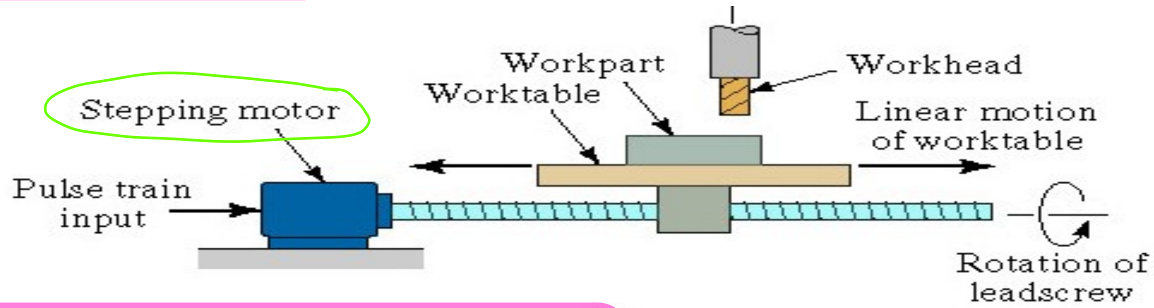
وظيفته تشغيل الActuator

Stepper Motor

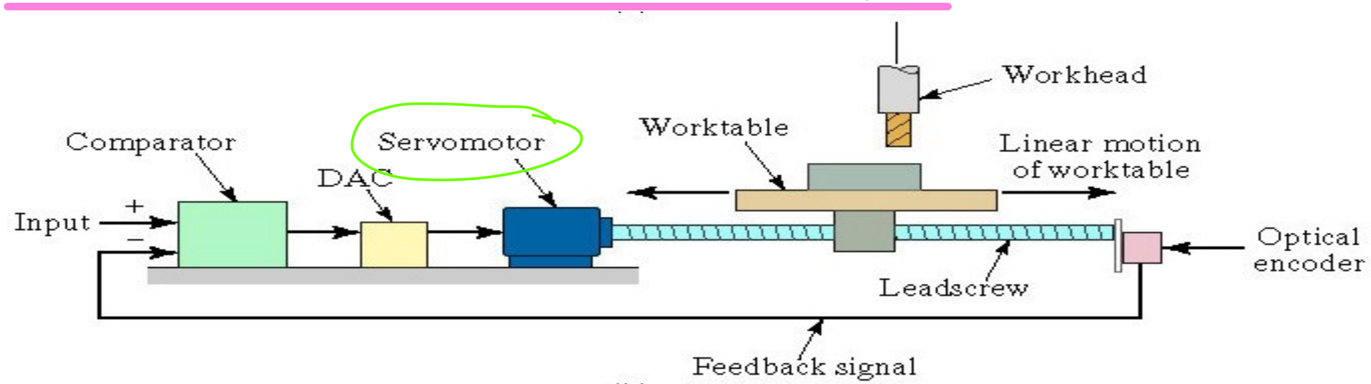
Control Systems

Stepper Motor Characteristic

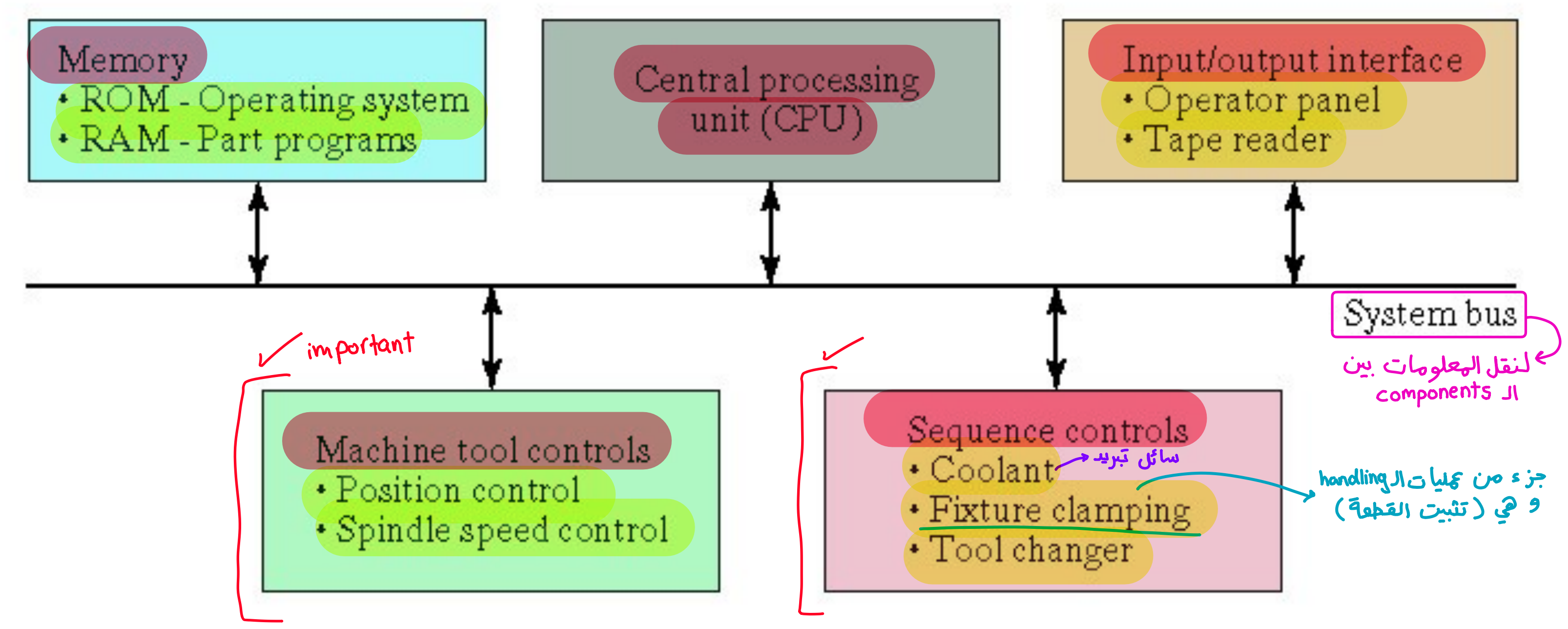
- **Open-Loop Motion Control System**
  - Operates without verifying that the actual position achieved in the move is the desired position



- **Closed-Loop Motion Control System**
  - Uses feedback measurements to confirm that the final position of the worktable is the location specified in the program



Basic Components of Controller



https://www.youtube.com/watch?v=54D1IGBMw_E

Motion Control Systems

- Point-to-Point systems
- Also called position systems
- System moves to a location and performs an operation at that location (e.g., drilling)
- Also applicable in robotics

- Continuous path systems
- Also called contouring systems in machining
- System performs an operation during movement (e.g., milling and turning)

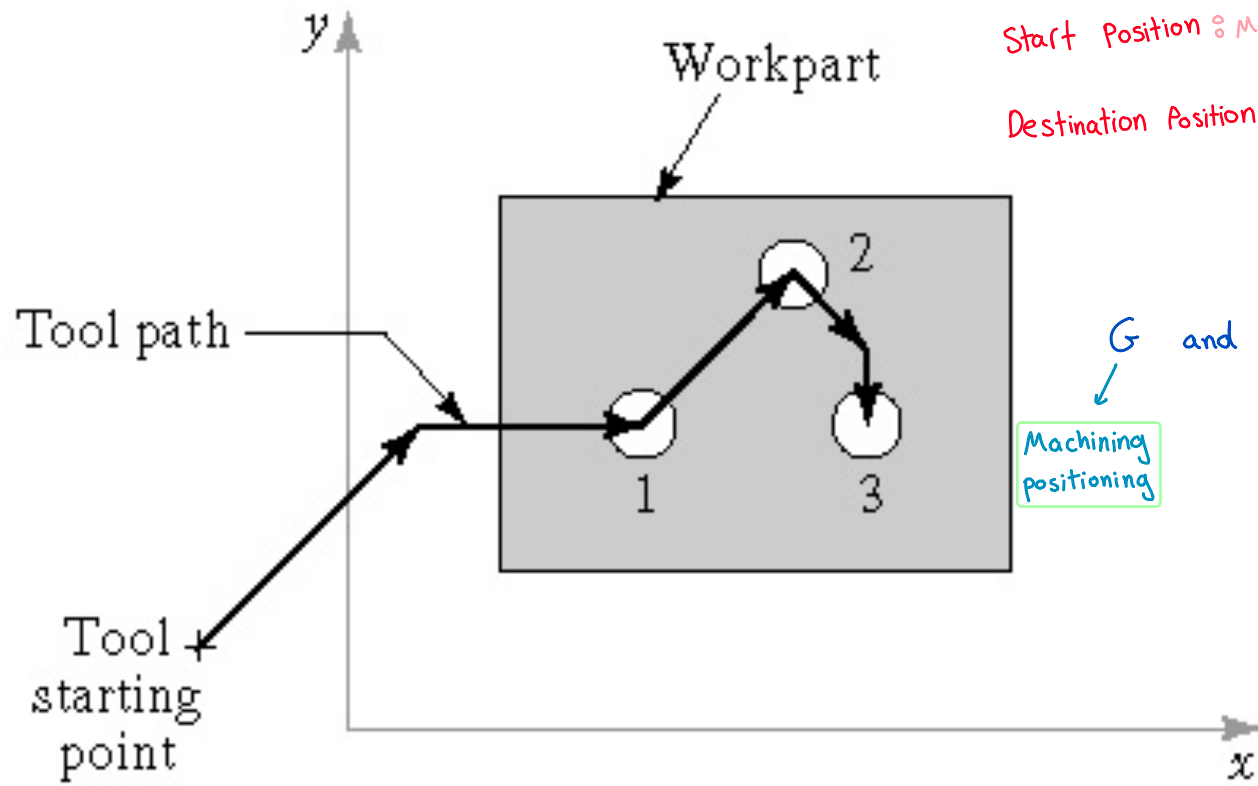
Point-To-Point Control in NC

Example: Drilling of Three Holes in Flat Plate

Home Position : reset position

Start Position : Machining start point

Destination Position : Maching end point



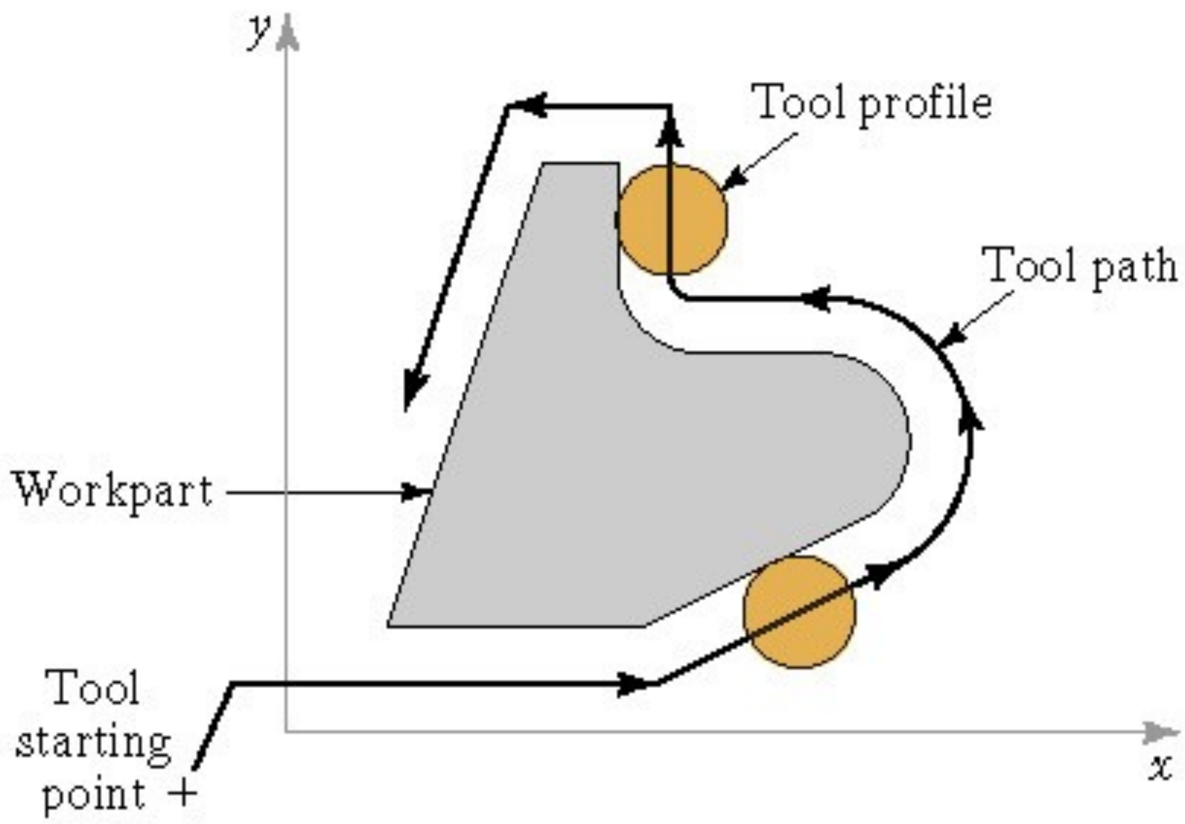
G and M code

G → Machining positioning

M → Auxiliary functions
- -coolant ON/OFF
- -spindle CW/CCW
- -RPM
- -Feedrate

Continuous Path Control in NC

Example: Profile Milling of Part Outline



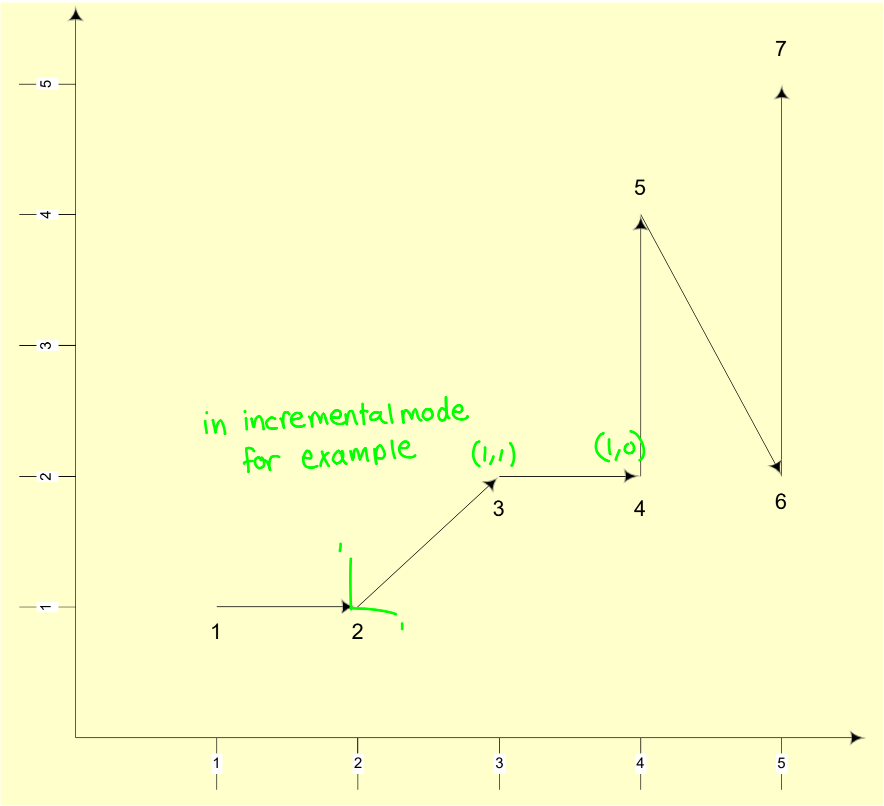
كود خاص لكل واحد منهم
G-code

Absolute Vs. Incremental Mode

- **Absolute Mode** (Reference: datum/origin)
  - the distances moved are relative to the program zero.

- **Incremental Mode:** (reference: the previous point (Last point))
  - the distances moved are relative to the machine's current position.

Example



2 Types

Point	Absolute Mode (Refrence is (0,0))	Incremental Mode (Reference is the (previous point))
1	X 1.0 Y 1.0	X 1.0 Y 1.0
2	X 2.0 Y 1.0	X 1.0 Y 0.0
3	X 3.0 Y 2.0	X 1.0 Y 1.0
4	X 4.0 Y 2.0	X 1.0 Y 0.0
5	X 4.0 Y 4.0	X 0.0 Y 2.0
6	X 5.0 Y 2.0	X 1.0 Y –2.0
7	X 5.0 Y 5.0	X 0.0 Y 3.0

Motion Interpolation Methods

G90 absolute Mode
G91 Incremental Mode

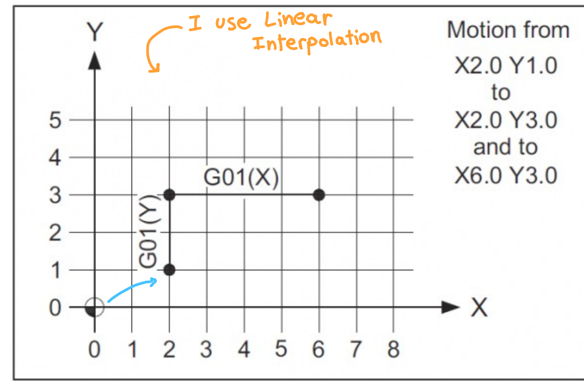
1. **Linear interpolation**

Linear → code G01

G90
G00 X2 Y1 Z0
Move from Home position to Start position
G01 X2 Y3 Z0
G01 X6 Y3 Z0

- Straight line between two points in space
- used in part programming to make a straight cutting motion from the cutter start position to its end position.

G90
G00 X2 Y1 Z0
G01 X2 Y3 Z0
G01 X6 Y3 Z0

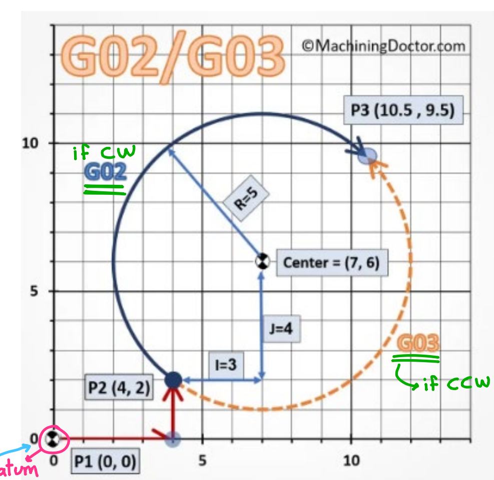


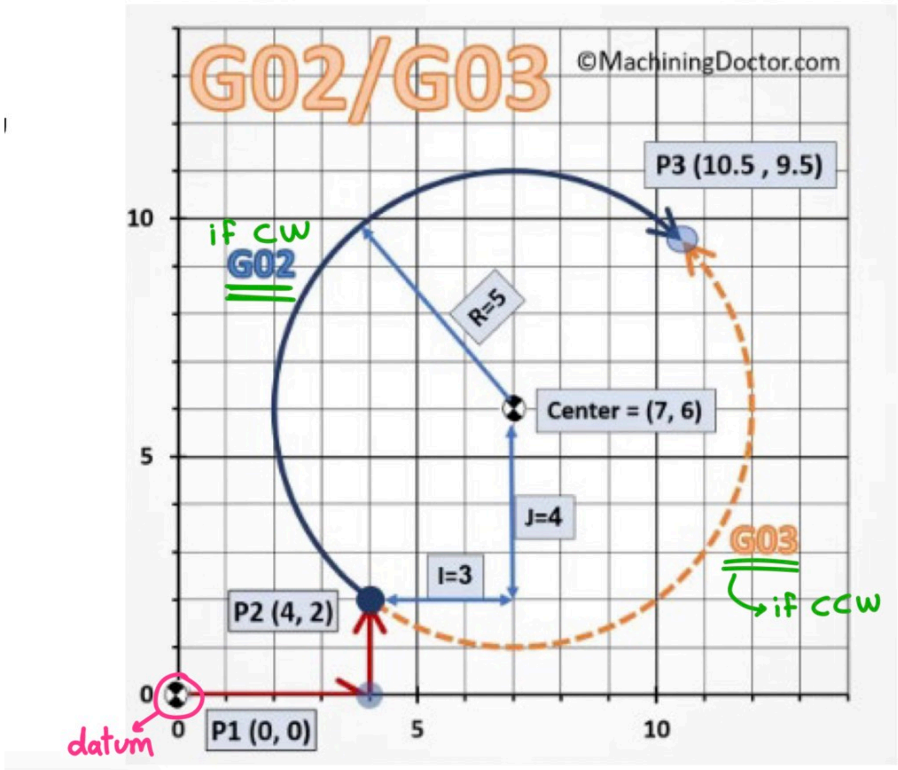
Home Position datum

2. **Circular interpolation** → (CW/CCW)

- Circular arc defined by starting point, end point, center or radius, and direction
- G02 instructs the CNC machine to move along a Circular Arc from its current position to a new coordinate

Next slide ←





G90 absolute Mode
G91 Incremental Mode

P1 Home
P2 start
P3 distination

G90
G00 X4 Y2 Z0
G02 X10.5 Y9.5 Z0 R5

cw (G02)

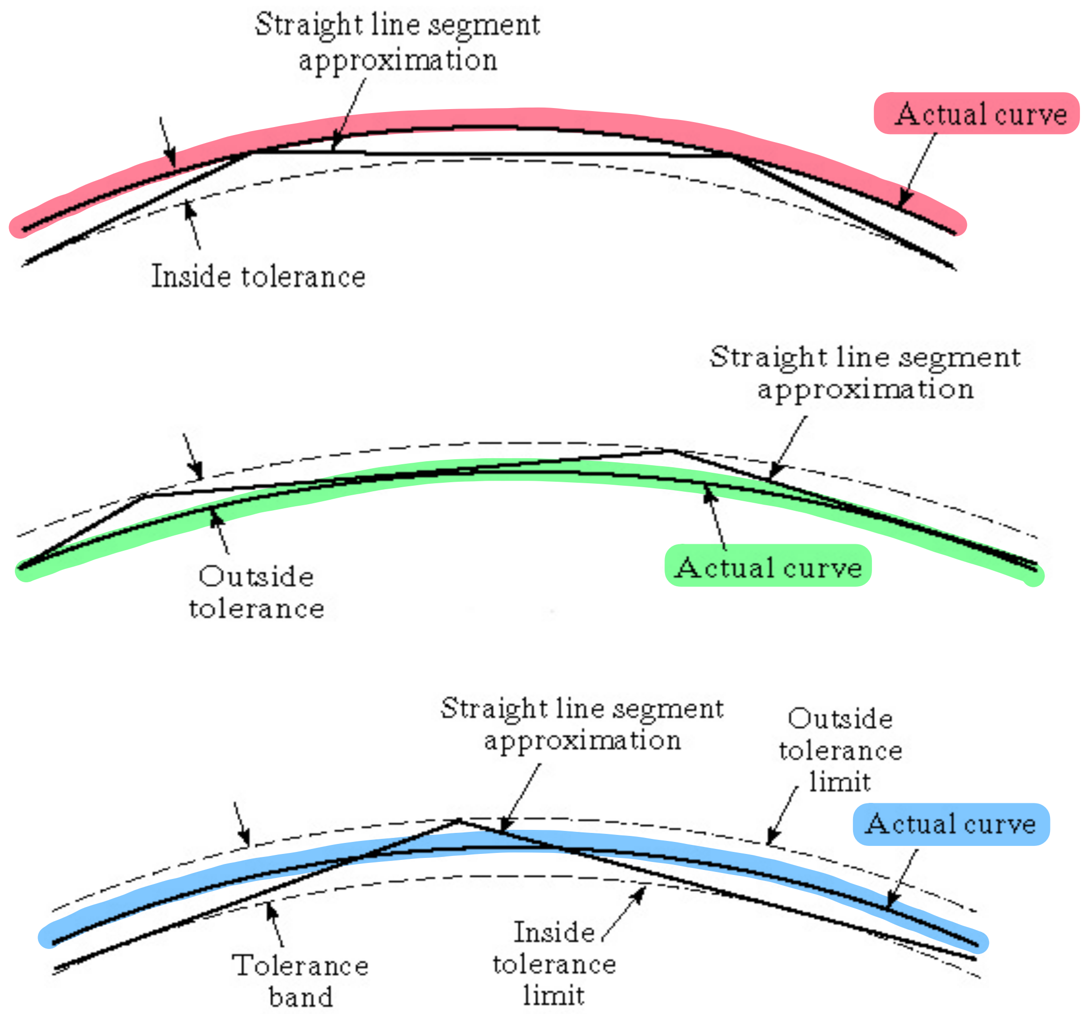
ccw (G03)

Motion Interpolation Methods

3. Helical interpolation
   - Circular plus linear motion

4. Parabolic and cubic interpolation
   - Free form curves using higher order equations

Circular Motion



G-code → specialized in motion and machining way
N-code → specialized in operations (مثل زيادة السرعة)

NC Part Programming

- Data for producing a part by NC machining
  - Part drawing (design) information

depends on product design

    - Dimension - length, width, height, radius, etc.
    - Segment shape to calculate tool path - linear, circular, parabolic, etc.
    - Diameter of holes to be drilled
  - Machining parameters

depends on application and material

    - Depend on surface quality, required tolerances, type of work piece (material) and cutting tools, feed rates, spindle speeds, and auxiliary functions (on/off coolant)
  - Part programmer determined data

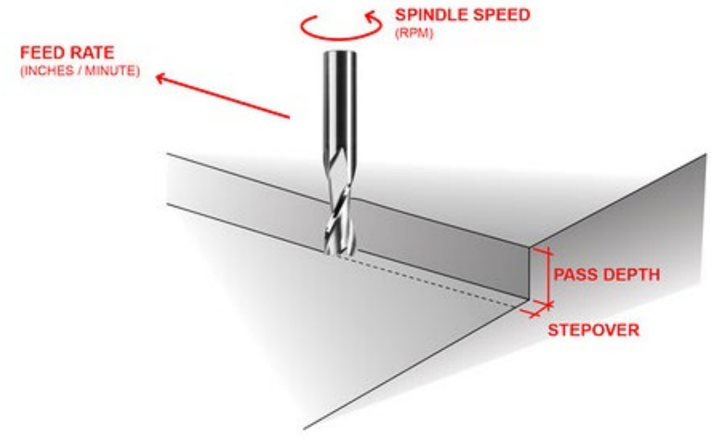
depends on human experience

    - Cutting direction, change of tools, and sequence of operations (optimal - OR problem)

يتناسب عكسياً مع مقاومة المادة

What is Feed Rate?

- Feed rate is the distance which the cutting tool during one spindle revolution. It is also defined as the velocity at which the cutter is advanced against the workpiece. It is measured in either inch per revolution or millimeters per revolution (ipr or mpr) for turning and boring processes.



Feed Rate and Spindle Speed

NC Programming Languages

- There does not exist a standard NC programming language
- Every CNC machine manufacturer has a special language for programming their machines.
- The closest to a standard language are G/M codes.
  - A G/M code CNC program is made up of a series of commands. Each command or block is made up of words
  - Each word is composed of a letter address (X,Y,Z,R, etc.) and a numerical value.

word	word	word			
N005	G00	X10	Y10	Z10	M03
sequence number	G code	dimensions for G code			

Block or Command

Components of a G/M Code Program

- Sequence number (N-words)
- Preparatory work (G-words)
  - Example: Instructions to the controller G00 Point-to-point operation (rapid speed)
- Coordinates (x-, y-, z-words)
- Feed rate (F-words)
  - Feed rate - in./min.
- Spindle speed (S-words)
  - RPM - rev./min.
- Tool selection (T-words)
- Tool length offset (H-words)
- Tool radius offset (D-words)
- Specifies Miscellaneous functions (M-words)

Standard codes

(بالعادة الدكتور بجيبهم بالامتحان)

M- Words

- Miscellaneous function (<u>M-words</u>)

M00	Stop program
M03	Start spindle on CW direction
M04	Start spindle on CCW direction
M05	Stop spindle
M06	Tool change
M07	Turn coolant on (mist mode) Turn
M08	coolant on (flood mode) Turn
M09	coolant off
M30	End of program

G-Words

- Instructions to the controller

G00 Point-to-point operation (rapid speed) G01 Linear interpolation

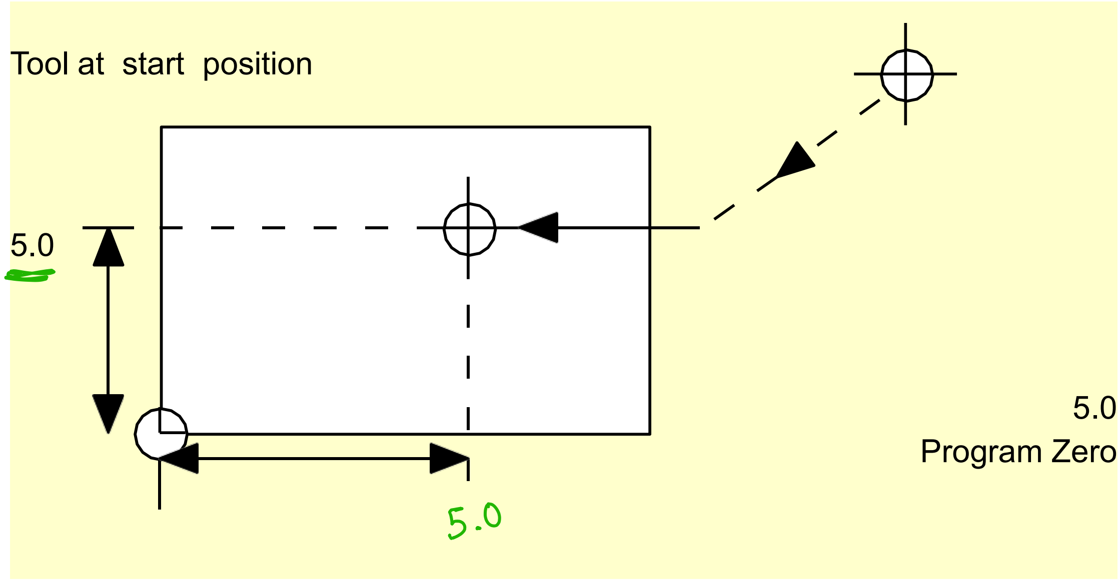
G02 Circular interpolation - clockwise

G03 Circular interpolation - counterclockwise G04 Dwell (wait) for programmed duration G90 Absolute mode

G91 Incremental mode

Example 1

N015 G00 X5.0Y5.0

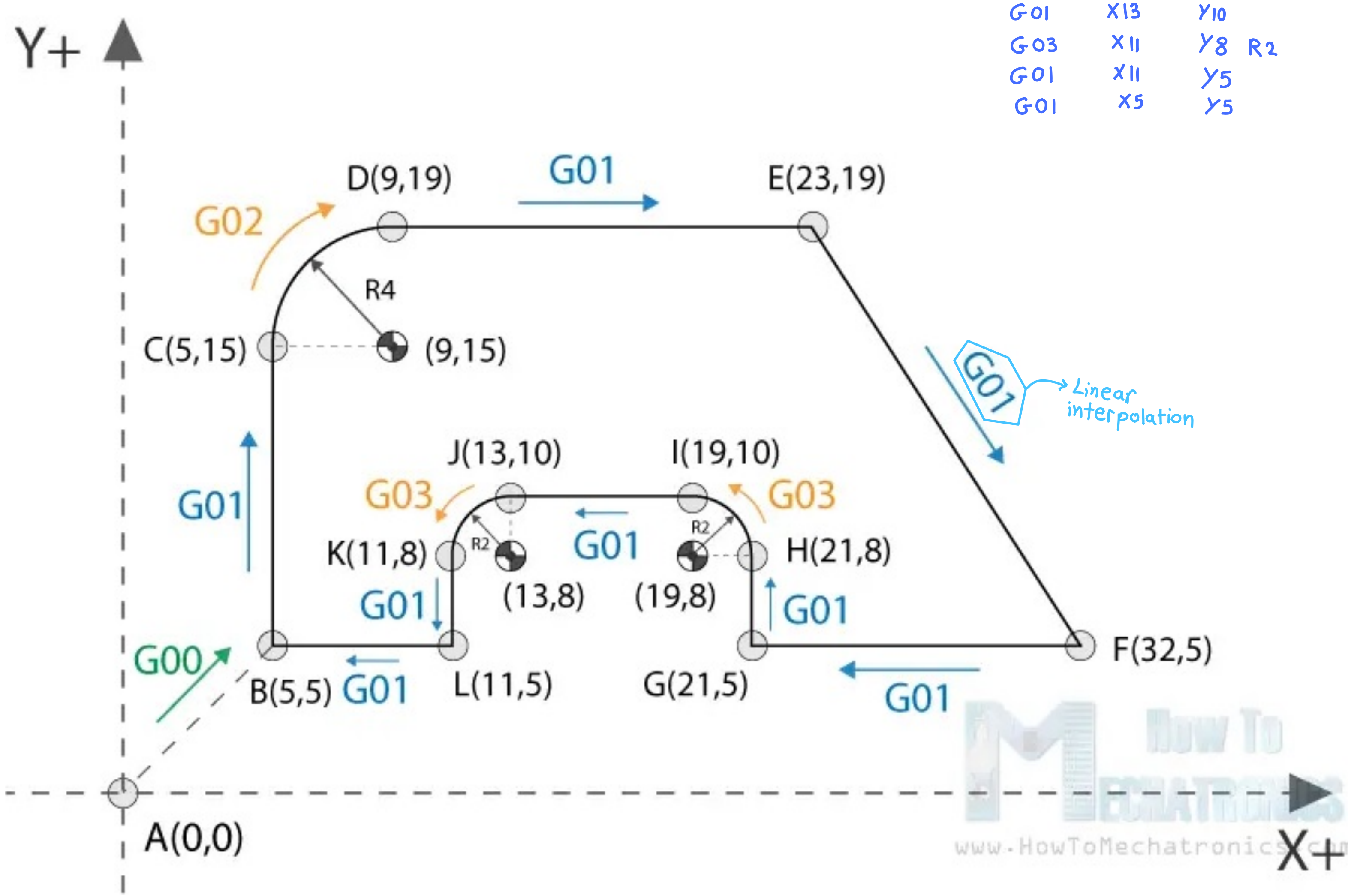


Example 2

إما السؤال يحدد الـ direction أو انا بحدده

G90

G00 X5 Y5
G01 X5 Y15
G02 X9 Y19 R4
G01 X23 Y19
G01 X32 Y5
G01 X21 Y5
G01 X21 Y8
G03 X19 Y10 R2
G01 X13 Y10
G03 X11 Y8 R2
G01 X11 Y5
G01 X5 Y5



I_x or I_y = center point of the arc − started point of the arc

(CP − CE)

يمكن
غلط

$I_x = 200 - 140$

Example 3

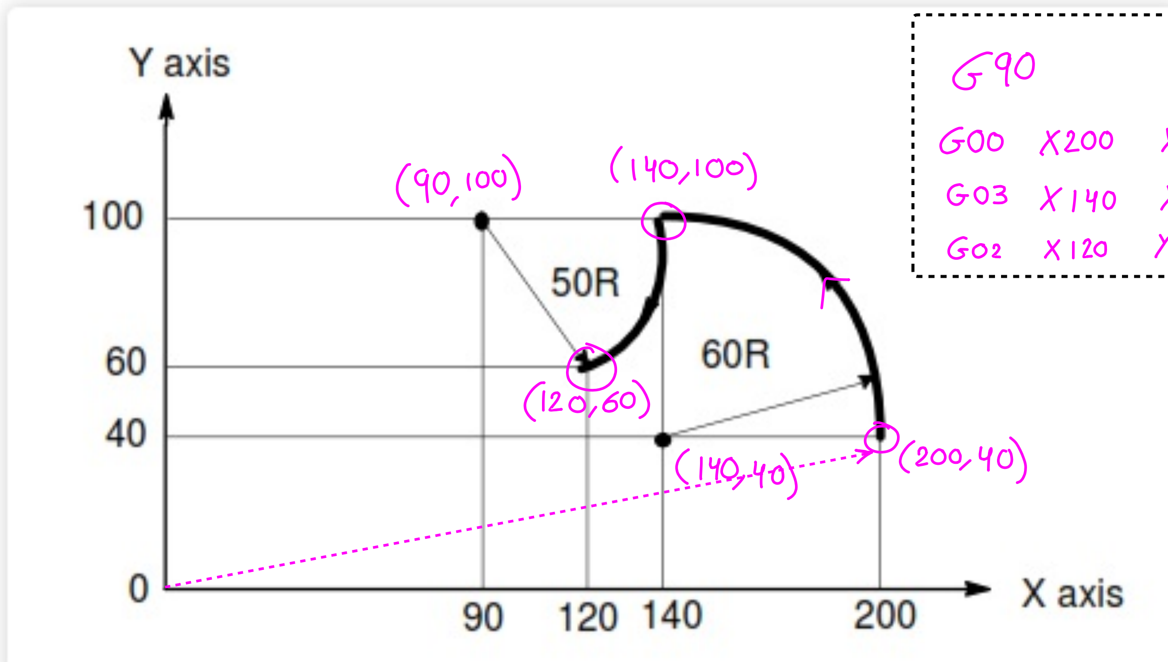
center (140, 40)

start (200, 40)

Another way

```
G90 G00 X200 Y40
    G03 X140 Y100 R60   F1000
                        for example
    G02 X120 Y60 R50
```

```
G90
G00 X200 Y40
G03 X140 Y100 R60
G02 X120 Y60 R50
```

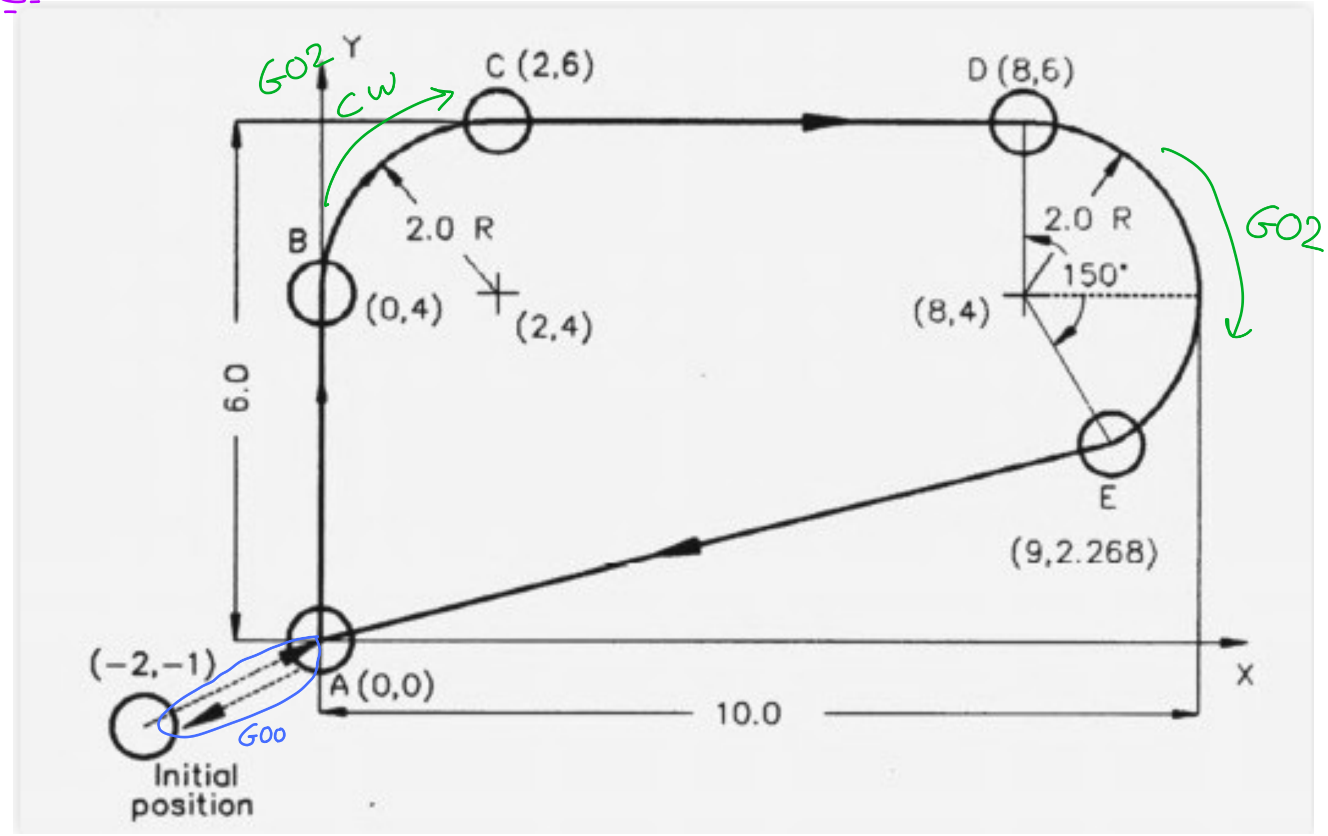



```
G90
G00 X200 Y40 Z0
G03 X140 Y100 Z0 R60 I-60 J0
G02 X120 Y60 Z0 R50 I-50 J0
```

G90 G00 X0 Y0
G01 X0 Y4
G02 X2 Y6 R2
G01 X8 Y6
G02 X9 Y2.268 R2
G01 X0 Y0
G00 X-2 Y-1

Example 4

السؤال معطيني الـdirections والـPoints



الترتيب حفظ

Example 5

N0027 G01 X175.25 Y325.00 Z136.50 F125 S800 T1712 M03 M08

spindle

M code
آخر اشي

Statement Number 27 (N0027) a linear-interpolation motion (G01) to a position defined by (X175.25 Y325.00 Z136.50), with a feed rate of 125 mm/min (F125), and a spindle speed of 800 rpm (S800), using a tool Number 1712 (T1712), performing a CW turn of the spindle (M03), and having the coolant on (M08).

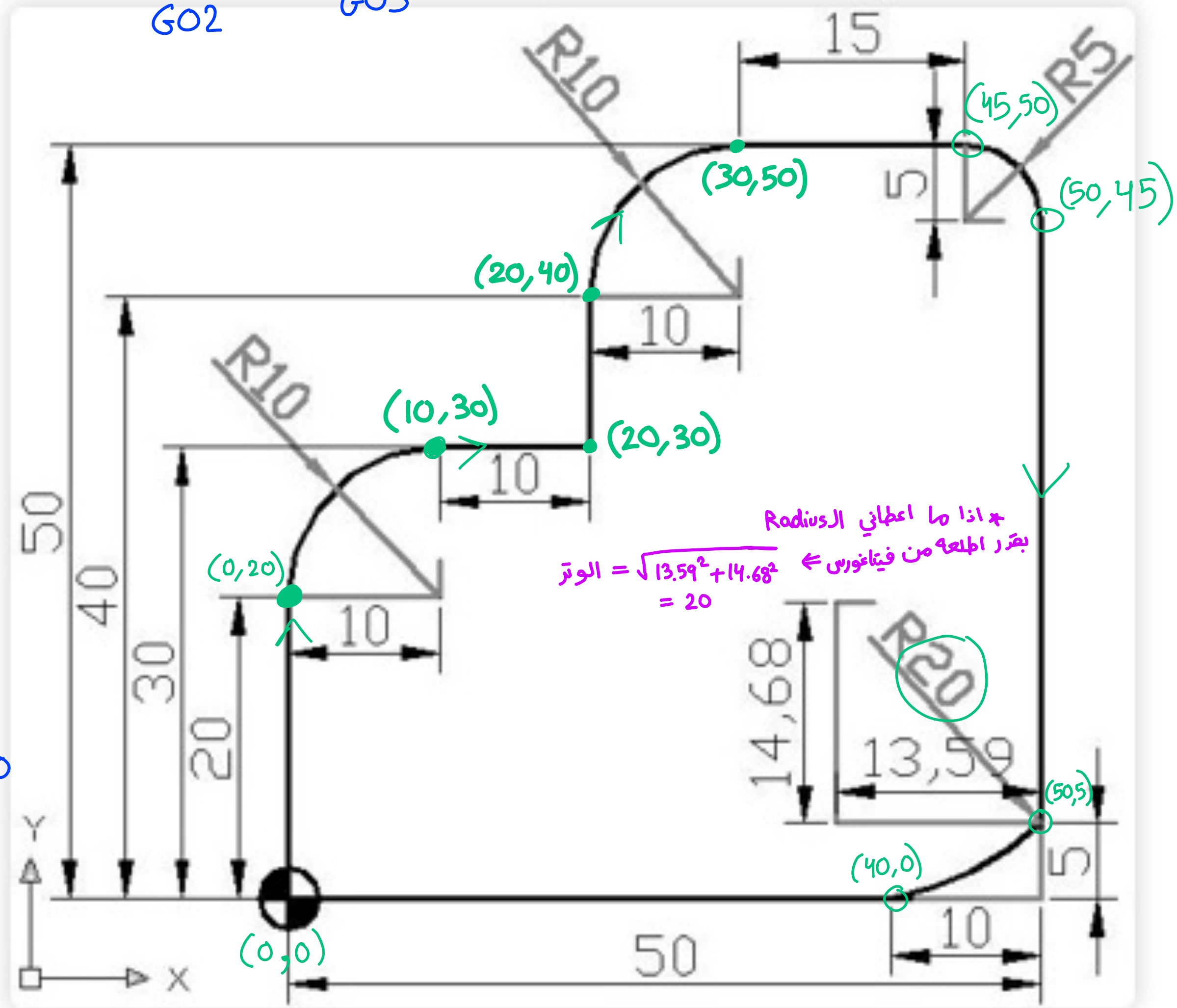
ممكن مرات نحتاج نستخدم فيتاغورس

لحل هذا النوع من الأسئلة يجب في البداية تحديد ← Points / direction

Example 6

CW G02   CCW G03

```
G90
G00  X0   Y0
G01  X0   Y20
G02  X10  Y30  R10
G01  X20  Y30
G01  X20  Y40
G02  X30  Y50  R10
G01  X45  Y50
G02  X50  Y45  R5
G01  X50  Y5
G02  X40  Y0   R20
G01  X0   Y0
```



NC Part Programming

- Methods of NC Part Programming
  - Manual part programming
    - A punched tape is prepared directly from a part program manuscript
  - Computer assisted part programming
    - Much of the tedious computational work required in manual programming is performed by the computer
  - Manual data input (MDI)
    - NC program is entered directly into the MCU at the site of the processing machine
  - NC programming using CAD/CAM
    - an interactive graphics system equipped with NC programming software is used to facilitate the part programming task
  - Computer-automated part programming
    - extends the notion of automating certain portions of the NC part programming procedure to its logical conclusion

NC Programming Using CAD/CAM

- CAD/CAM system
  - A computer interactive graphics system equipped with software to accomplish certain functions in design and mfg.
- Geometry definition using CAD/CAM
  - Has the capability to create/modify and retrieve/store the part geometric model
  - No need to recreate the geometry of the part during the NC programming procedure
- Tool path generation using CAD/CAM
  - Has tool libraries to identify the available tools in tool crib
  - Tool offset calculations are done automatically
  - Graphic display for the tool path selection and generation

CNC (3D)

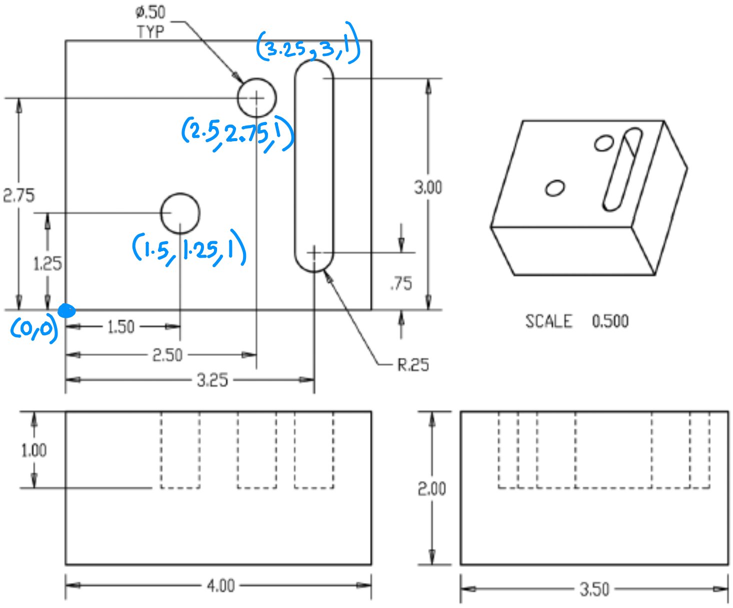
Write the G and M code program according to the flowchart to manufacture the part in the Figure below.

Set up
- Absolute Position
- Start position (0,0,1) T22
- M 06 Tool change Tool # 22
- Feed rate 4 rpm F4
- M 03 spindle forward clkwise At 2000 rpm S2000

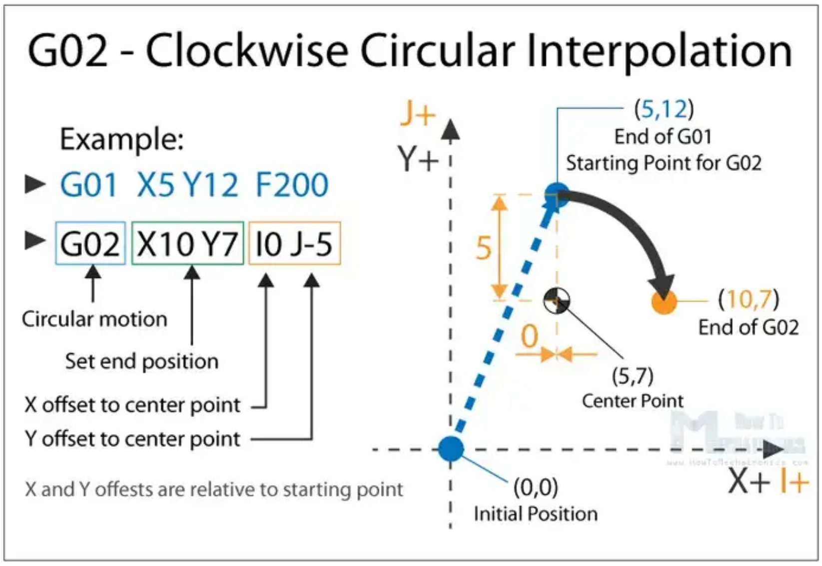
Drilling and Milling
- Drilling 1st hole
- Drilling 2sd hole
- Milling the slot in four passes (each pass 0,25 inch)
- M 03 spindle forward clkwise At 2000 rpm

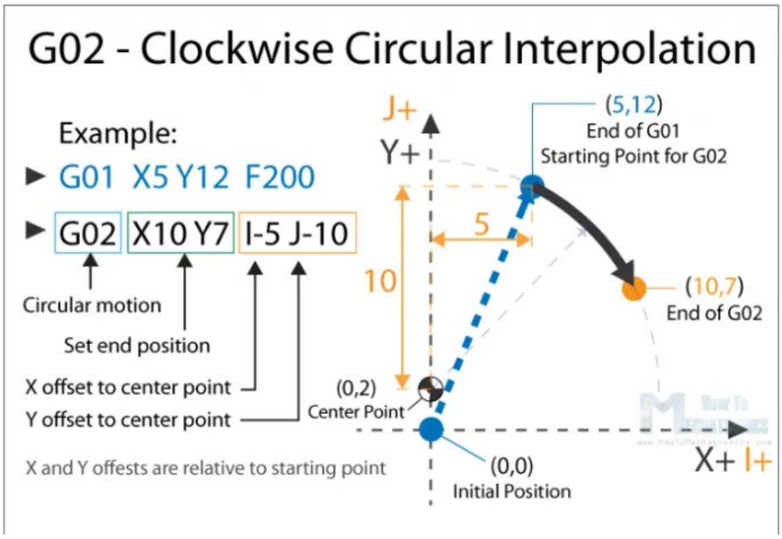
Use linear interpolation in z- direction for drilling and milling, consider z = 0 at the surface of the peace.

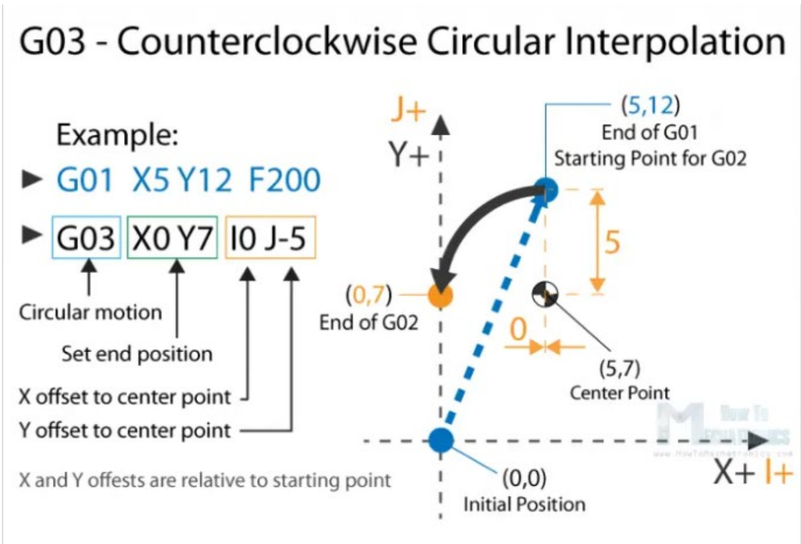
System Shutdown
- Return back to the home poistion (0,0,1)
- Shutdown Spindle M 05
- End program M30

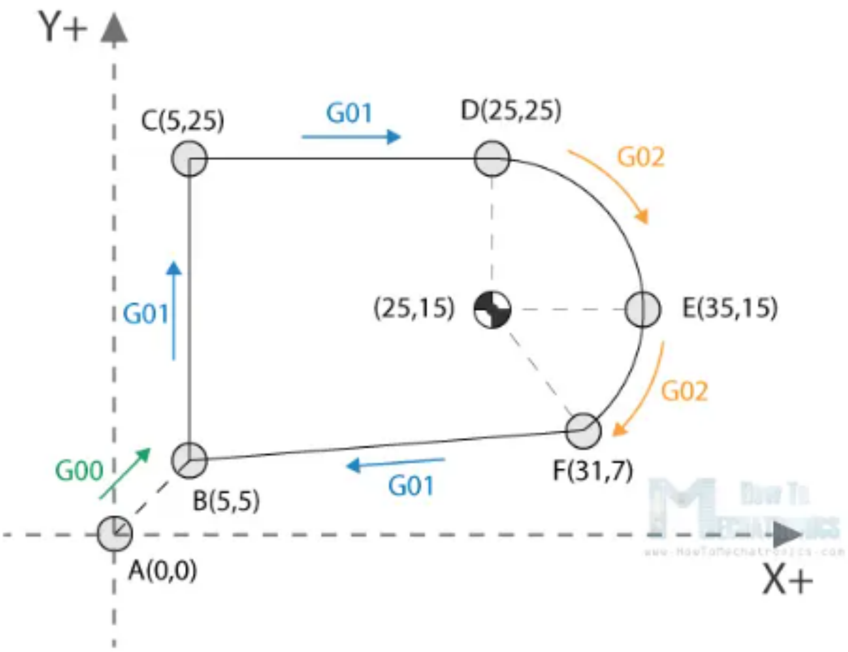



```
N00 G90
N05 G00 X0 Y0 Z1 F4 T22 S2000 M06 M03   ] system setup
N10 G00 X1.5 Y1.25 Z1
N15 G01 X1.5 Y1.25 Z-1
N20 G00 X1.5 Y1.25 Z1
N25 G00 X2.5 Y2.75 Z1
N30 G01 X2.5 Y2.75 Z-1
N35 G00 X2.5 Y2.75 Z1
N40 G00 X3.25 Y3 Z1
N45 G01 X3.25 Y3 Z-0.25
N50 G01 X3.25 Y0.75 Z-0.25
N55 G01 X3.25 Y0.75 Z-0.5
N60 G01 X3.25 Y3 Z-0.5
N65 G01 X3.25 Y3 Z-0.75
N70 G01 X3.25 Y0.75 Z-0.75
N75 G01 X3.25 Y0.75 Z-1
N80 G01 X3.25 Y3 Z-1
N85 G00 X3.25 Y3 Z1
N90 G00 X0 Y0 Z1 M05 M30
```


G02 - Clockwise Circular Interpolation
Example:
G01 X5 Y12 F200
G02 X10 Y7 I0 J-5
Circular motion
Set end position
X offset to center point
Y offset to center point
X and Y offests are relative to starting point
J+
Y+
5
0
(5,12)
End of G01
Starting Point for G02
(10,7)
End of G02
(5,7)
Center Point
(0,0)
Initial Position
X+ I+


G02 - Clockwise Circular Interpolation
Example:
G01 X5 Y12 F200
G02 X10 Y7 I-5 J-10
Circular motion
Set end position
X offset to center point
Y offset to center point
X and Y offests are relative to starting point
J+
Y+
5
10
(5,12)
End of G01
Starting Point for G02
(10,7)
End of G02
(0,2)
Center Point
(0,0)
Initial Position
X+ I+


G03 - Counterclockwise Circular Interpolation
Example:
G01 X5 Y12 F200
G03 X0 Y7 I0 J-5
Circular motion
Set end position
X offset to center point
Y offset to center point
X and Y offests are relative to starting point
J+
Y+
(5,12)
End of G01
Starting Point for G02
5
(0,7)
End of G02
0
(5,7)
Center Point
(0,0)
Initial Position
X+ I+



To get the toolpath for the shape shown in the image above we need to following G-code commands:

incremental mode → G91

```
G00 X5 Y5              ; point B
G01 X0 Y20 F200        ; point C
G01 X20 Y0             ; point D
G02 X10 Y-10 I0 J-10   ; point E
G02 X-4 Y-8 I-10 J0    ; point F
G01 X-26 Y-2           ; point B
```

Industrial Automation

Chapter Thirteen:

Introduction to Manufacturing Systems

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Department of Industrial Engineering

Manufacturing System Defined

integration between workers and machines

the main objective for it is to add value

- *"A collection of integrated equipment and human resources, whose function is to perform one or more processing and/or assembly operations on a starting raw material, part, or set of parts"*
- A Manufacturing System is where the value added work is accomplished on the parts and the products.
- A value addition is done over here.

Production System

- عمليات تصنيع
  Manufacturing Operations cost 60%
  (Machining /Material Removal)
  * Milling
  * Turning
  * Drilling

- عمليات تجميع
  Assembly Operations cost 40%
  - **Handling process**
    * Moving
    * orienting
    * Picking
    * gripping
    * blocking
    * feeding
    * fixturing
    * pillet system
  - **Joining**
    * welding
    * screwing
    * gleuing
    * rivating

Manufacturing System Defined

① production machines and tools
② material handling and work positioning devices
③ computer systems

Equipment includes

- Production machines and tools

manufacturing (Machining) (Material Removal)

Assembly operations

Manufacturing System Defined

✱ Transport :

Fixed → fixed system production line (High production Rate)

Variable

- Material handling and work positioning devices

- Load
- unload
- transportation
- storage

  - Work positioning
  - Work transportation

product based — ↑ volume

process based — ↑ variety

↑ high poduction volume ⇒ (Fixed Routing)

workstations ثابتة

□→□→□

(workstation ↑)

(تعقيد ال manufacturing system ↑)

(تعقيد ال product ↑)

(value added ↑)

Variable Routing ⇒ (flexible variety) ↑

Manufacturing System Defined

- Computer systems

Manufacturing System Defined

- Human resources are required either full-time or periodically to keep the system running.

Workstation

- In a manufacturing system, the term WORKSTATION refers to a location in the factory, where a well-defined task or operation is accomplished by an automated machine, a worker and a machine combination, or a worker using hand tools and/or portable power tools.

Production Line

- A given manufacturing system consists of one or more workstations.
- A system with multiple workstations is called a *production line*, *machine cell* depending on its configuration and function.

Material Handling System

- In most manufacturing systems that process or assemble discrete parts and products, the following material handling functions must be provided:
  1. Loading work units at each station
  2. Positioning work units at each station
  3. Unloading work units at each station
  4. Transporting work units between stations in multi-station systems
  5. Temporary storage of work units

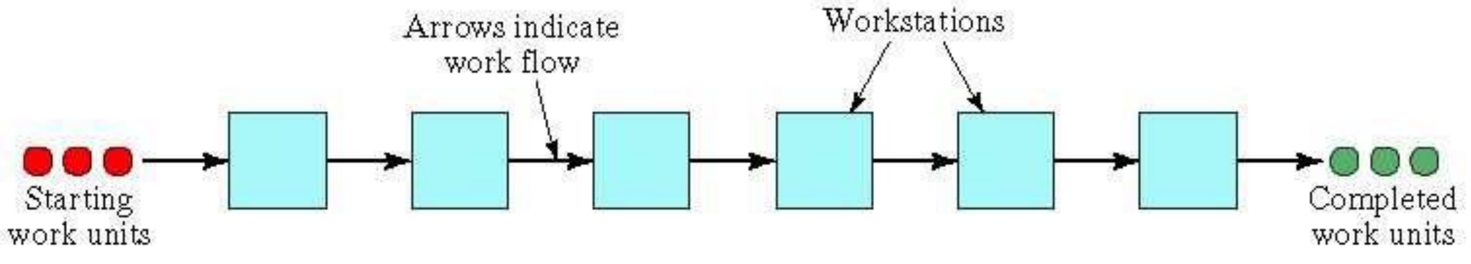
Work Transport Between Stations

- Two general categories of work transport in multi-station manufacturing systems:

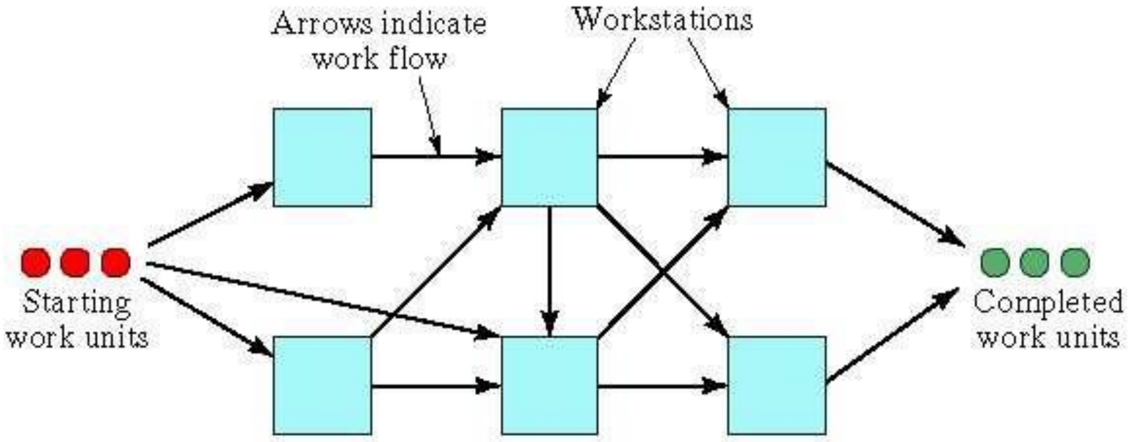
1. *Fixed routing*
   - Work units always flow through the same sequence of workstations
   - Most production lines (flow shop) exemplify this category
     مثل
2. *Variable routing*
   - Work units are moved through a variety of different station sequences
   - Most job shops exemplify this category

(a) Fixed Routing (flow shop), and

(b) Variable Routing (job shop, cells, fms)



(a)



(b)

Classification of Manufacturing Systems

Factors that define and distinguish manufacturing systems:

1. *Types of operations performed (assembly/process)*
2. *Number of workstations*
3. *System layout*
4. *Automation and manning level*
5. *Part or product variety*

Types of Operations Performed

- Processing operations on work units versus assembly operations to combine individual parts into assembled entities
- Type(s) of materials processed
- Size and weight of work units
- Part or product complexity
  - For assembled products, number of components per product
  - For individual parts, number of distinct operations to complete processing
- Part geometry
  - For machined parts, rotational vs. non-rotational

Number of Workstations

- Convenient measure of the size of the system
  - Let n = number of workstations (n=1 single station, n>1 multi station system)
  - Individual workstations can be identified by subscript i, where $i = 1, 2,\ldots,n$
- Affects performance factors such as workload capacity, production rate, and reliability
  - As n increases↑, this usually means greater workload capacity↑ and higher production↑ rate
  - There must be a synergistic effect that derives from n multiple stations working together vs. n single stations

Workload defined

- The WORKLOAD is the amount of processing or assembly work accomplished by the system, expressed in terms of the time required to perform the work.
- It is the sum of the cycle times of all the work units completed by the system in a given period of interest.
- *Work content* is the total time of all work elements that must be performed on the line to make one unit of the product.

System Layout

- Applies mainly to multi-station systems
- Fixed routing vs. variable routing
  - In systems with fixed routing, workstations are usually arranged linearly (product)
  - In systems with variable routing, a variety of layouts are possible (process, cellular)
- System layout is an important factor in determining the most appropriate type of material handling system

Automation and Manning Levels

- Level of workstation automation
  - Manually operated
  - Semi-automated
  - Fully automated
- Manning level M_i = *proportion of time worker is in attendance at station i*
  - $M_i = 1$ means that one worker must be at the station continuously
  - $M_i \geq 1$ indicates manual operations
  - $M_i < 1$ usually denotes some form of automation

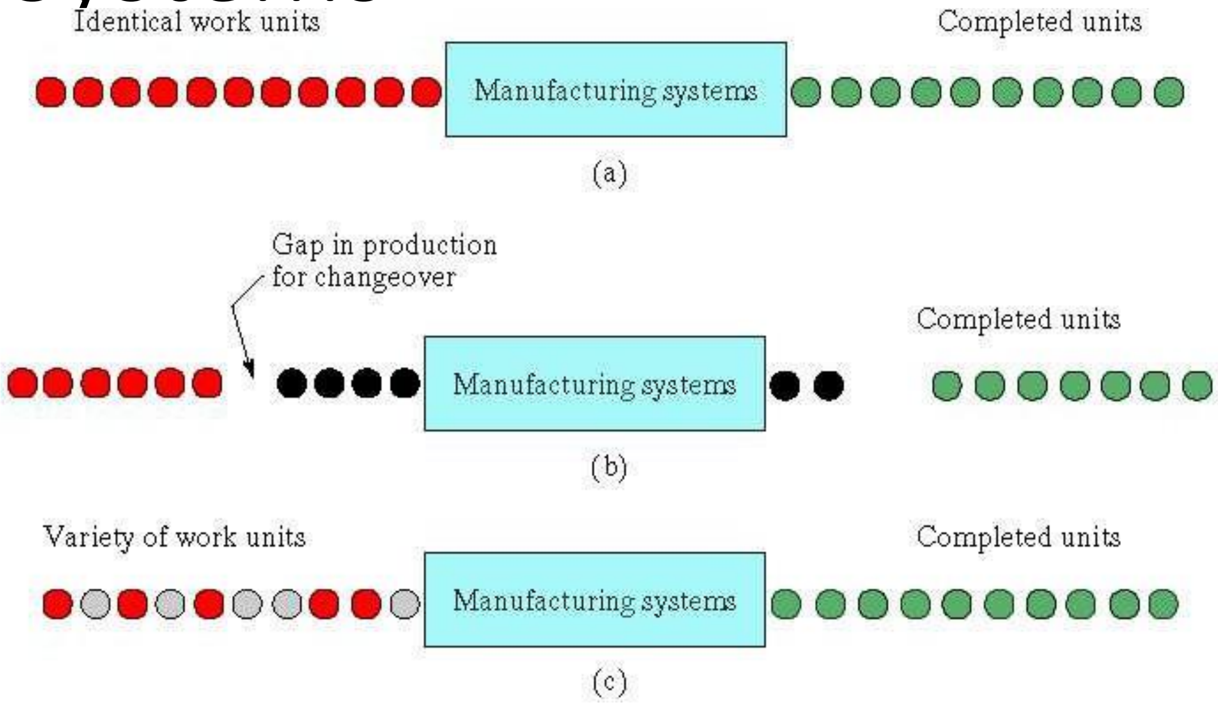
Part or Product Variety: Flexibility

"The degree to which the system is capable of dealing with variations in the parts or products it produces"

Three cases:

1. *Single-model case* - all parts or products are identical (sufficient demand/fixed automation)
2. *Batch-model case* - different parts or products are produced by the system, but they are produced in batches because changeovers are required (hard product variety)
3. *Mixed-model case* - different parts or products are produced by the system, but the system can handle the differences without the need for time-consuming changes in setup (soft product variety)

Three Cases of Product Variety in Manufacturing Systems

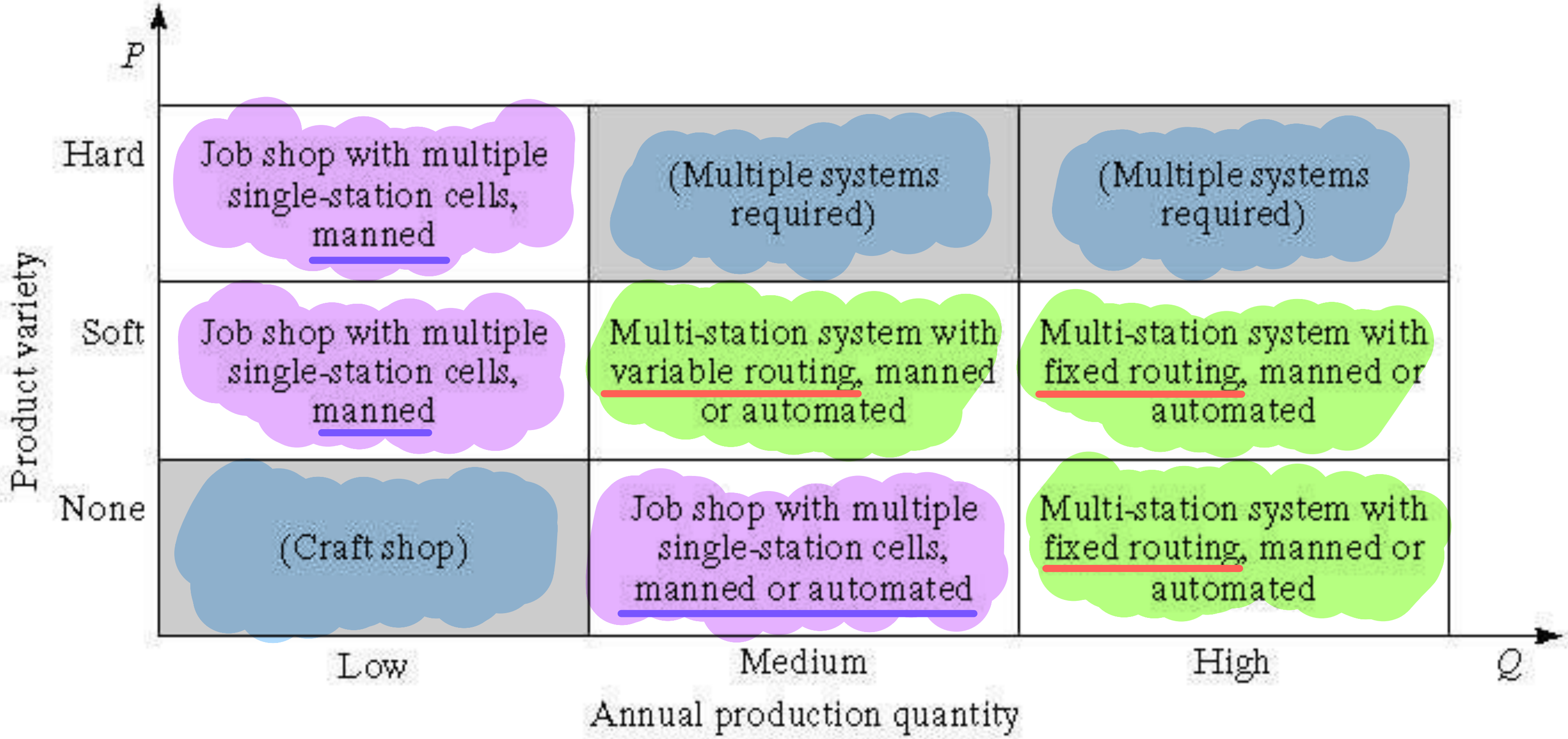


(a) Single-model case, (b) batch model case, and (c) mixed-model case

Enablers of Flexibility

- <u>Identification of the different work units</u>
  - The system must be able to identify the differences between work units in order to perform the correct processing sequence
- <u>Quick changeover of operating instructions</u>
  - The required work cycle programs must be readily available to the control unit
- <u>Quick changeover of the physical setup</u>
  - System must be able to change over the fixtures and tools required for the next work unit in minimum time

Manufacturing Systems for Medium or High Product Complexity



Overview of Classification Scheme

- Single-station cells
  - $n = 1$
  - Manual or automated
- Multi-station systems with fixed routing
  - $n > 1$
  - Typical example: production line
- Multi-station systems with variable routing
  - $n > 1$

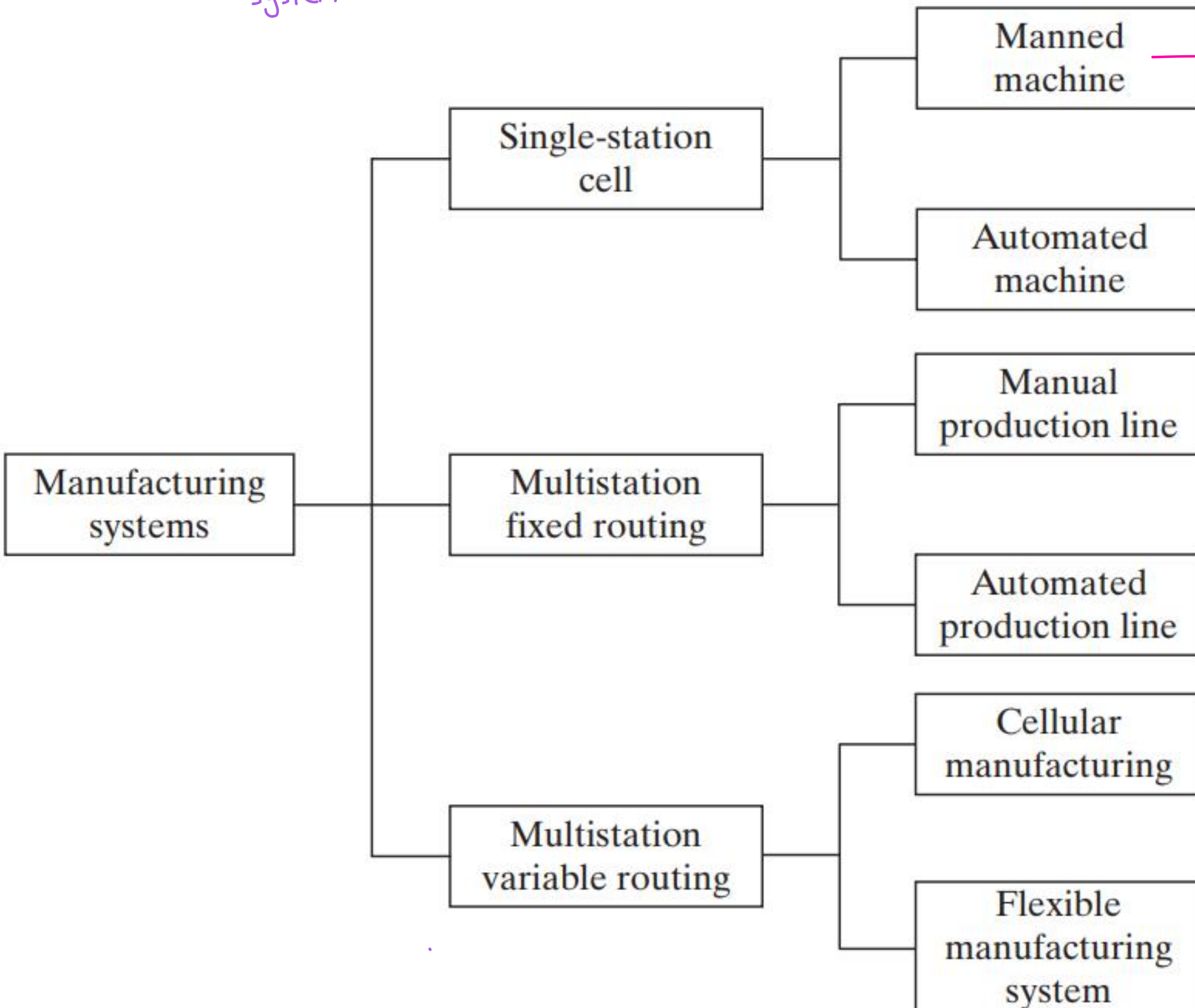
manufacturing systems → to add value to a Raw material
→ integration between workers and machines

Automation

Chapter Fourteen:
Single-Station Manufacturing Cells

Dr. Eng. Baha'eddin Alhaj Hasan
Department of Industrial Engineering

تختلف ال Manufacturing system باختلاف ال Product



→ Manual

# of workers > # of machines

⟹ manual

# of workers < # of machines

→ Automated
→ Semi automated

يوجد علاقة عكسية بين ال Product volume و ال Product variety

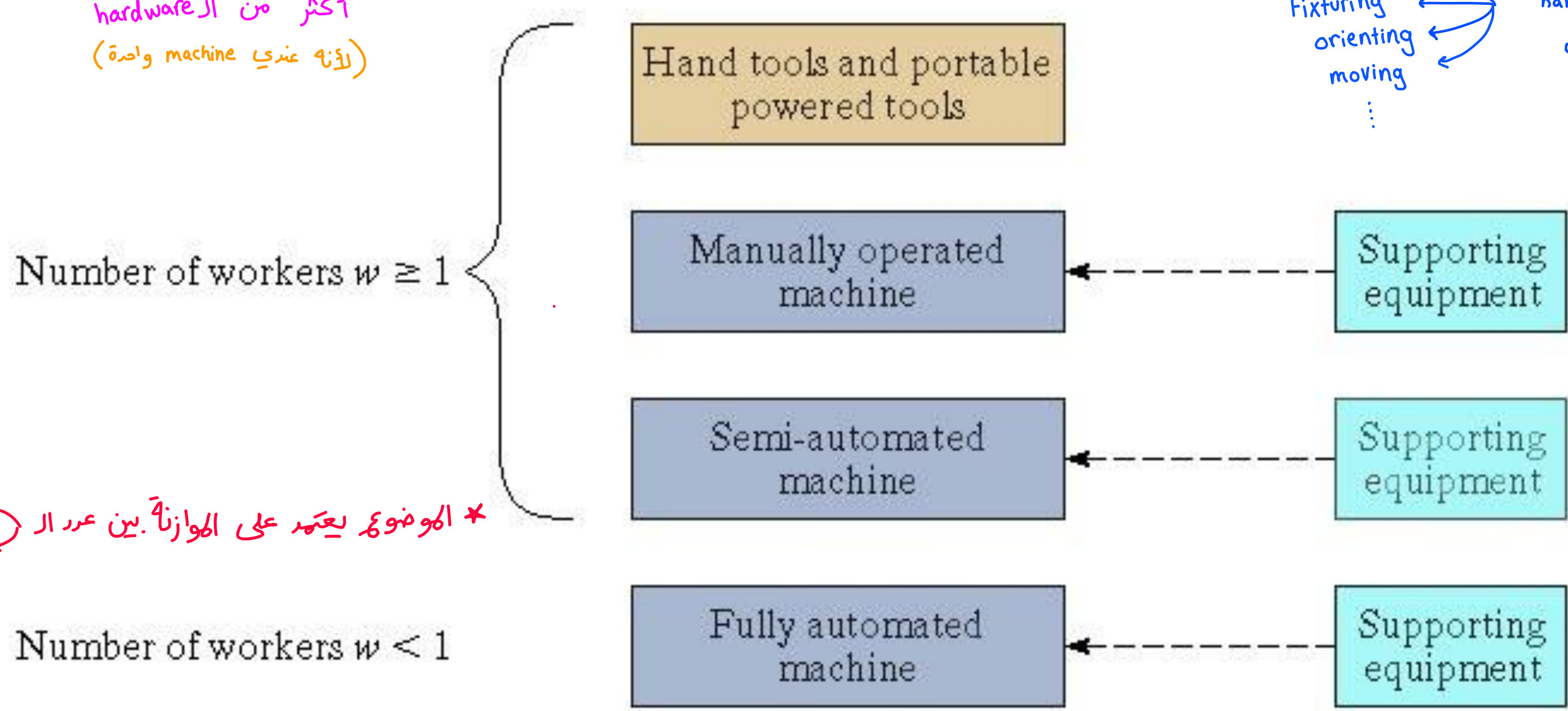
كلما زاد تعقيد الـProduct يزداد تعقيد الـ manufacturing system

Classification of Single-Station Manufacturing Cells

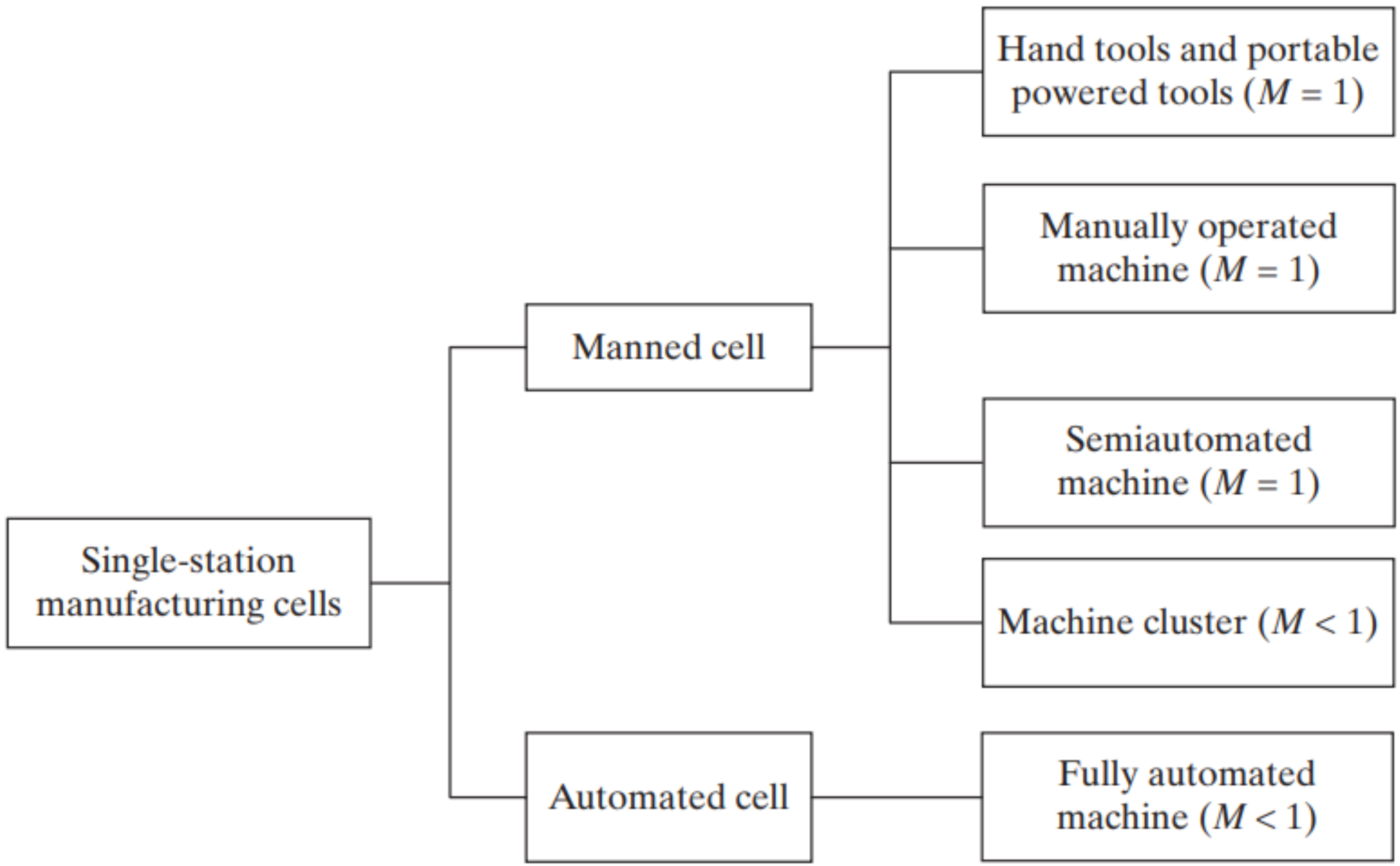
flexibility ↑

التغيير يكون على مستوى الـsoftware أكثر من الـhardware
(لأنه عندي machine واحدة)

عمليات الـ handling تشمل
Feeding
Fixturing
orienting
moving
⋮



* الموضوع يعتمد على الموازنة بين عدد الـ workers والـ machines


Hand tools and portable powered tools ($M = 1$)
Manually operated machine ($M = 1$)
Manned cell
Semiautomated machine ($M = 1$)
Single-station manufacturing cells
Machine cluster ($M < 1$)
Automated cell
Fully automated machine ($M < 1$)

Single-Station Manufacturing Cells

- Most common manufacturing system in industry
- Operation is independent of other stations
- Perform either processing or assembly operations (machining) [material removal]
- Can be designed for:
  - Single model production
  - Batch production إنتاج الدفعات → hard variety
  - Mixed model production → soft variety

Single-Station Manned Cell

1 1

One worker tending one production machine (most common model)

- Most widely used production method, especially in job shop and batch production
- Reasons for popularity:
  - Shortest time to implement
  - Requires least capital investment
  - Easiest to install and operate
  - Typically, the lowest unit cost for low production
  - Most flexible for product or part changeovers

Single-Station Manned Cell Examples

- Worker operating a standard machine tool
  - Worker loads & unloads parts, operates machine

    عمليات ال handling (manual)
  - Machine is manually operated
- Worker operating semi-automatic machine
  - Worker loads & unloads parts, starts semi-automatic work cycle
  - Worker attention not required continuously during entire work cycle
- Worker using hand tools or portable power tools at one location

Variations of Single-Station Manned Cell

أبرز مثال عليها
مصانع ال Plastic

Manual → handling / post processing

- Two (or more) workers required to operate machine
  - Manual
  - Two workers required to manipulate heavy forging at forge press
  - هنا نحتاج على الأقل 2 workers
  - Welder and fitter in arc welding work cell
- One principal production machine plus support equipment
  - Drying equipment for a manually operated injection molding machine
  - Trimming shears at impression-die forge hammer to trim flash from forged part

Single-Station Automated Cell

Fully automated production machine capable of operating unattended for longer than one work cycle

- Worker not required except for periodic tending

observation

- Reasons why it is important:
  - Labor cost is reduced
  - Easiest and least expensive automated system to implement
  - Production rates usually higher than manned cell
  - First step in implementing an integrated multi-station automated system

Enablers for Unattended Cell Operation

high volume

- For single model and batch model production:
  - Programmed operation for all steps in work cycle
  - Parts storage subsystem
  - Automatic loading, unloading, and transfer between parts storage subsystem and machine
  - Periodic attention of worker for removal of finished work units, resupply of starting work units, and other machine tending
  - Built-in safeguards to avoid self-destructive operation or damage to work units

Enablers for Unattended Cell Operation

- For mixed model production:
  - All of the preceding enablers, plus:
  - Work unit identification:

    ممكن عن طريق camera programming

    - Automatic identification (e.g., bar codes) or sensors that recognize alternative features of starting units
    - If starting units are the same, work unit identification is unnecessary
  - Capability to download programs for each work unit style (programs prepared in advance)
  - Capability for quick changeover of physical setup

Parts Storage Subsystem and Automatic Parts Transfer

- Necessary conditions for unattended operation
- Given a capacity = n_p parts in the storage subsystem, the cell can theoretically operate for a time, Tc cycle time: the time required for apart to be processed. TC equal for all parts.

\# of parts   processing time

$$UT = n_p T_c$$

where UT = unattended time of operation

  - In reality, unattended time will be less than UT because the worker needs time to unload finished parts and load raw workparts into the storage subsystem

Parts Storage Capacity

- Typical objectives in defining the desired parts storage capacity n_p:
  - Make $n_p T_c$ = a fixed time interval that allows one worker to tend multiple machines
  - Make $n_p T_c$ = time between scheduled tool changes
  - Make $n_p T_c$ = one complete shift
  - Make $n_p T_c$ = one overnight ("lights-out operation")

Storage Capacity of One Part

- Example: two-position automatic pallet changer (APC)
- With no pallet changer, work cycle elements of loading/unloading and processing would have to be performed sequentially

$$T_c = T_m + T_s$$

machine time — worker service time

where T_m = machine time and T_s = worker service time

- With pallet changer, work cycle elements can be performed simultaneously

$$T_c = \text{Max}\{T_m, T_s\} + T_r$$

repositioning time of pallet changer

where T_r = repositioning time of pallet changer

Videos

https://www.youtube.com/watch?v=GnZqQpeHV0E

https://www.youtube.com/watch?v=zIh5RSE0_PI

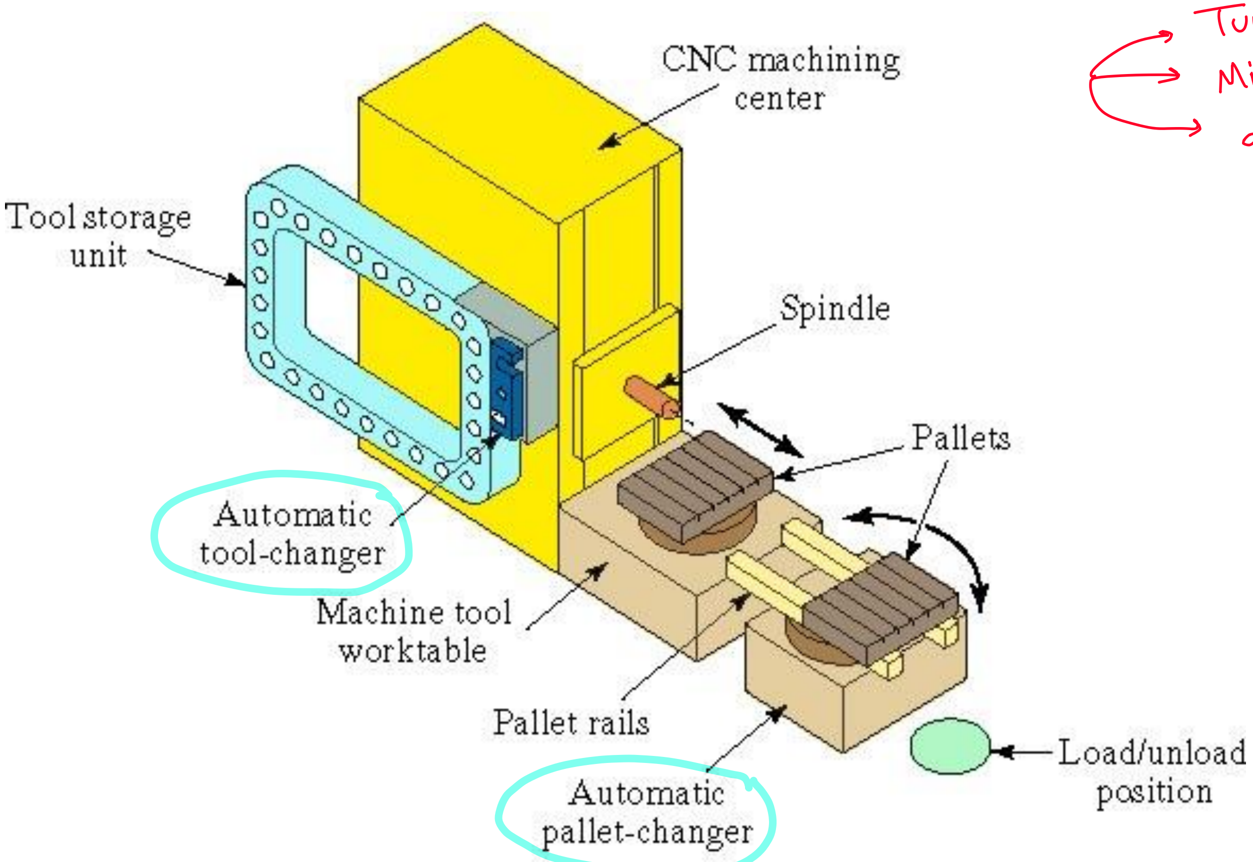
https://www.youtube.com/watch?v=V1bT-cQLOpk

https://www.youtube.com/watch?v=_55eWvfEPMU

https://www.youtube.com/watch?v=wARIRCTwSSk

https://www.youtube.com/watch?v=svCiWIOx7M4

CNC Machining Center with Automatic Pallet Changer - Stores One Part

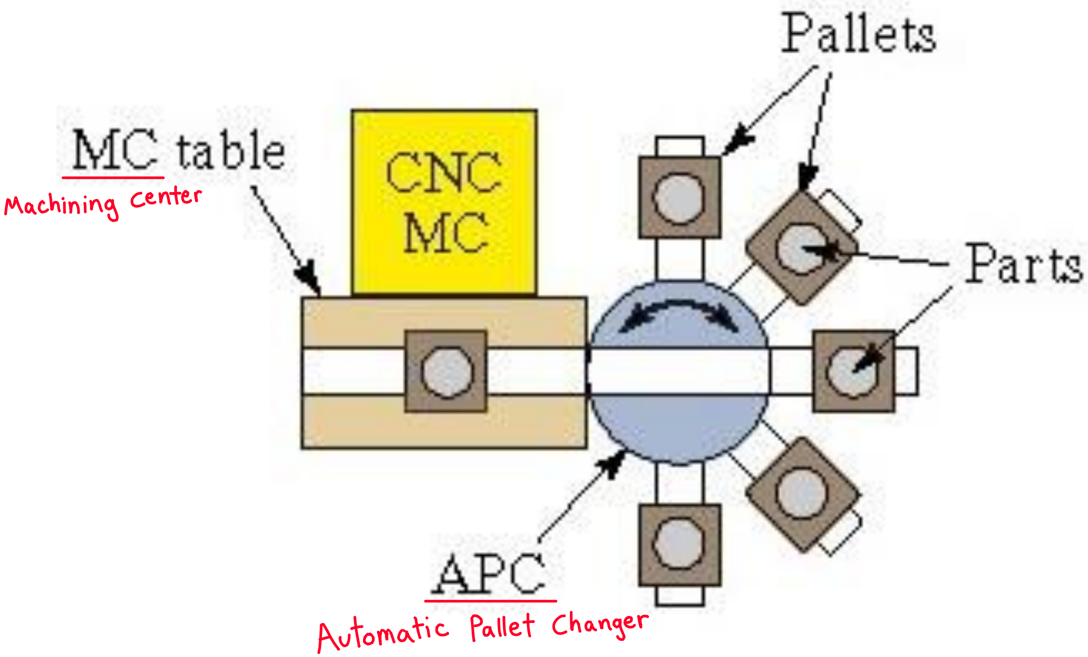


Turning
Milling
and more
. . . . .
operations

Storage Capacities Greater Than One

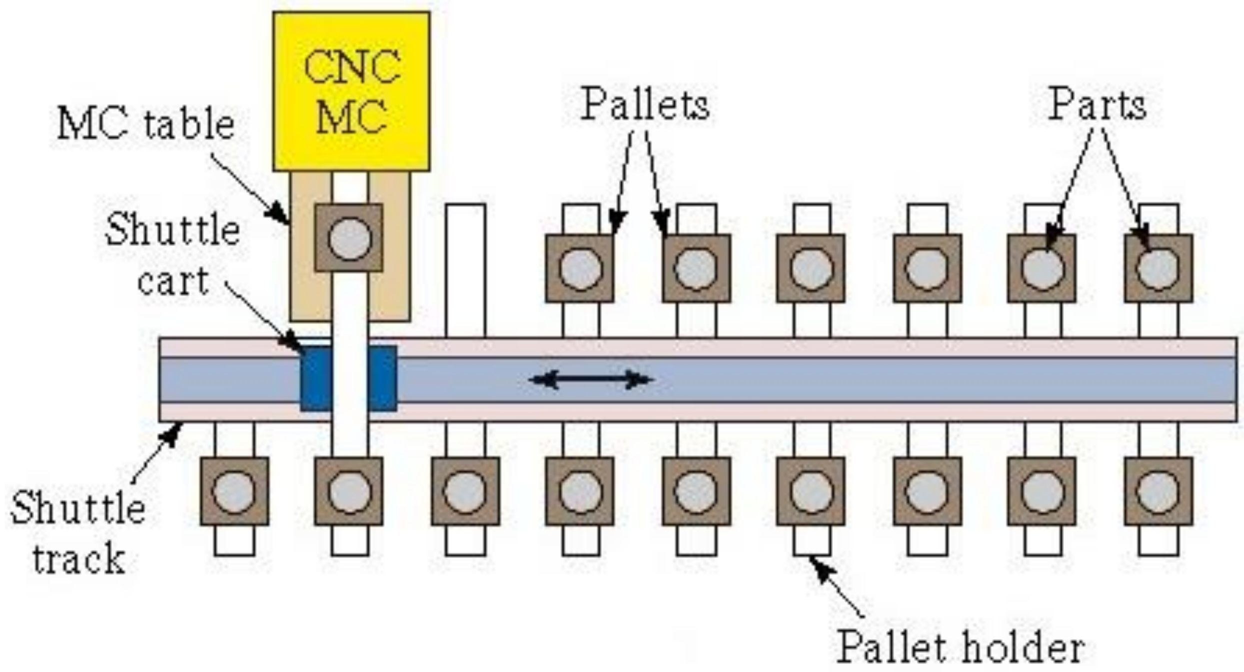
- Machining centers:
  - Various designs of parts storage unit interfaced to automatic pallet changer (or other automated transfer mechanism)
- Turning centers:
  - Industrial robot interface with parts carousel
- Plastic molding or extrusion:
  - Hopper contains sufficient molding compound for unattended operation
- Sheet metal stamping:
  - Starting material is sheet metal coil

Storage Capacities Greater Than One



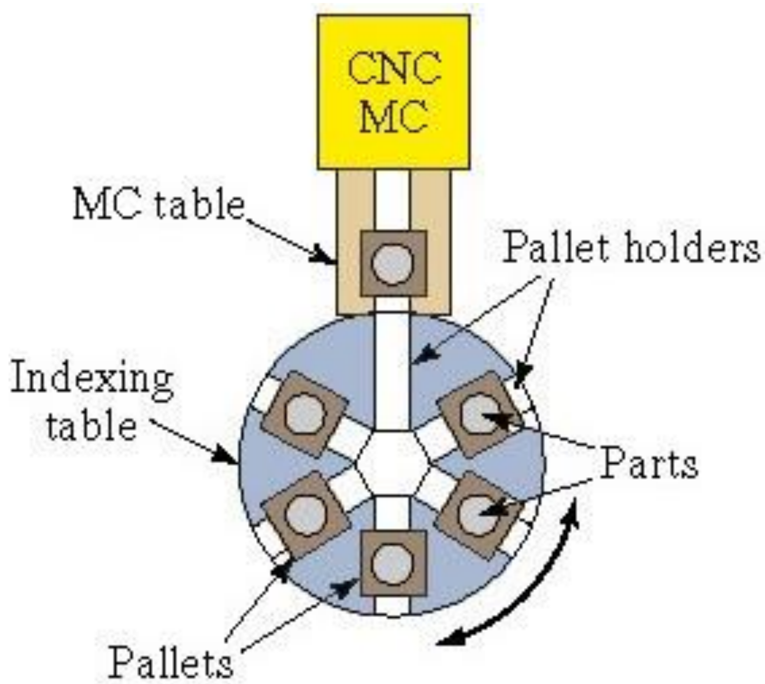
Machining center and automatic pallet changer with pallet holders arranged radially; parts storage capacity = 5

Storage Capacities Greater Than One



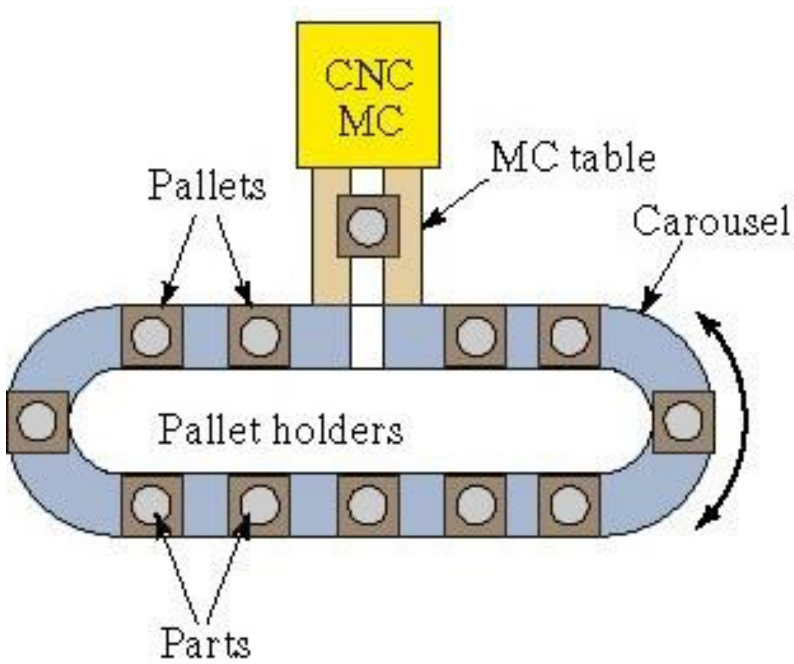
Machining center and in-line shuttle cart system with pallet holders along its length; parts storage capacity = 16

Storage Capacities Greater Than One



Machining center with pallets held on indexing table; parts storage capacity = 6

Storage Capacities Greater Than One



دائري التخزين

Machining center and parts storage carousel with parts loaded onto pallets; parts storage capacity = 12

حسب ال storage capacity

Applications of Single Station Manned Cells

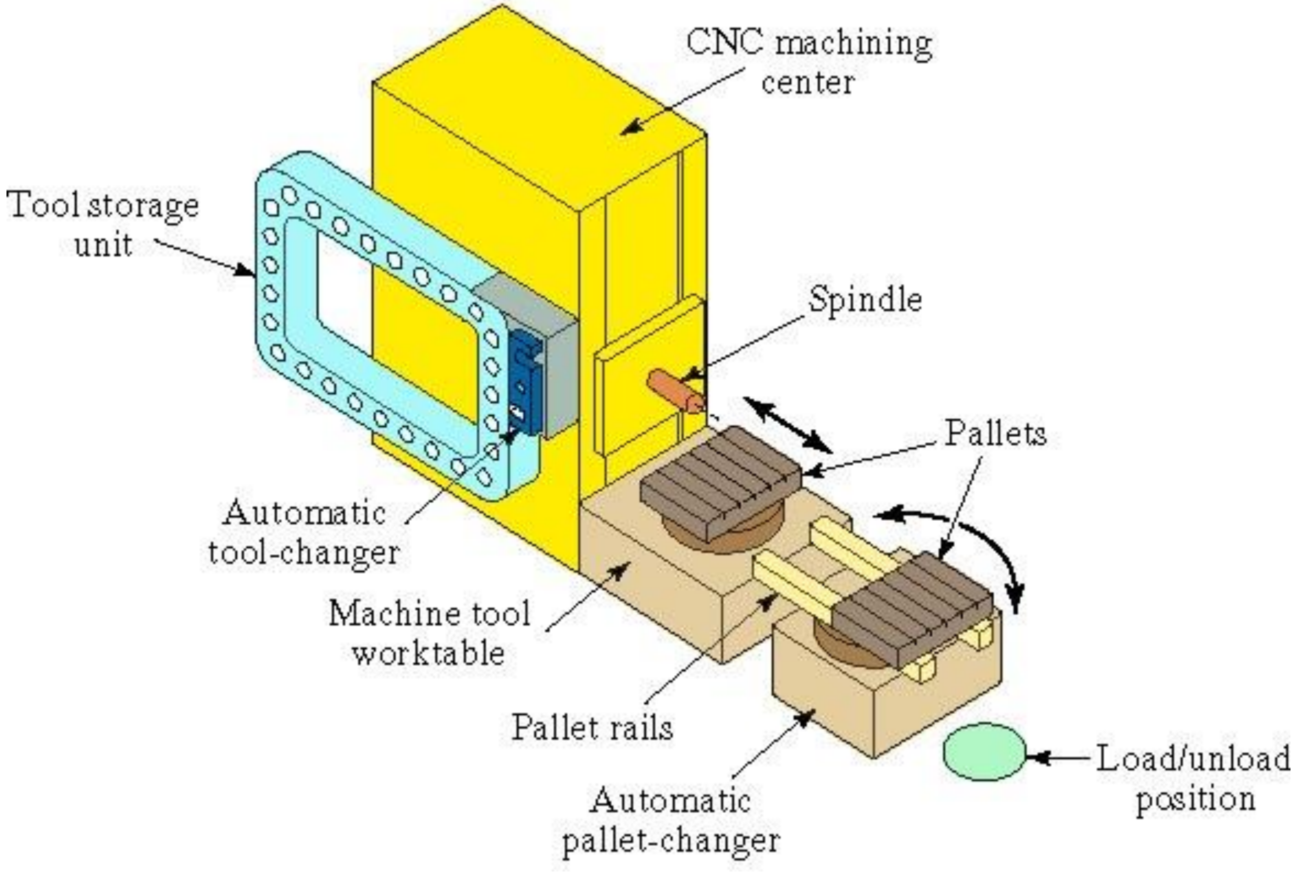
- CNC machining center with worker to load/unload
- CNC turning center with worker to load/unload
- Cluster of two CNC turning centers with time sharing of one worker to load/unload
- Plastic injection molding on semi-automatic cycle with worker to unload molding, sprue, and runner
- One worker at electronics subassembly workstation inserting components into PCB
- Stamping press with worker loading blanks and unloading stampings each cycle

CNC Machining Center

Machine tool capable of performing multiple operations that use rotating tools on a workpart in one setup under NC control

- Typical operations: milling, drilling, and related operations
- Typical features to reduce nonproductive time:
  - Automatic tool changer
  - Automatic workpart positioning
  - Automatic pallet changer

CNC Horizontal Machining Center

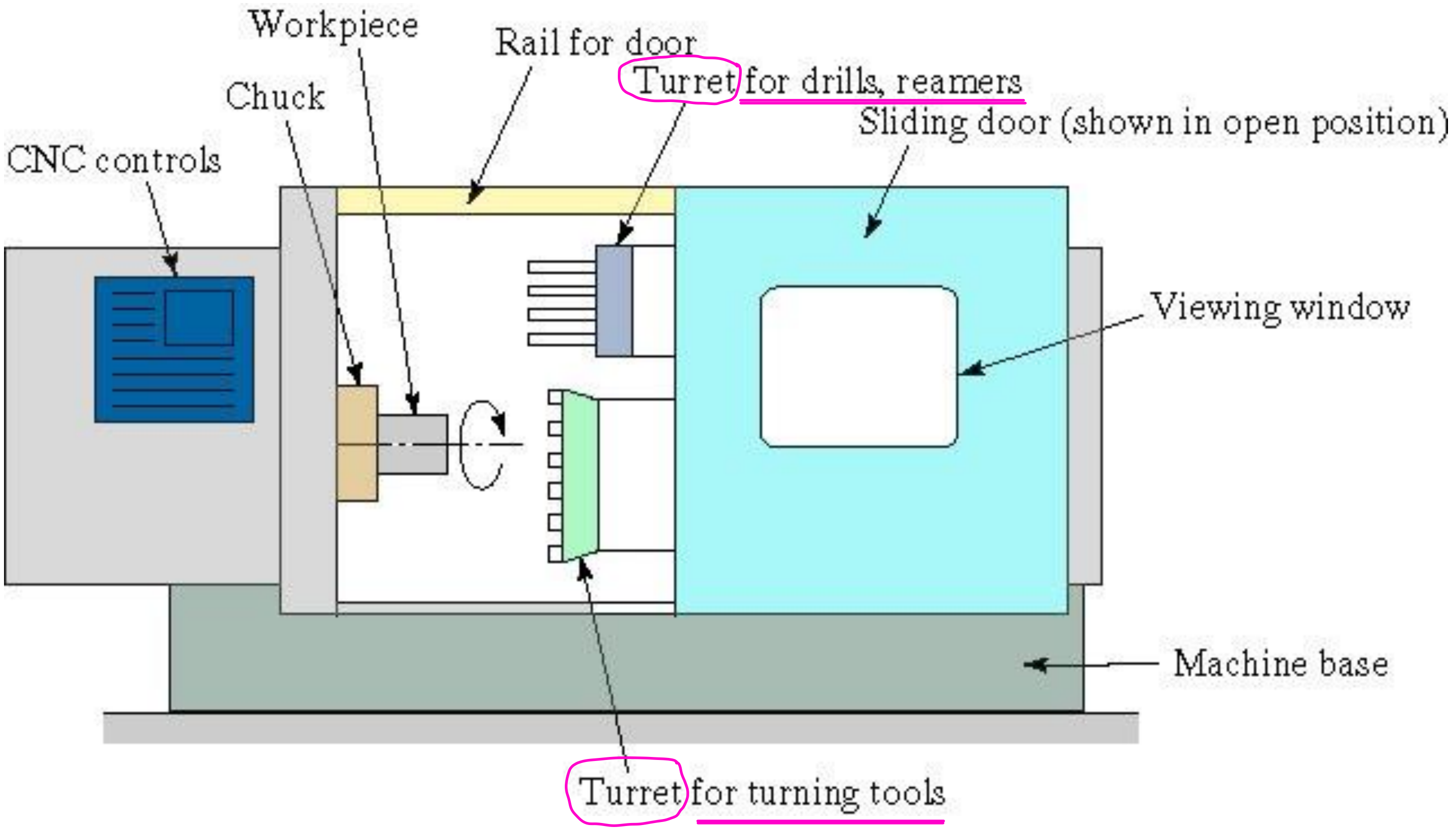


CNC Turning Center

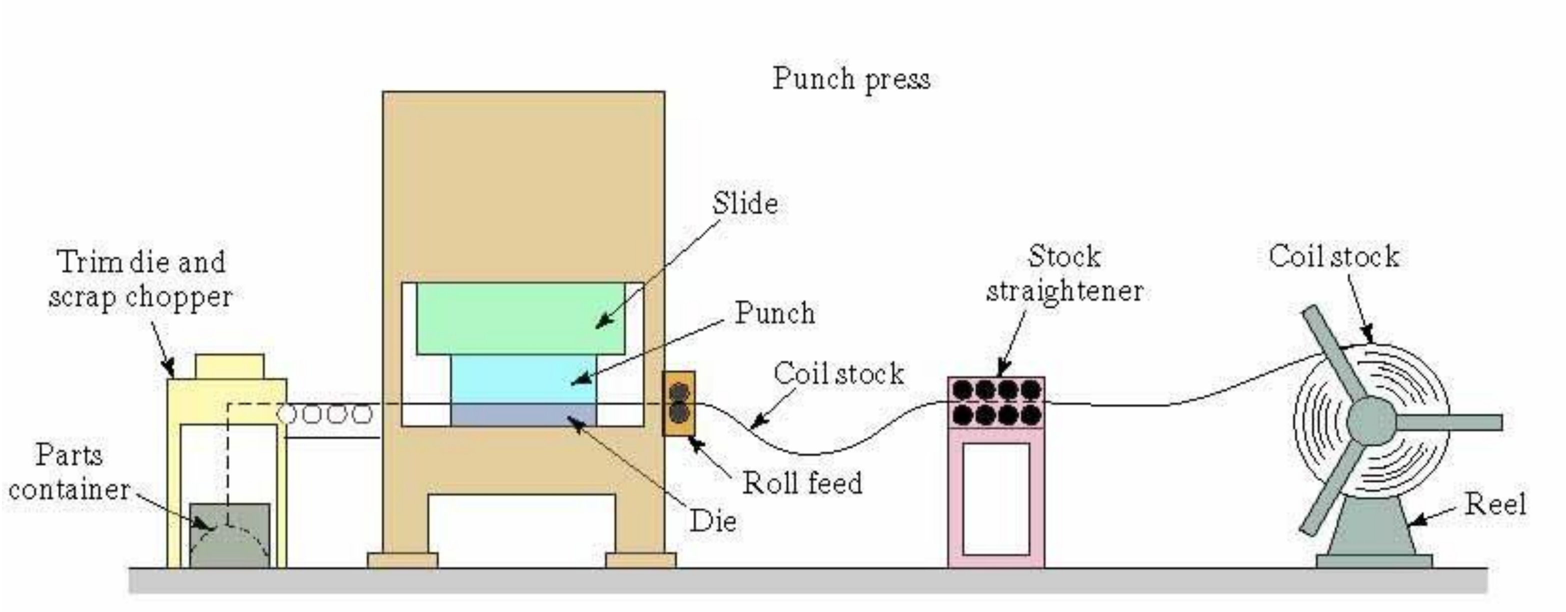
Machine tool capable of performing multiple operations on a rotating workpart in one setup under NC control

- Typical operations:
  - Turning and related operations, e.g., contour turning
  - Drilling and related operations along workpart axis of rotation

CNC Turning Center



Automated Stamping Press



Stamping press on automatic cycle producing stampings from sheet metal coil

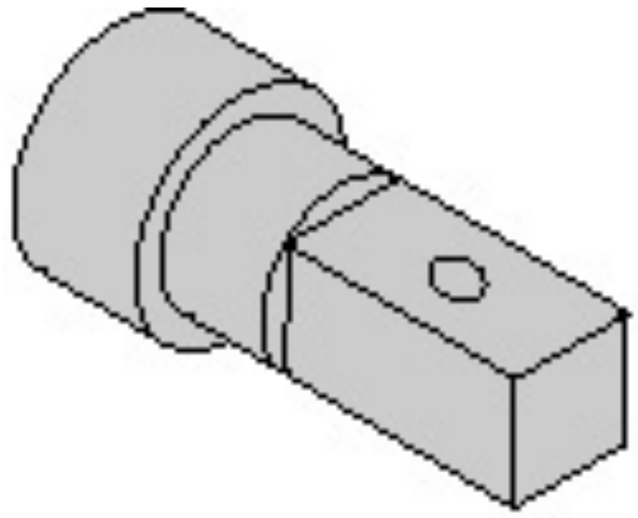
CNC Mill-Turn Center

يعتمد على ال skills
يلي بدي اياها لتصميم
ال Product

Machine tool capable of performing multiple operations either with single point turning tools or rotating cutters in one setup under NC control

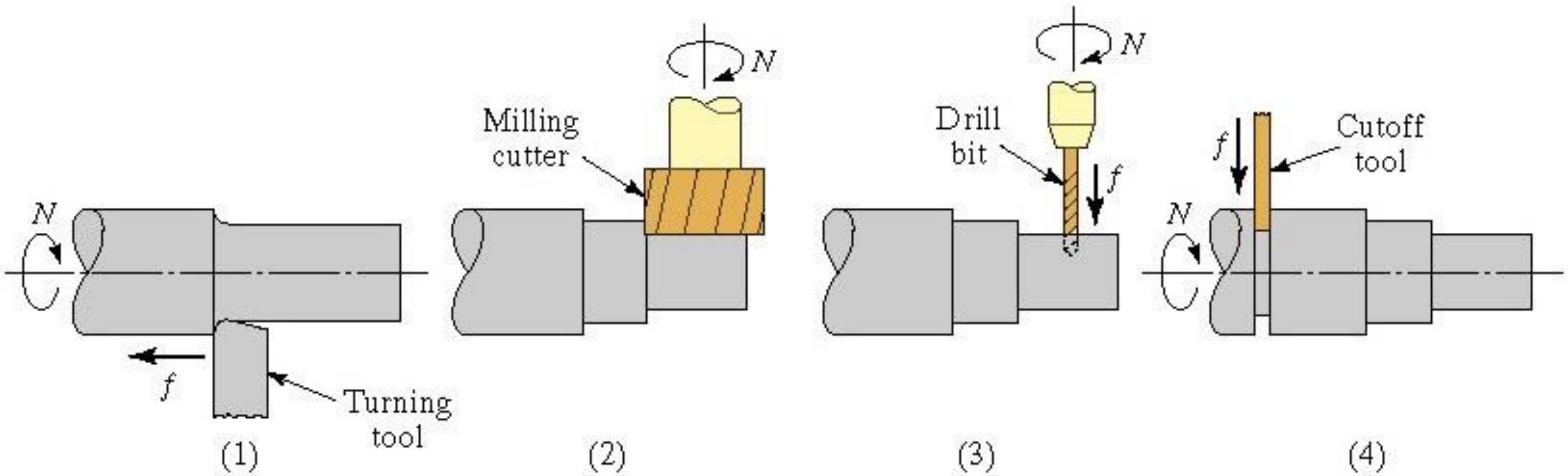
- Typical operations:
  - Turning, milling, drilling and related operations
- Enabling feature:
  - Capability to control position of c-axis in addition to *x*- and *z*-axis control (turning center is limited to *x*- and *z*-axis control)

Part with Mill-Turn Features



Example part with turned, milled, and drilled features

Sequence of Operations of a Mill-Turn Center for Example Part



(1) Turn smaller diameter, (2) mill flat with part in programmed angular positions, four positions for square cross section; (3) drill hole with part in programmed angular position, and (4) cutoff of the machined piece

Automation

Chapter Sixteen:
Automated Production Lines

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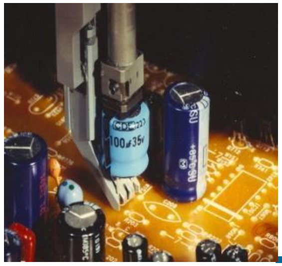
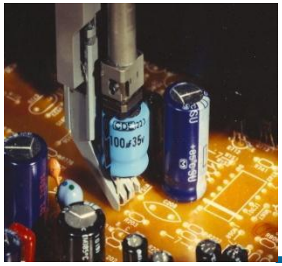
Department of Industrial Engineering



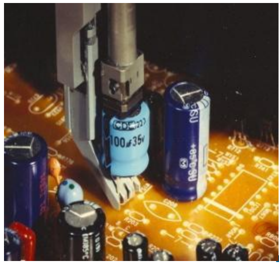
Automated Production Lines

- High production of parts requiring multiple processing operations
- Fixed automation
- Applications:
  - Transfer lines used for machining
  - Robotic spot welding lines in automotive final assembly
  - Sheet metal stamping
  - Electroplating of metals



Where to Use Automated Production Lines

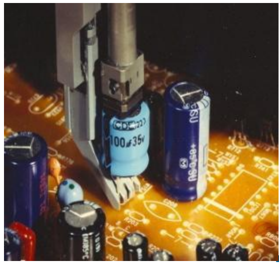
- *High product demand*
  - Requires large production quantities
- *Stable product design*
  - Difficult to change the sequence and content of processing operations once the line is built
- *Long product life*
  - At least several years
- *Multiple operations required on product*
  - Different operations are assigned to different workstations in the line



Benefits of Automated Production Lines

- Low direct labor content
- Low product cost
- High production rates
- Production lead time and work-in-process are minimized
- Factory floor space is minimized

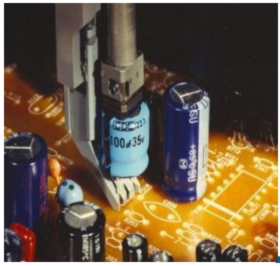
❖ Production lead time (or manufacturing lead time) is the period of time
التاجر
between a merchant's purchase order being placed and the manufacturer completing the order.



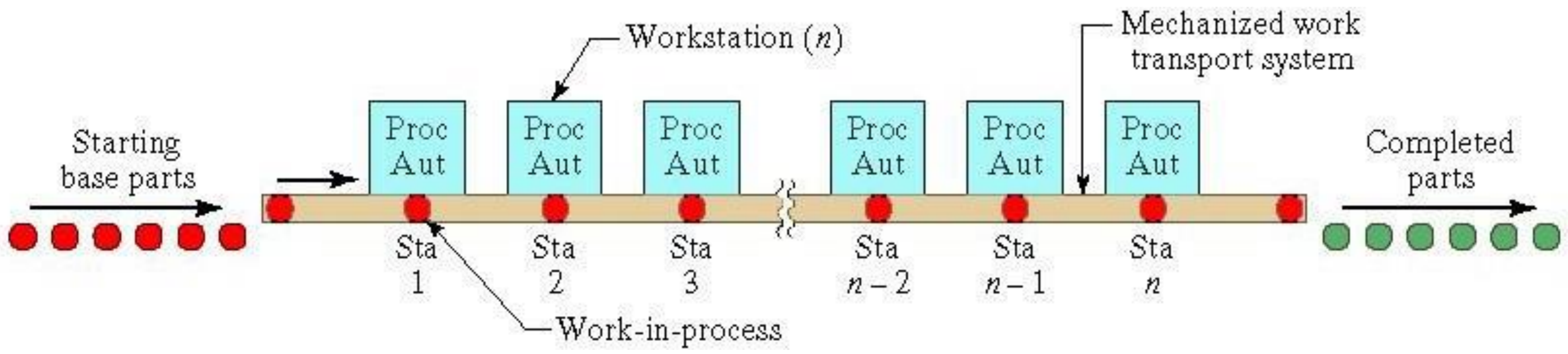
Automated Production Line

"Fixed-routing manufacturing system that consists of multiple workstations linked together by a material handling system to transfer parts from one station to the next"

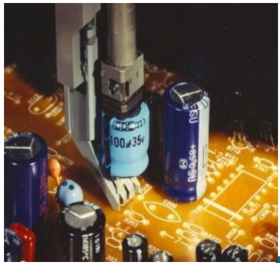
- Slowest workstation sets the pace of the line (bottleneck)
- In a paced line, the items are attached to a conveyor (ناقل), which moves at a certain speed that allows each worker to work on an item for the duration of a predetermined takt time (TT).
- Workpart transfer:
  - Palletized transfer line
    - Uses pallet fixtures to hold and move work parts between stations
  - Free transfer line
    - Part geometry allows transfer without pallet fixtures



Automated Production Line

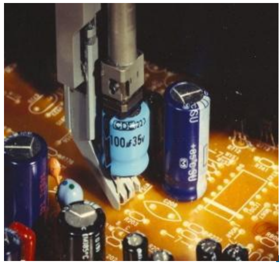


General configuration of an automated production line consisting of *n* automated workstations that perform processing operations



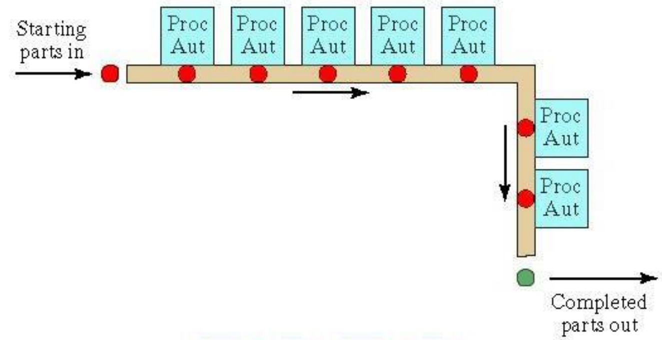
System Configurations

- *In-line* - straight line arrangement of workstations
- *Segmented in-line* – two or more straight line segments, usually perpendicular to each other
- *Rotary indexing machine* (e.g., dial indexing machine)

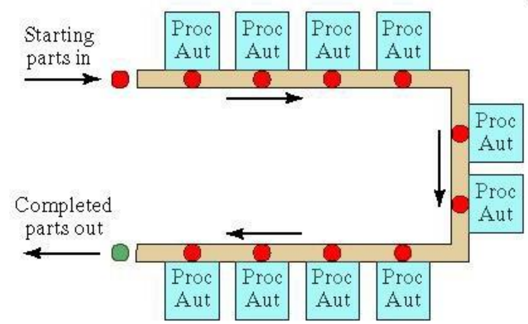


Segmented In-Line Configurations

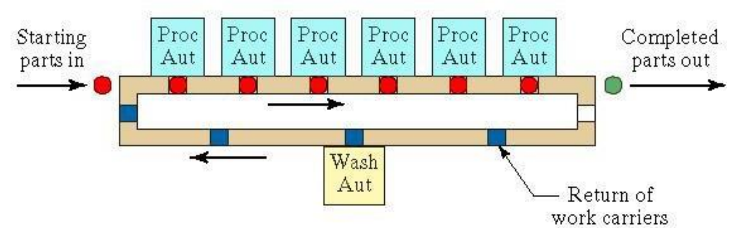
L-shaped layout



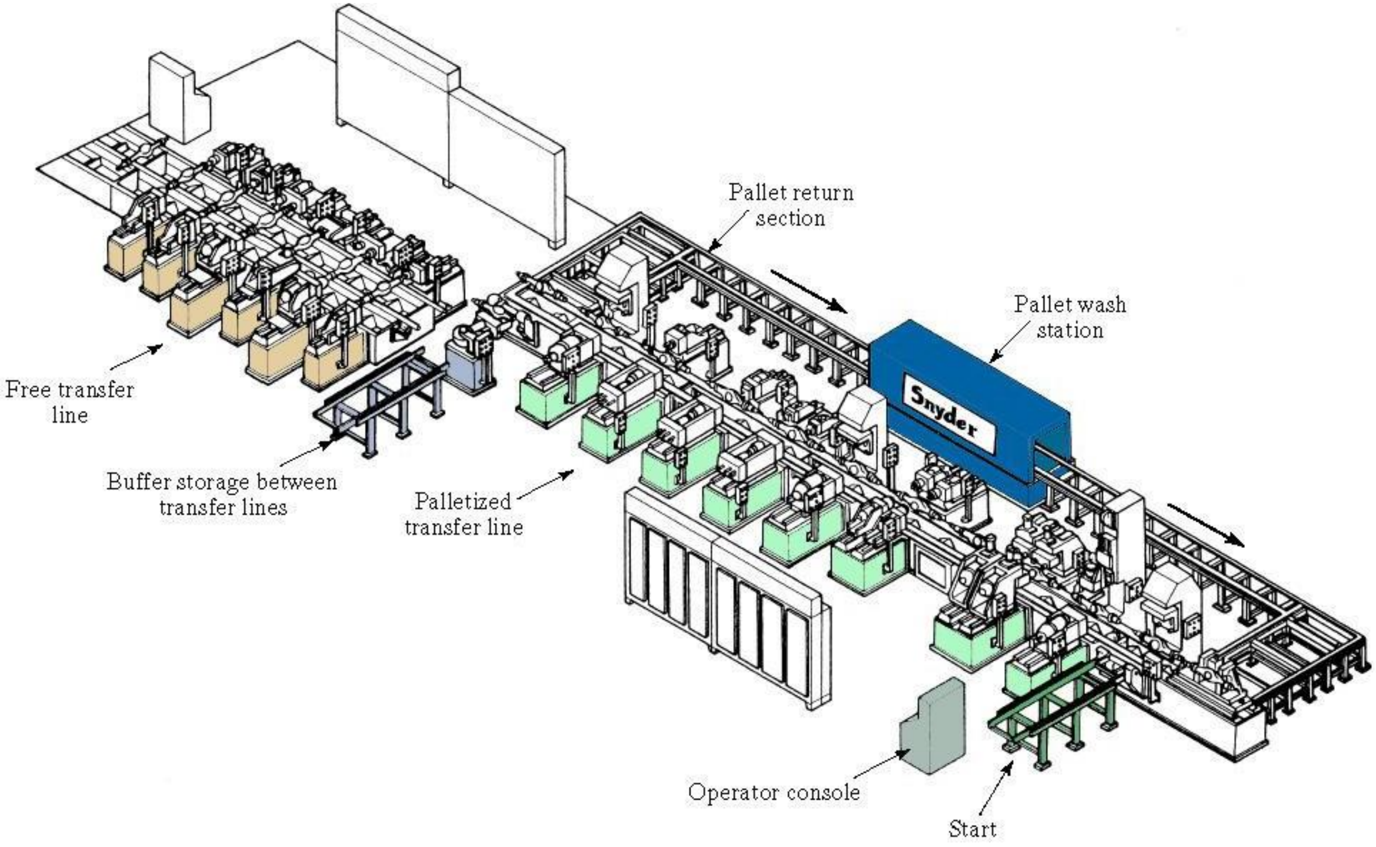
U-shaped layout



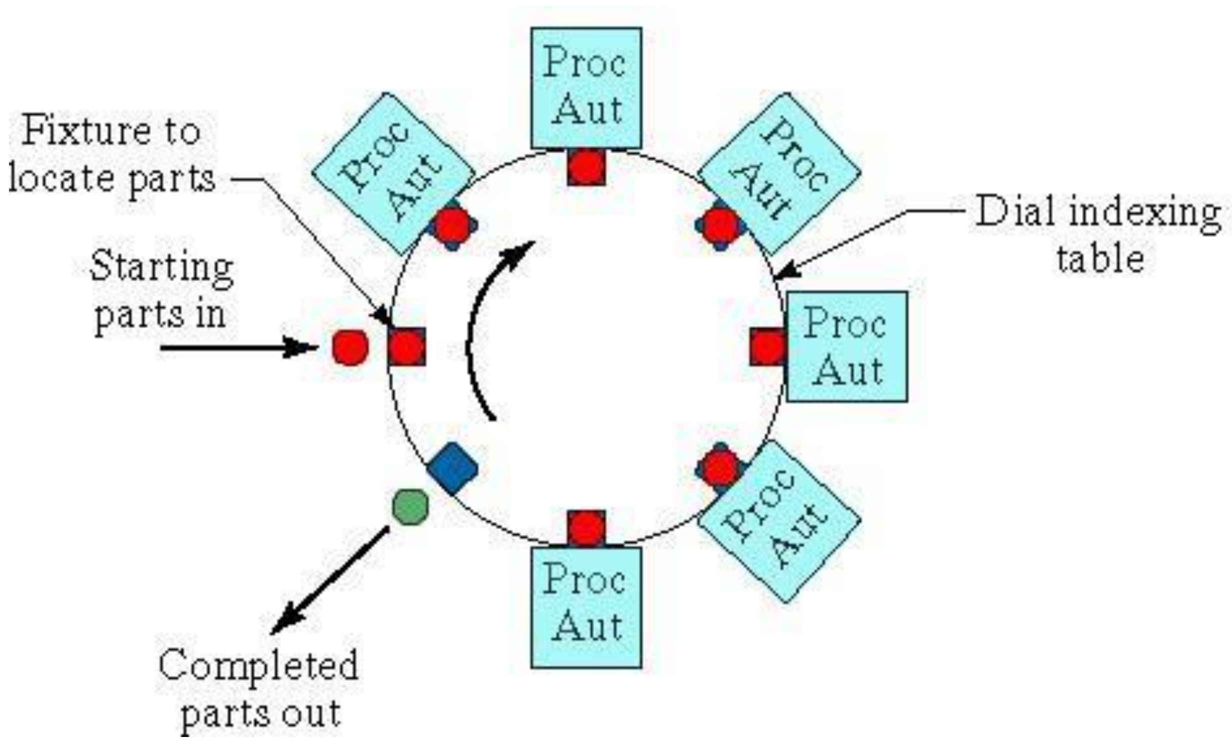
Rectangular configuration

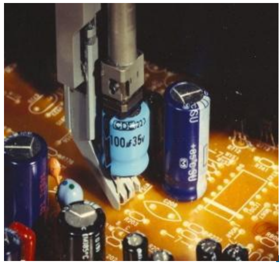


Two Machining Transfer Lines



Rotary Indexing Machine

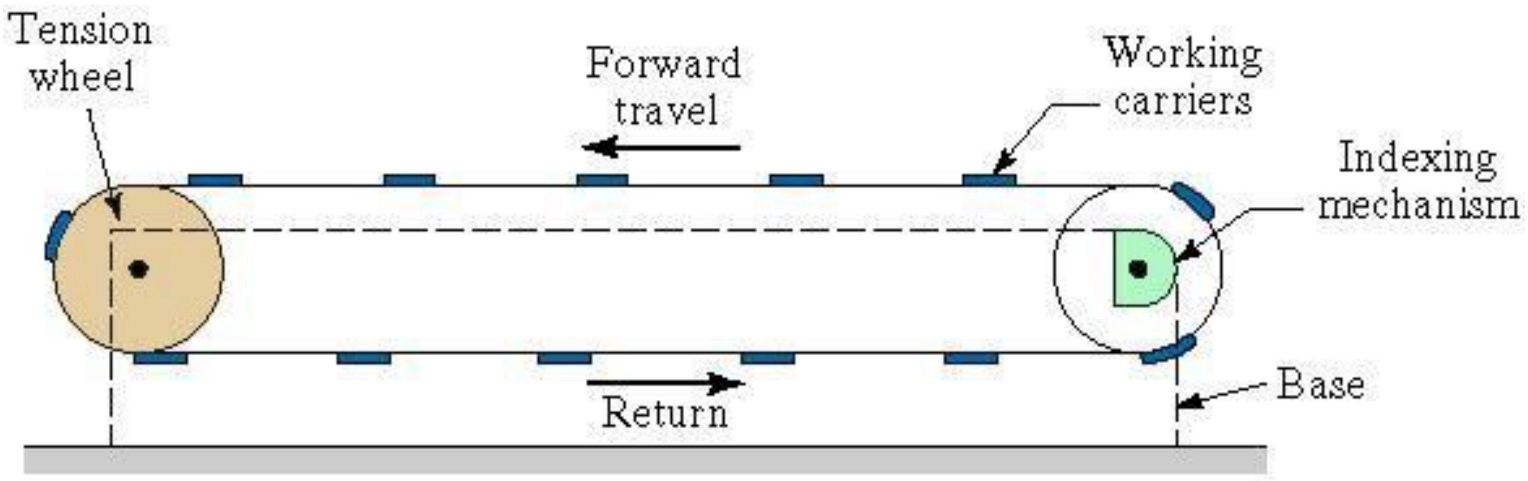




Workpart Transfer Mechanisms

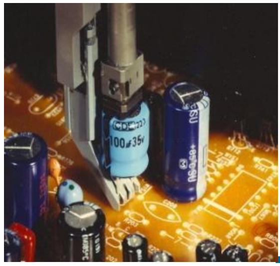
- Linear transfer systems:
  - حركة مستمرة Continuous motion – not common for automated systems
  - حركة متزامنة Synchronous motion – intermittent (حركة متقطعة) motion, all parts move simultaneously
  - حركة غير متزامنة Asynchronous motion – intermittent motion, parts move independently
- Rotary indexing mechanisms:
  - Geneva mechanism
  - Others

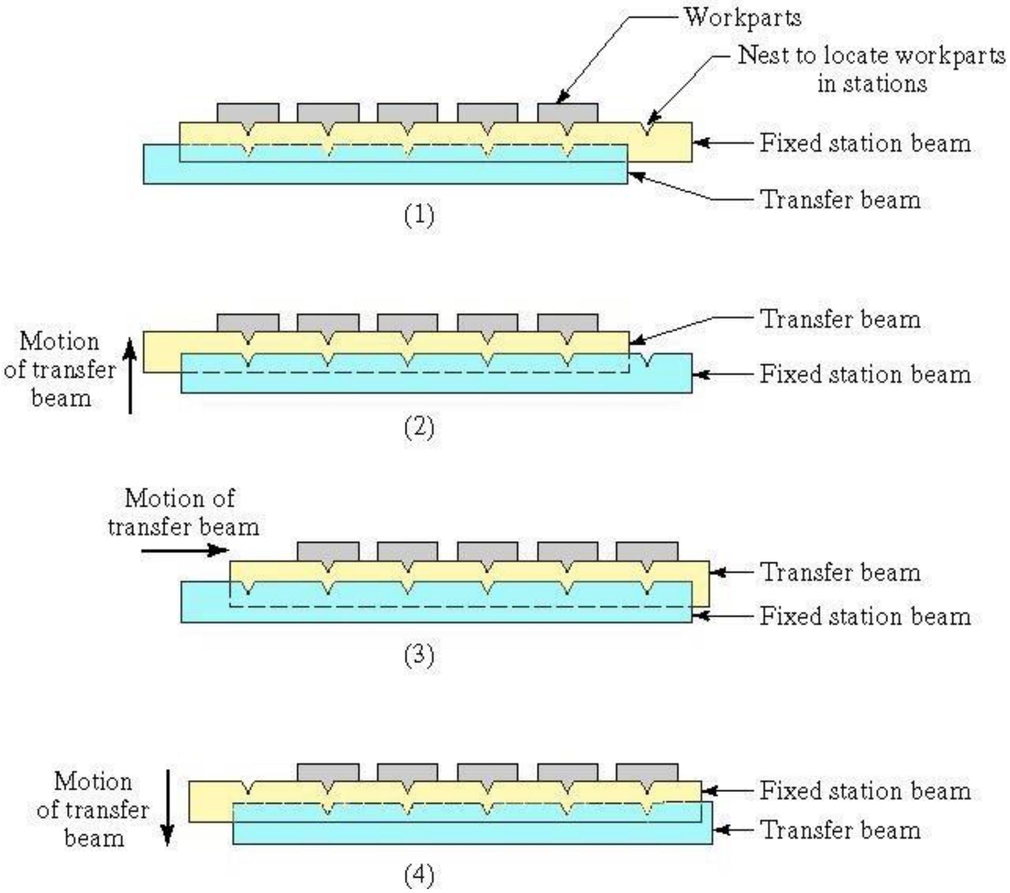
Belt-Driven Linear Transfer System

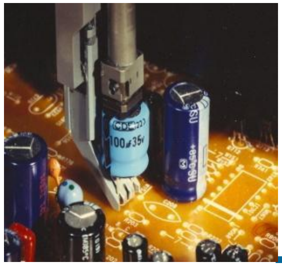


Side view of chain or steel belt-driven conveyor (over and under type) for linear transfer using work carriers

Walking Beam Transfer System







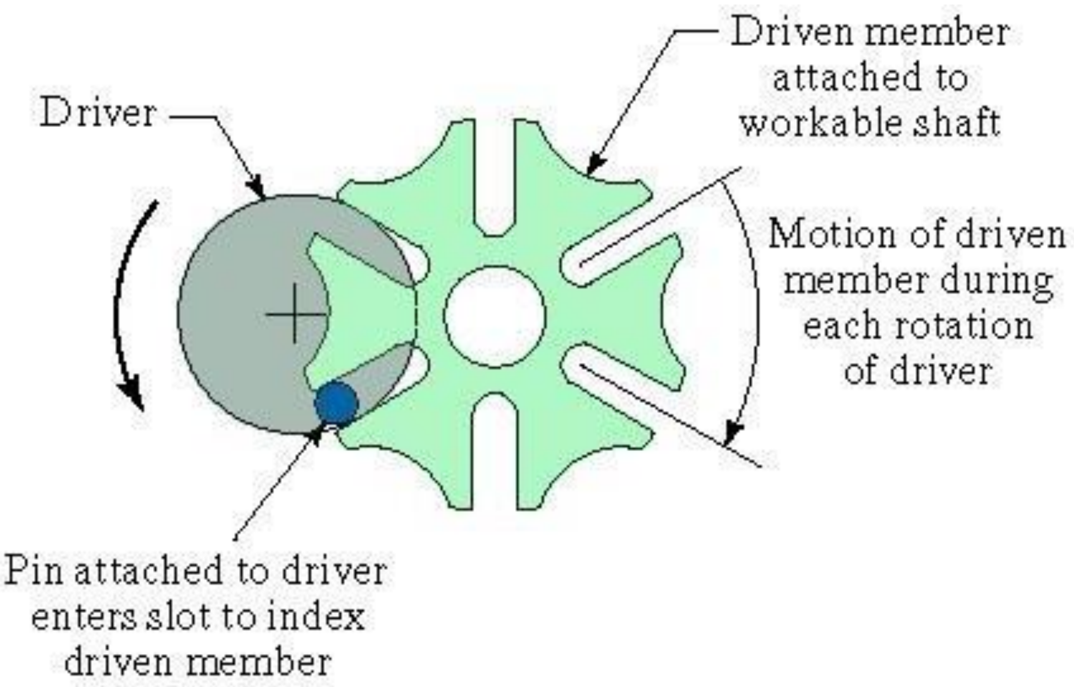
Videos

https://www.youtube.com/watch?v=gks8wVLSeVE

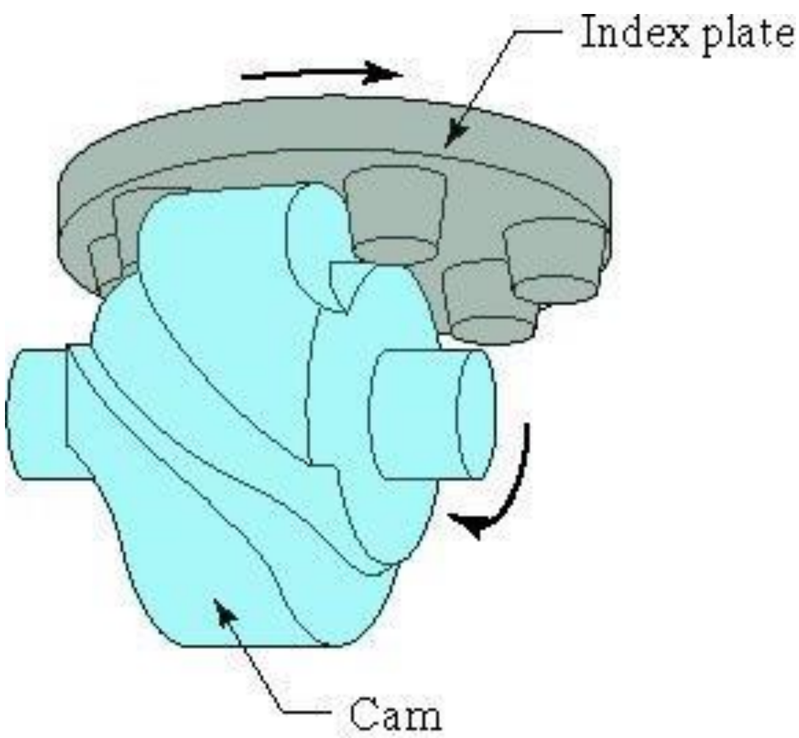
https://www.youtube.com/watch?v=2atiOFA-qnQ

https://www.youtube.com/watch?v=qRqeE6KArDY

Geneva Mechanism with Six Slots



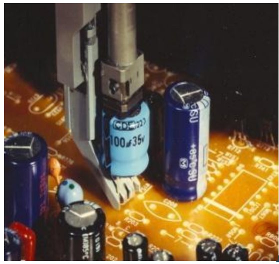
Cam Mechanism to Drive Dial Indexing Table



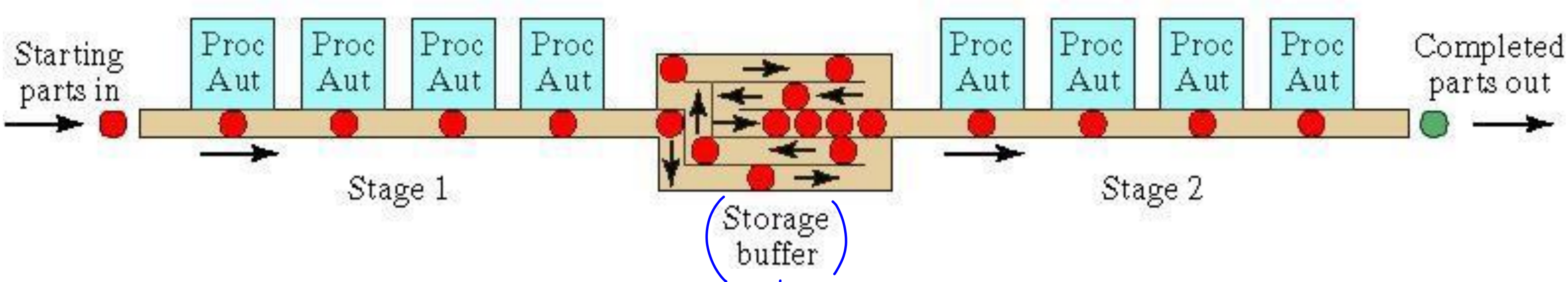
Storage Buffers in Production Lines

"A location in the sequence of workstations where parts can be collected and temporarily stored before proceeding to subsequent downstream stations"

- 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

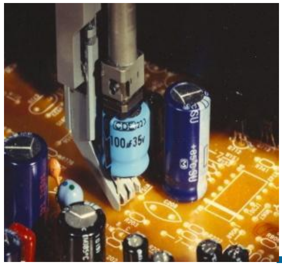


Storage Buffer



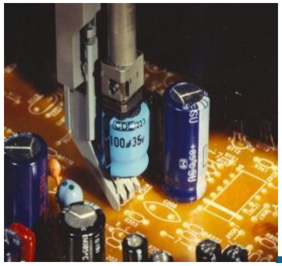
تخزين مؤقت عندما تكون واحدة من الworkstations
سرعتها أعلى من الثانية و تُنتج كمية أكبر

Storage buffer between two stages of a production line



Control Functions in an Automated Production Line

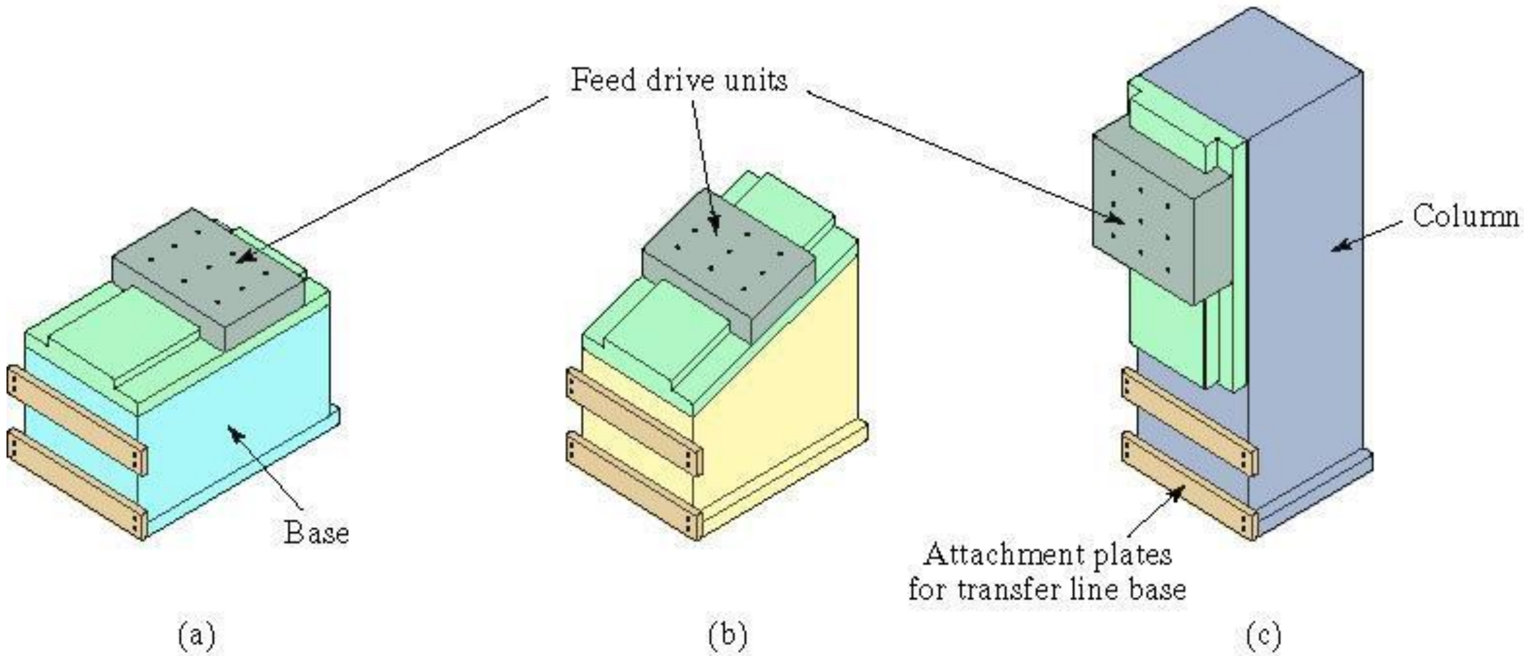
- *Sequence control*
  - To coordinate the sequence of actions of the transfer system and workstations
- *Safety monitoring*
  - To avoid hazardous operation for workers and equipment
- *Quality control*
  - To detect and possibly reject defective work units produced on the line



Applications of Automated Production Lines

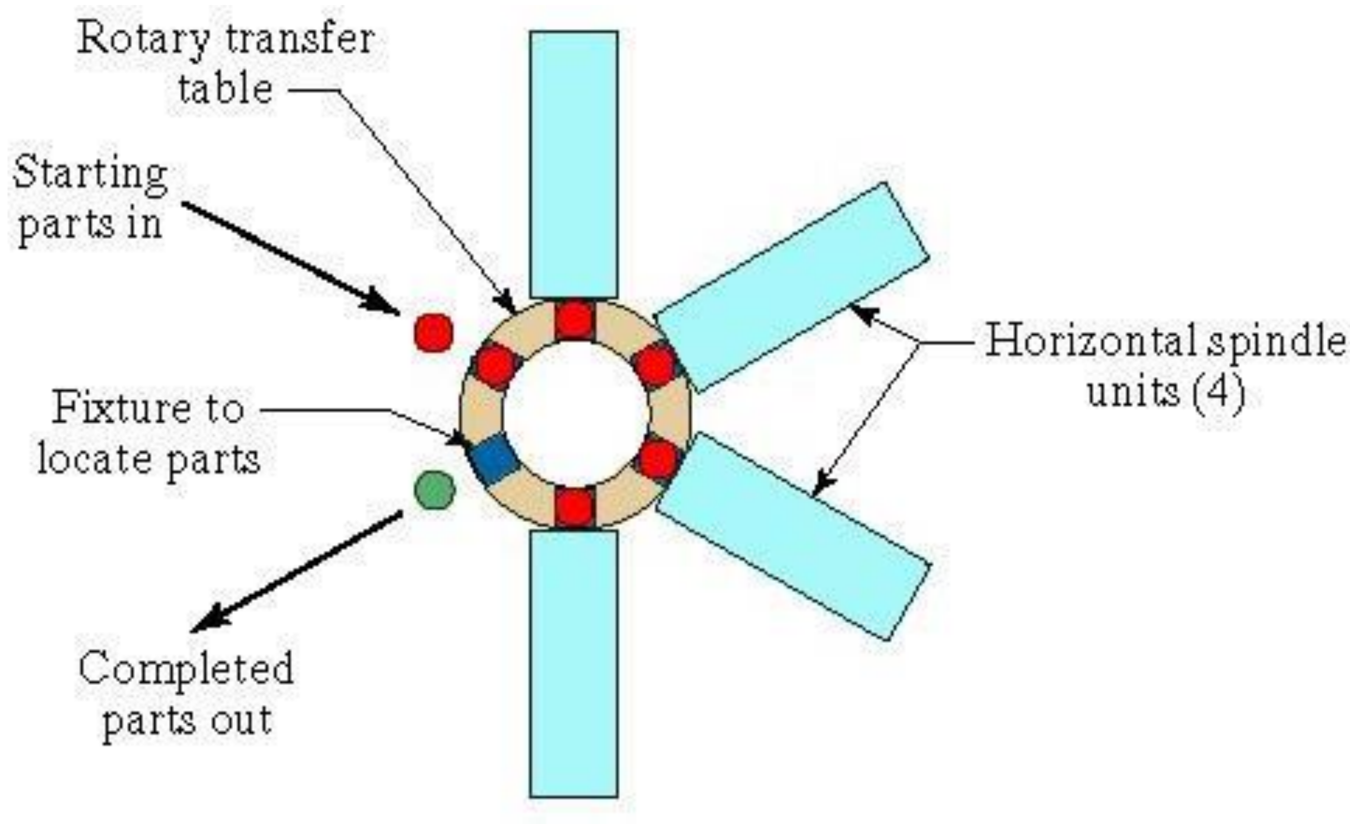
- Transfer lines for machining
  - Synchronous or asynchronous workpart transport
  - Transport with or without pallet fixtures, depending on part geometry
  - Various monitoring and control features available
- Rotary transfer machines for machining
  - Variations include center column machine and trunnion machine

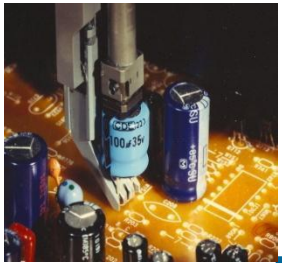
Standard Feed Units used with In-Line or Rotary Transfer Machines



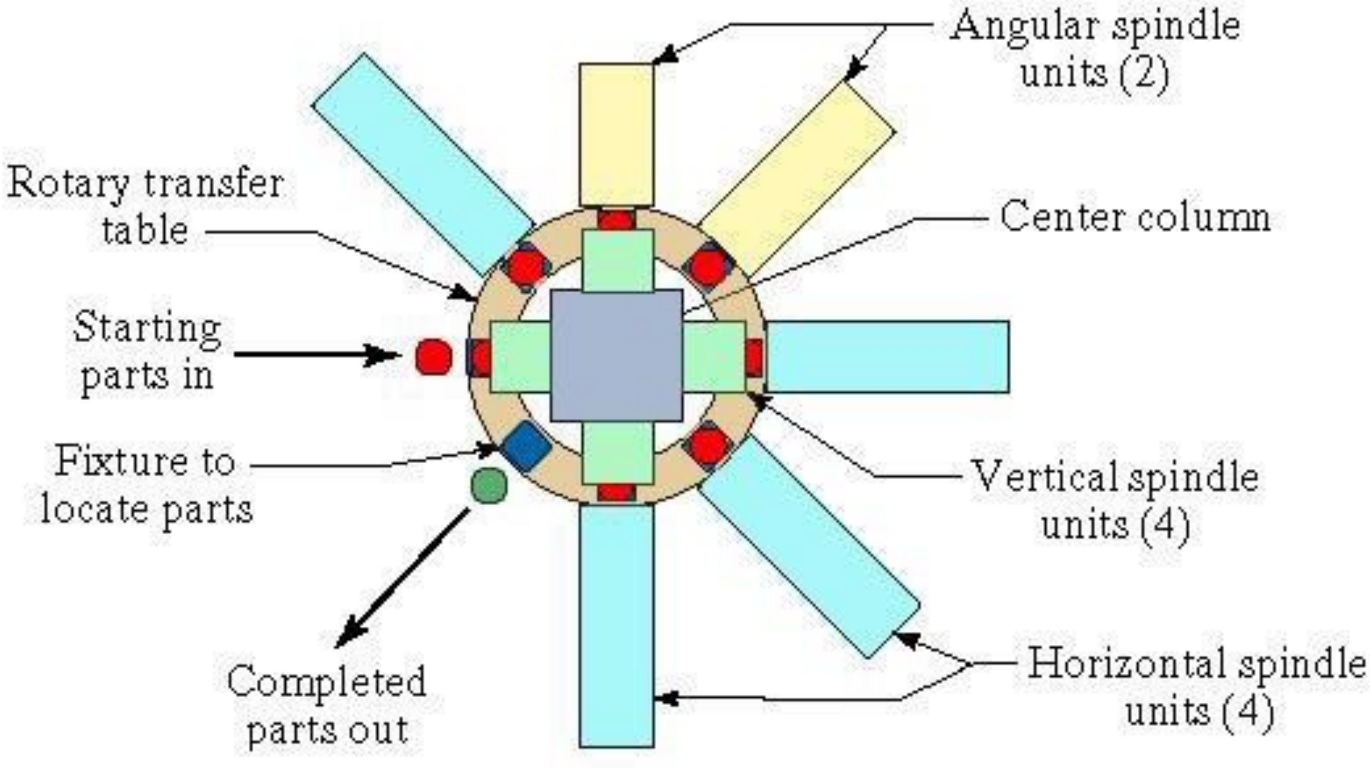
(a) Horizontal feed drive unit, (b) angular feed drive unit, and (c) vertical column feed drive unit

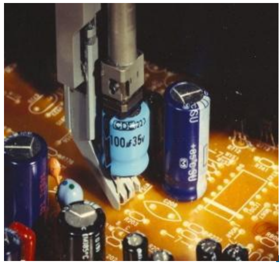
Rotary Transfer Machine (Plan View)





Center Column Machine (Plan View)





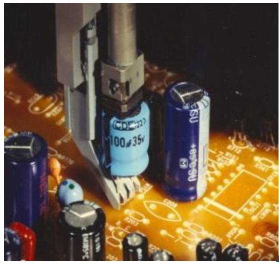
Analysis of Transfer Lines

- Three problem areas must be considered:

1. Line balancing
   - To divide the total work load among workstations as evenly as possible
2. Processing technology
   - Theory and principles about the manufacturing or assembly processes used on the line
3. System reliability - two cases:

تعتمد على سرعة
الانتاج و التخزين
والمدة لنقل البضائع

   - Transfer lines with no internal parts storage
   - Transfer lines with internal storage buffers



What the Equations Tell Us – Lines with No Storage Buffers

- *As the number of workstations increases*
  - Line efficiency and production rate are adversely affected
- *As reliability of individual workstations decreases*
  - Line efficiency and production rate are adversely affected

Automation

Chapter Eighteen
Cellular Manufacturing

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product Assembly

part ① (Manufacturing Features)
- Feature 1 (L)
- Feature 2 (D)

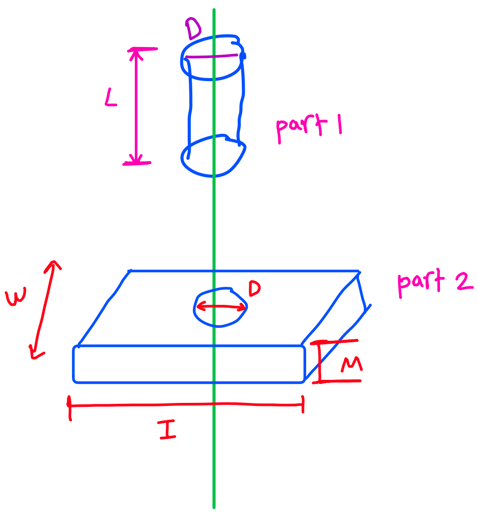
Assembly features
شرط coincident

part ②
- Feature(1) Dimensions W, I, M
- Feature 2 Hole D

علاقة طردية
↑ Knowledge sharing (between them)
↑ Efficiency

⟺

Production System
- Assembly
  - Holding
  - Joining
- Manufacturing
  - Drilling
  - Milling
  - Turning
  - ...



كل تغير هنا
يؤثر على العملية أو
الـ Skill بالـ production system

Cellular Manufacturing

To Eliminate waste

Cellular manufacturing is a lean method of producing similar products using cells, or groups of team members, workstations, or equipment to facilitate operations by eliminating setup and unneeded costs between operations.

ممكن يتكون من Machine واحدة أو أكثر

A work cell is a work unit larger than an individual machine or workstation but smaller than the usual department. Cells might be designed for a specific process, part, or complete product.

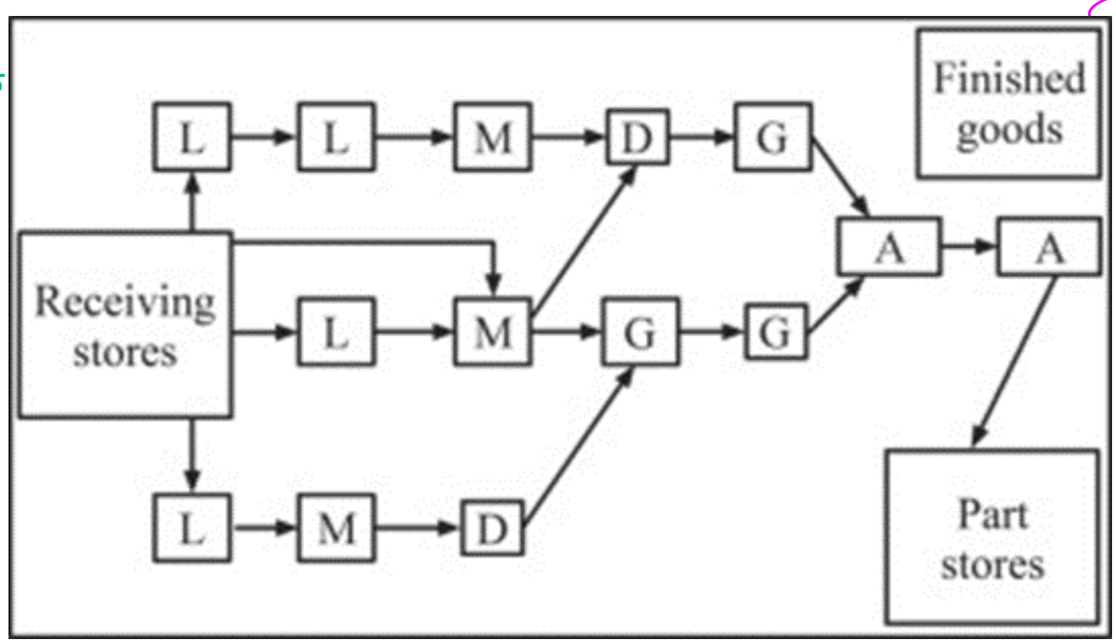
Cellular Manufacturing

* بدل ما يمر الـProduct بجميع الـ work stations
← بعطيه فقط للـ cells يلي بحتاجها عشان يتصنع

Cellular manufacturing has all the benefits of the product layout, but at the same time has a provision for additional small, general-purpose machines like a lathe, a drill, etc., to provide some extent of flexibility

تقسيم الـ cells يكون بناءاً على الـ process placed speifications

كل مجموعة Parts في الـProduct التي تحتاج نفس الـprocesses ⇐ بحطهم في part family خاصة فيها



مجموعة cells

كل cell مكونة من مجموعة machines أو workstations بتعطيني مقدار معين من الـ processes

مثلاً process 1 2 3 ...

Benefits of $\boxed{\text{cellular manufacturing}}$

يقلل ال Handling time

- Cells shorten the distance a part or product has to move. This reduces materials handling costs, allows quicker feedback on potential quality problems, reduces work-in-process inventories, permits easier scheduling, and reduces throughput time.
- Cells organize the locating of materials at the point of use. This makes it easy to see the work ahead.
- Cell teams better understand the whole process of making parts/assemblies.
- Cell members feel responsibility to a small group, rather than to an impersonal company. Understandable, logical participation leads to a feeling of empowerment.

ال cellular manufacturing حالة خاصة من ال Process Layout

Process versus Product Layout

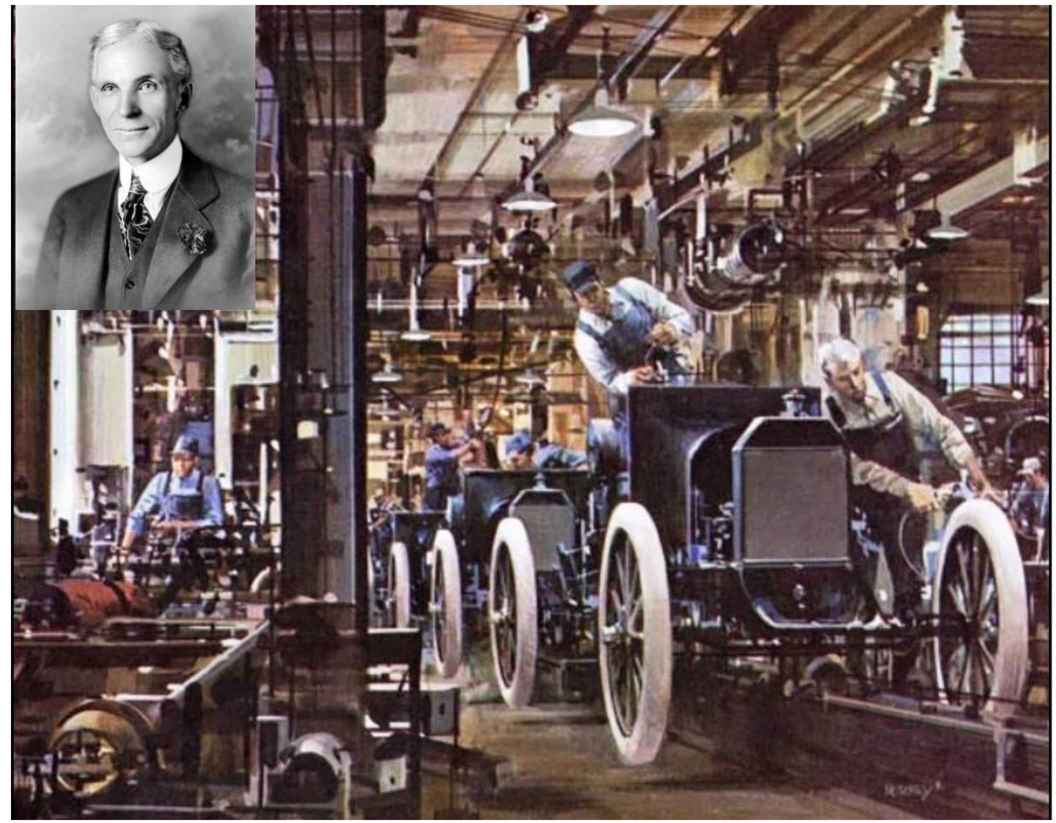
- Customized goods
- Functional grouping of activities
- Varied path/routing
- Low/fluctuating demand
- General purpose equip.
- Fixed costs=low; variable costs=high
- Labor skills high/varied

- Standardized goods
- Sequential arrangement of activities
- Fixed path/routing
- High/stable demand
- Special purpose equip.
- Fixed costs=high; variable costs=low
- Labor skills limited

Production Line (product layout)

- Henry Ford:

- Founder of Ford Motor Company.
- Invented the Model T car. Introduced the moving assembly line method of production into the car industry.
- Popularized the 40-hour work week.



Henrry Ford’s assembly line in full production of the T -Model

Group Technology (GT) Defined

"A manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in design and production"

- Similarities among parts permit them to be classified into ***part families***.
  - In each part family, ***processing steps*** are similar.
- The improvement is typically achieved by organizing the production facilities into ***manufacturing cells*** that specialize in production of certain part families.

Overview of Group Technology

- Parts in the medium production quantity range are usually made in batches.

إنتاج دفعة واحدة

- Disadvantages of batch production:
  - *Downtime for changeovers*
  - *High inventory carrying costs*

- GT minimizes these disadvantages by recognizing that although the parts are different, there are groups of parts that possess similarities.

Part Families and Cellular Manufacturing

يستغل

- GT exploits the part similarities by utilizing similar processes and tooling to produce them.
- Machines are grouped into cells, each cell specializing in the production of a part family called *cellular manufacturing.*
- Cellular manufacturing can be implemented by manual or automated methods. When automated, the term *flexible manufacturing system* is often applied.

When to Use GT and Cellular Manufacturing

1. *The plant currently uses traditional batch production and a process type layout:*
   This results in much material handling effort, high in process inventory, and long manufacturing lead times.
2. *The parts can be grouped into part families:*
   A necessary condition to apply group technology. Each machine cell is designed to produce a given part family, or a limited collection of part families, so it must be possible to group parts made in the plant into families.

Problems in Implementing GT

1. *Identifying the part families*
   - Reviewing all of the parts made in the plant and grouping them into part families is a substantial task
2. *Rearranging production machines into GT cells*
   - It is time-consuming and costly to physically rearrange the machines into cells, and the machines are not producing during the changeover

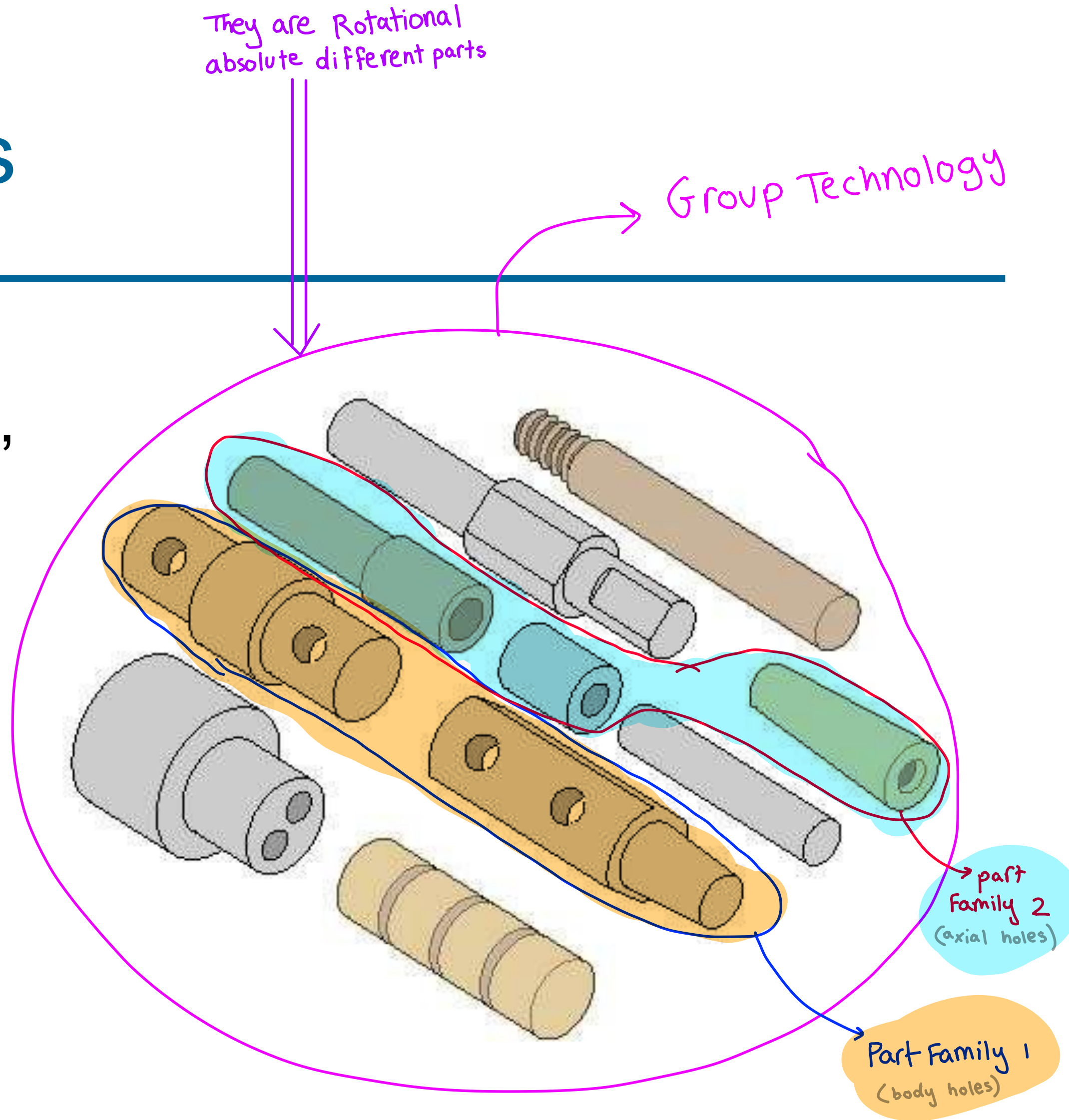
Part Family

"A collection of parts that possess similarities in geometric shape and size, or in the processing steps used in their manufacture"

- Part families are a central feature of group technology. There are always differences among parts in a family.
- But the similarities are close enough that the parts can be grouped into the same family.

Part Families

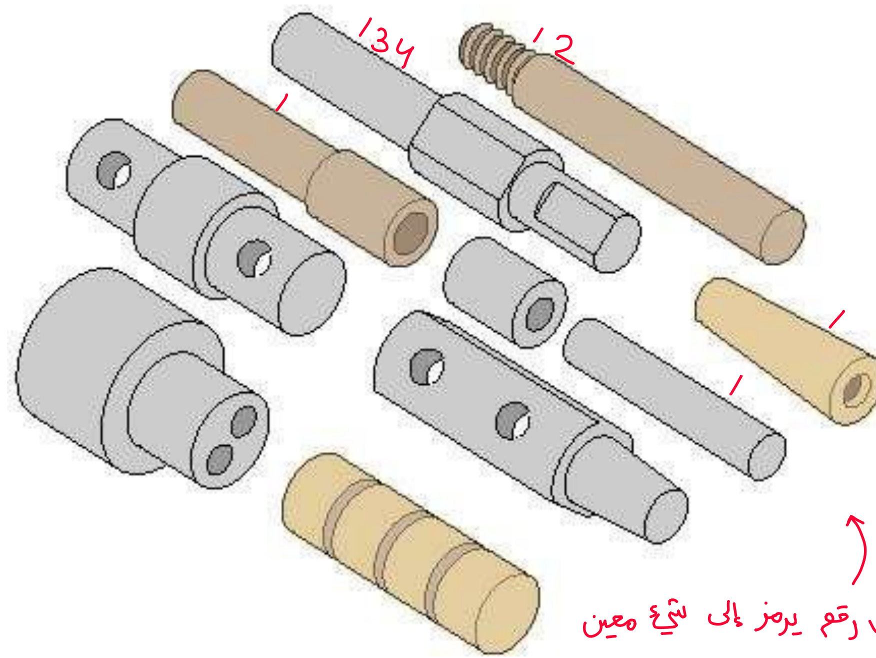
- Ten parts are different in size, shape, and material, but quite similar in terms of manufacturing
- All parts are machined from cylindrical stock by turning; some parts require drilling and/or milling



Part Families

بقدر اوزع ال Product ← إلى codes

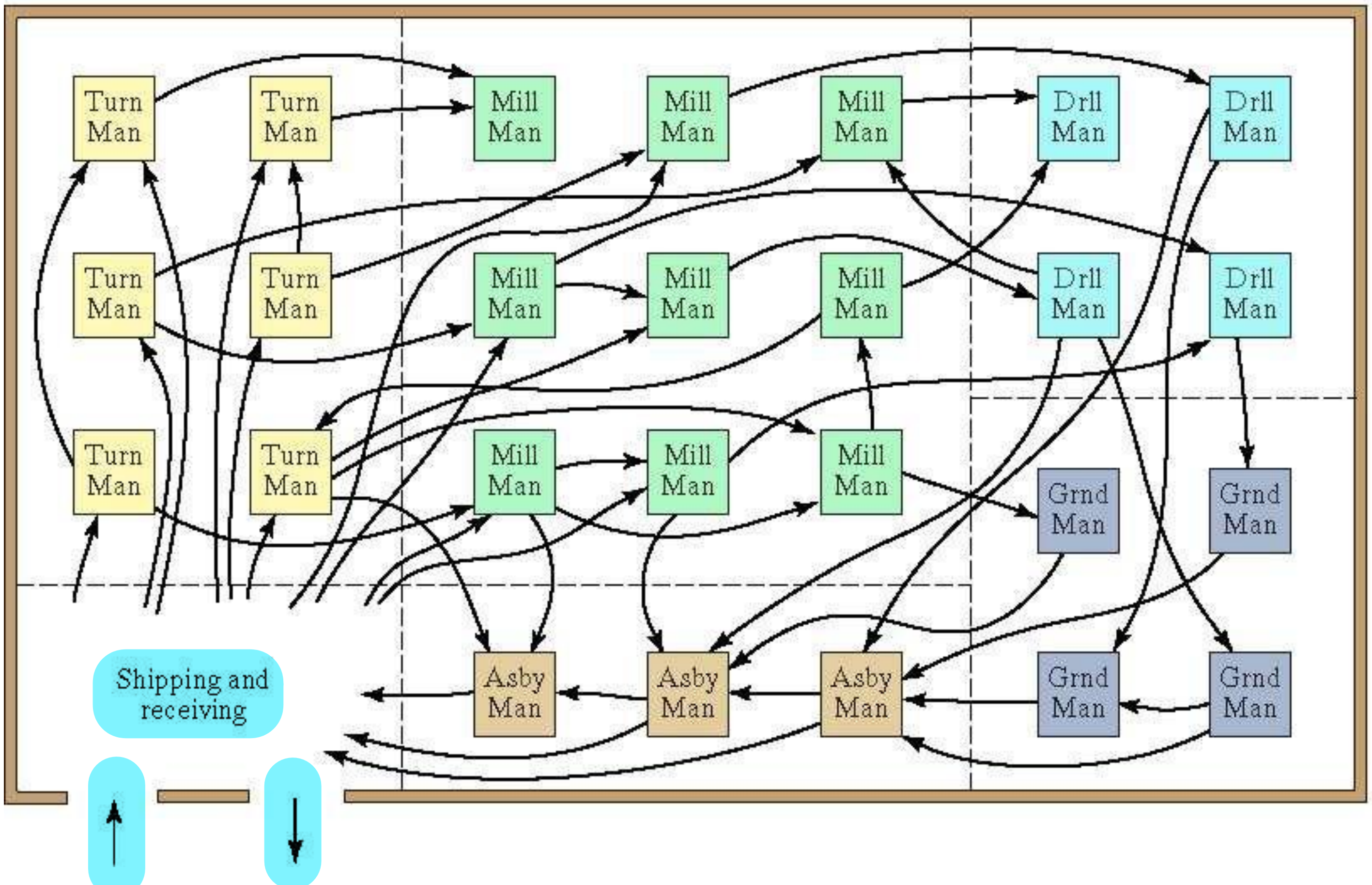
- Ten parts are different in size, shape, and material, but quite similar in terms of manufacturing
- All parts are machined from cylindrical stock by turning; some parts require drilling and/or milling



كل رقم يرمز إلى شيء معين

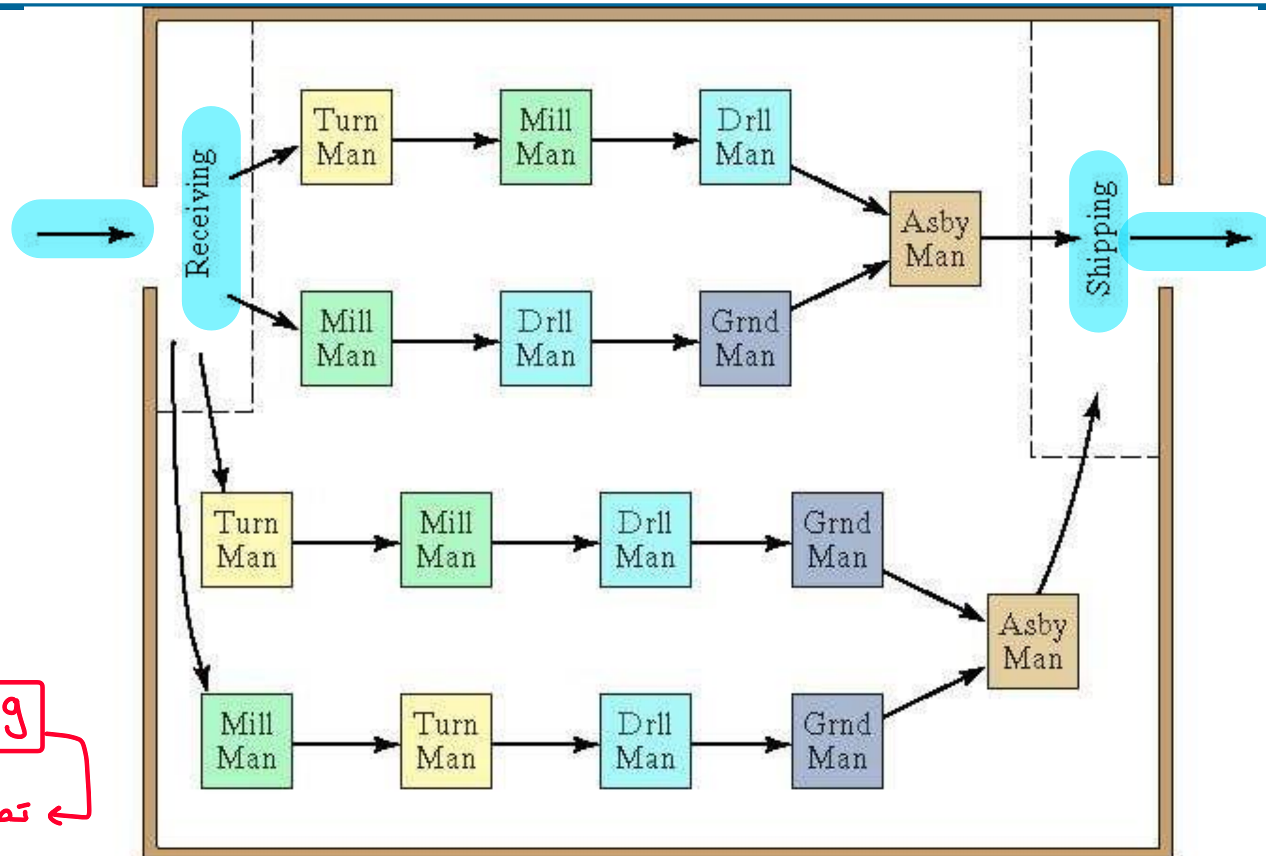
Traditional Process Layout

تجميع ال Machines المتشابهة مع بعض



Cellular Layout Based on GT

- Each cell specializes in producing one or a limited number of part families



Cellular Manufacturing

تضم مجموعة Machines مختلفة
لكن تؤدي مجموعة processes تساعد في
معالجة part family معينة

Ways to Identify Part Families

1. Visual inspection

في حال وجود عدد قليل من الparts

- Using best judgment to group parts into appropriate families, based on the parts or photos of the parts

2. Parts classification and coding
- Identifying similarities and differences among parts and relating them by means of a coding scheme

3. Production flow analysis

يعتمد بدرجة أولى على ال Process plan for the product

- Using information contained on route sheets to classify parts

Parts Classification and Coding

"Identification of similarities among parts and relating the similarities by means of a numerical coding system"

- Most time consuming of the three methods
- Must be customized for a given company or industry
- Reasons for using a coding scheme:
  - *Design retrieval:* access to a part that already exists
  - *Automated process planning:* process plans for similar code parts
  - *Machine cell design:* composite part concept

Features of Parts Classification and Coding Systems

- Most classification and coding systems are based on one of the following:
  - *Part design attributes* ✓ مثل الـ I, W, D, ... يلي رسمتهم في بداية الـchapter
  - *Part manufacturing attributes* (مثلاً حجم الـ hole)
  - *Both design and manufacturing attributes*

Part Design Attributes

- Major dimensions
- Basic external shape
- Basic internal shape
- Length/diameter ratio
- Material type
- Part function
- Tolerances
- Surface finish

Part Manufacturing Attributes

- Major process
- Operation sequence
- Batch size
- Annual production
- Machine tools
- Cutting tools
- Material type

Production Flow Analysis (PFA)

"Method for identifying part families and associated machine groupings based on production route sheets rather than part design data"

- A route sheet is a document which lists the exact sequence of operations needed to complete the job.
- Workparts with identical or similar route sheets are classified into part families.
- Advantages of using route sheet data

مع ذلك قد يتطلب

  - *Parts with different geometries may nevertheless require the same or similar processing*
  - *Parts with nearly the same geometries may nevertheless require different processing*

Steps in Production Flow Analysis

1. **Data collection** – operation sequence and machine routing for each part (number)
2. **Sortation of process routings** – parts with same sequences and routings are arranged into "packs"
3. **PFA chart** – each pack is displayed on a PFA chart
   - Also called a *part-machine incidence matrix*
4. **Cluster analysis** – purpose is to collect packs with similar routings into groups
   - Each machine group = a machine cell

Route sheet

كل Part ← ماهي ال machines
التي نحتاجها له

(Part 1) and (Part 4)
are produced by
(Machine 1)

		Parts				
		P_1	P_2	P_3	P_4	P_5
Machines	M_1	1	0	0	1	0
	M_2	0	1	1	0	1
	M_3	1	0	0	1	0
	M_4	0	1	1	0	1
	M_5	1	0	0	1	0

Cellular Manufacturing

"Application of group technology in which dissimilar machines or processes are aggregated into cells, each of which is dedicated to the production of a part family or limited group of families"

- Typical objectives of cellular manufacturing:
  - *To shorten manufacturing lead times and material handling*
  - *To reduce Work In Progress (WIP)*
  - *To improve quality*
  - *To simplify production scheduling and process planning*
  - *To reduce setup times*

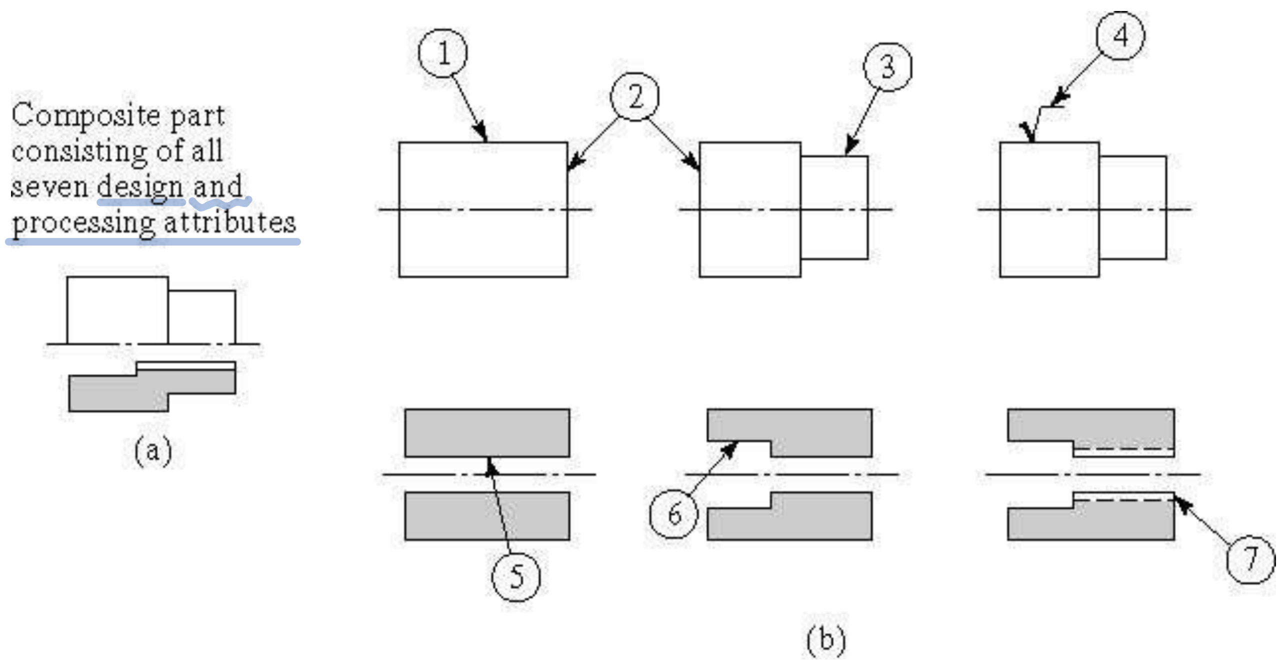
Composite Part Concept

"A composite part for a given family is a hypothetical part that includes all of the design and manufacturing attributes of the family"

- In general, an individual part in the family will have some of the features of the family, but not all of them.
- A production cell for the part family would consist of those machines required to make the composite part.
- Such a cell would be able to produce any family member, by omitting operations corresponding to features not possessed by that part.

Composite Part Concept

Composite part concept: (a) the composite part for a family of machined rotational parts, and (b) the individual features of the composite part



Part Features and Corresponding Manufacturing Operations

this will reduce the setup time

product Design

كل ما كان الـ integration بيتم أسرع

كل ما زاد الـ flexibility لـ manufacturing system

process Planning

<u>Design feature</u>		<u>Corresponding operation</u>
1. External cylinder	the process I need →	Turning
2. Face of cylinder	→	Facing
3. Cylindrical step	→	Turning
4. Smooth surface	→	External cylindrical grinding
5. Axial hole	→	Drilling
6. Counter bore	→	Counterboring
7. Internal threads	→	Tapping

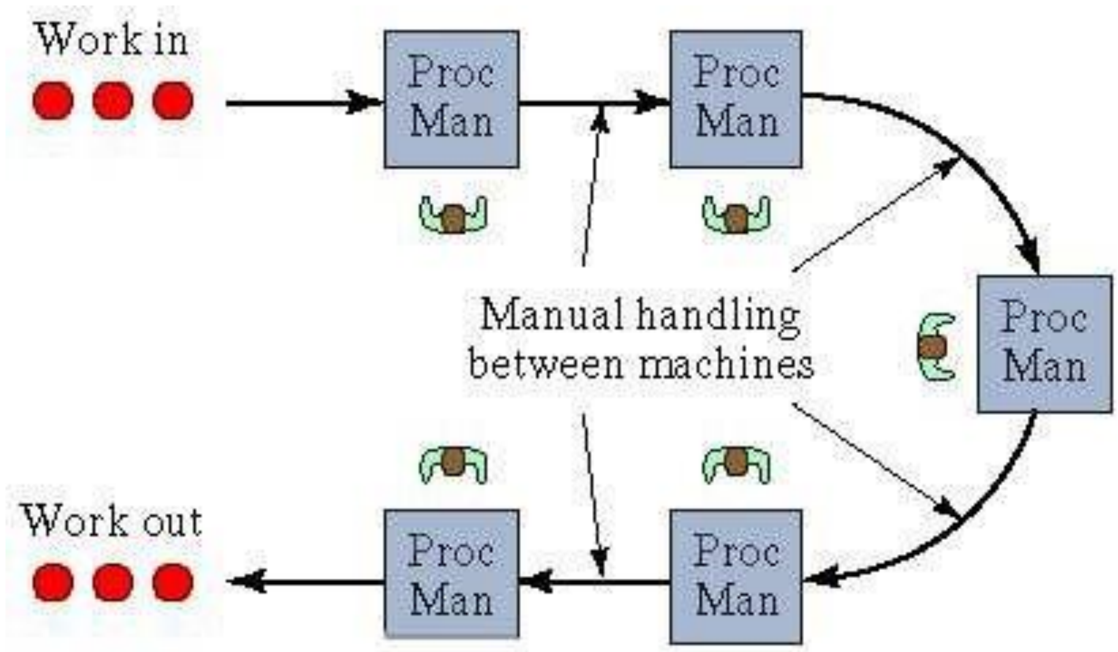
(↑ تعقيد الـ Product Design)

(↑ operations)

Machine Cell Designs

1. Single machine
2. Multiple machines with manual handling
   - Often organized into U-shaped layout
3. Multiple machines with semi-integrated handling
4. Automated cell – automated processing and integrated handling
   - *Flexible manufacturing cell*
   - *Flexible manufacturing system*

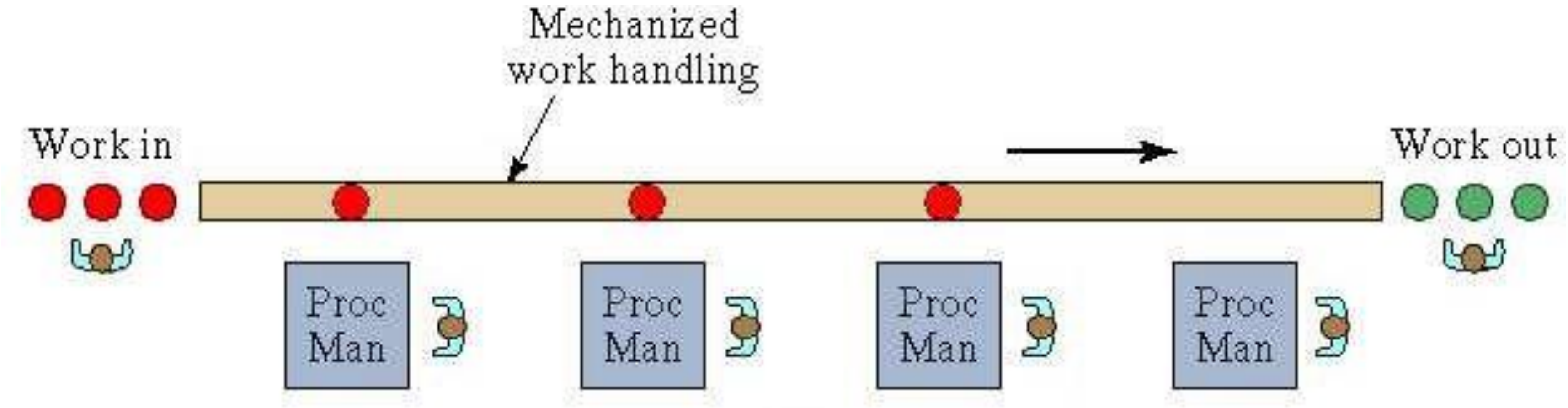
Machine Cell with Manual Handling



U-shaped machine cell with manual part handling between machines

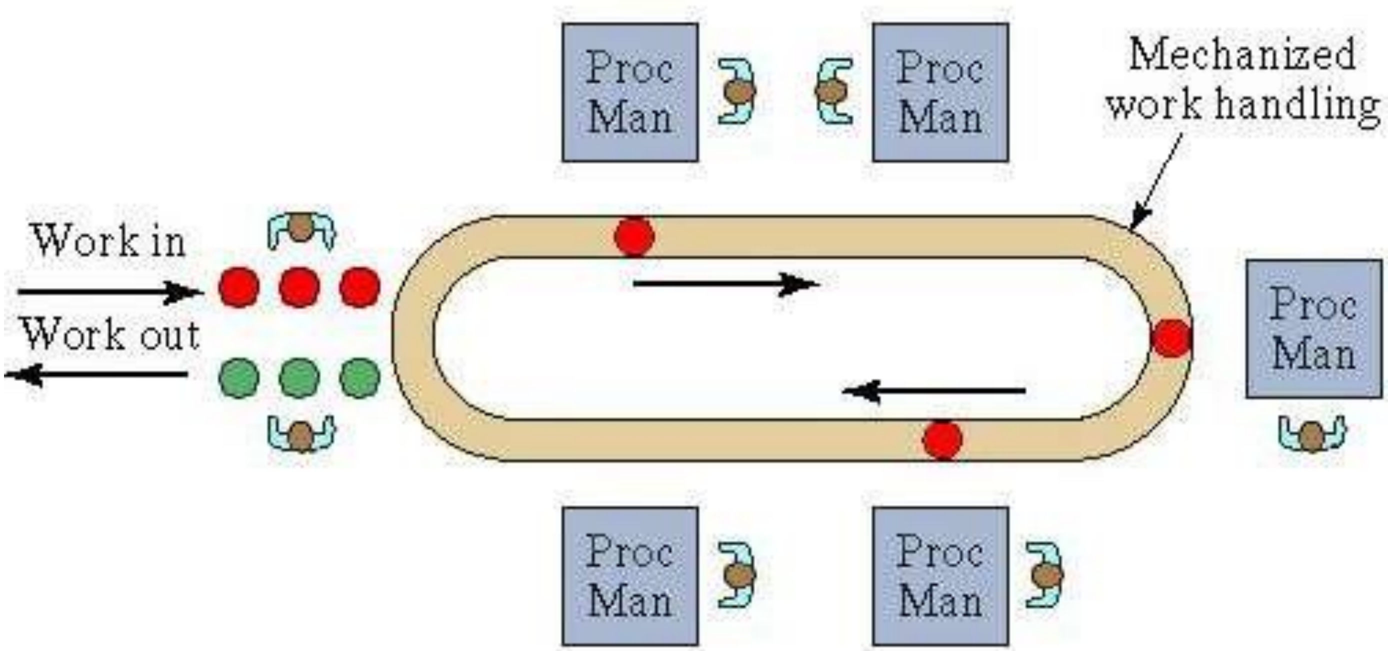
Cell with Semi-Integrated Handling

① In-line Layout
② Loop Layout
③ Rectangular Layout



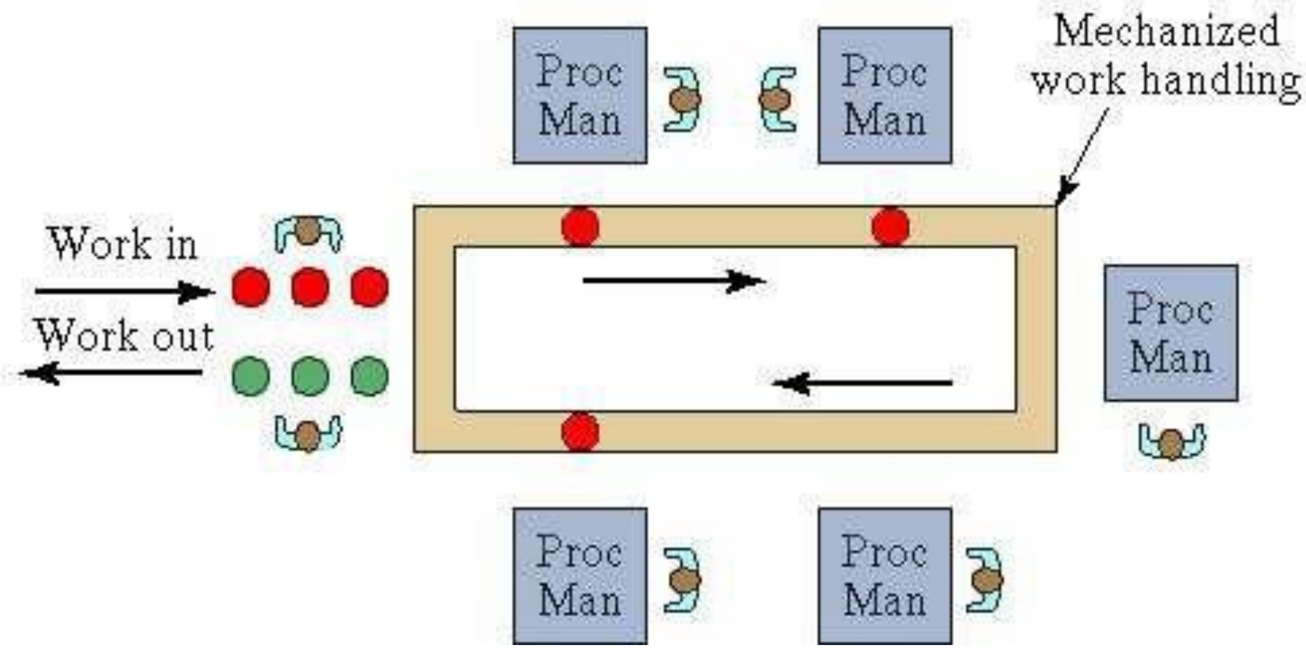
In-line layout using mechanized work handling between machines

Cell with Semi-Integrated Handling



Loop layout allows variations in part routing between machines.

Cell with Semi-Integrated Handling



Rectangular layout also allows variations in part routing and allows for return of work carriers if they are used.

Key Machine Concept

Here:-

Machine $\longrightarrow$ غير متخصصة

Worker $\longrightarrow$ متخصصين

- *"Applies in cells when there is one machine (the key machine) that is more expensive or performs certain critical operations"*
  - Other machines in the cell are supporting machines.
  - Important to maintain high utilization of key machine, even if this means lower utilization of supporting machines.

Benefits of Group Technology in Manufacturing

- Standardization of tooling, fixtures, and setups is encouraged.
- Material handling is reduced.
  - Parts are moved within a machine cell rather than the entire factory.
- Process planning and production scheduling are simplified.
- Work-in-process and manufacturing lead time are reduced.
- Improved worker satisfaction in a GT cell
- Higher quality work

Automated cellular systems $\xrightarrow[\text{تسمى}]{}$ flexible manufacturing

Videos

https://www.youtube.com/watch?v=PDSmRPh6TaM

https://www.youtube.com/watch?v=Br2eEpiiwvU

Automation

Chapter Nineteen
Flexible Manufacturing

Automated cellular Manufacturing

Dr. Eng. Baha'eddin Alhaj Hasan
Department of Industrial Engineering

Ch 19
Flexible Manufacturing Systems

Sections:

1. What is a Flexible Manufacturing System?
2. FMS Components
3. FMS Applications and Benefits
4. FMS Planning and Implementation Issues
5. Quantitative Analysis of Flexible Manufacturing Systems

Where to Apply FMS Technology

- The plant presently either:
  - Produces parts in batches or
  - Uses manned GT cells and management wants to automate the cells
- It must be possible to group a portion of the parts made in the plant into part families
  - The part similarities allow them to be processed on the FMS workstations
- Parts and products are in the mid-volume, mid-variety production range

Flexible Manufacturing System - Defined

"A highly automated GT machine cell, consisting of a group of processing stations (usually CNC machine tools), interconnected by an automated material handling and storage system, and controlled by an integrated computer system"

- The FMS relies on the principles of GT
  - No manufacturing system can produce an unlimited range of products
  - An FMS is capable of producing a single part family or a limited range of part families

Flexible Manufacturing
Cellular Manufacturing

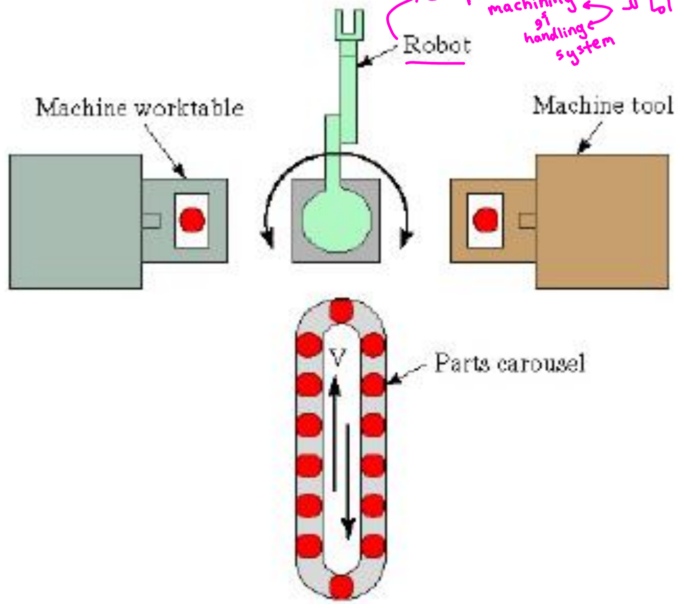
نستخدمهم بالدرجة الأولى للحصول على
مقدار من ال Flexibility
مقدار من ال Product Variety

Flexibility Tests in an Automated Manufacturing System

To qualify as being *flexible*, a manufacturing system should satisfy the following criteria (“yes” answer for each question):

1. Can it process different part styles in a non-batch mode?
2. Can it accept changes in production schedule?
3. Can it respond gracefully to equipment malfunctions and breakdowns?
4. Can it accommodate introduction of new part designs?

Automated Manufacturing Cell



computerized Robot
machining of handling system

Ussualy there is two machines and a conveyer or a handling system

Automated manufacturing cell with two machine tools and robot. Is it a flexible cell?

Is the Robotic Work Cell Flexible?

1. Part variety test
   - Can it machine different part configurations in a mix rather than in batches?
2. Schedule change test
   - Can production schedule and part mix be changed?

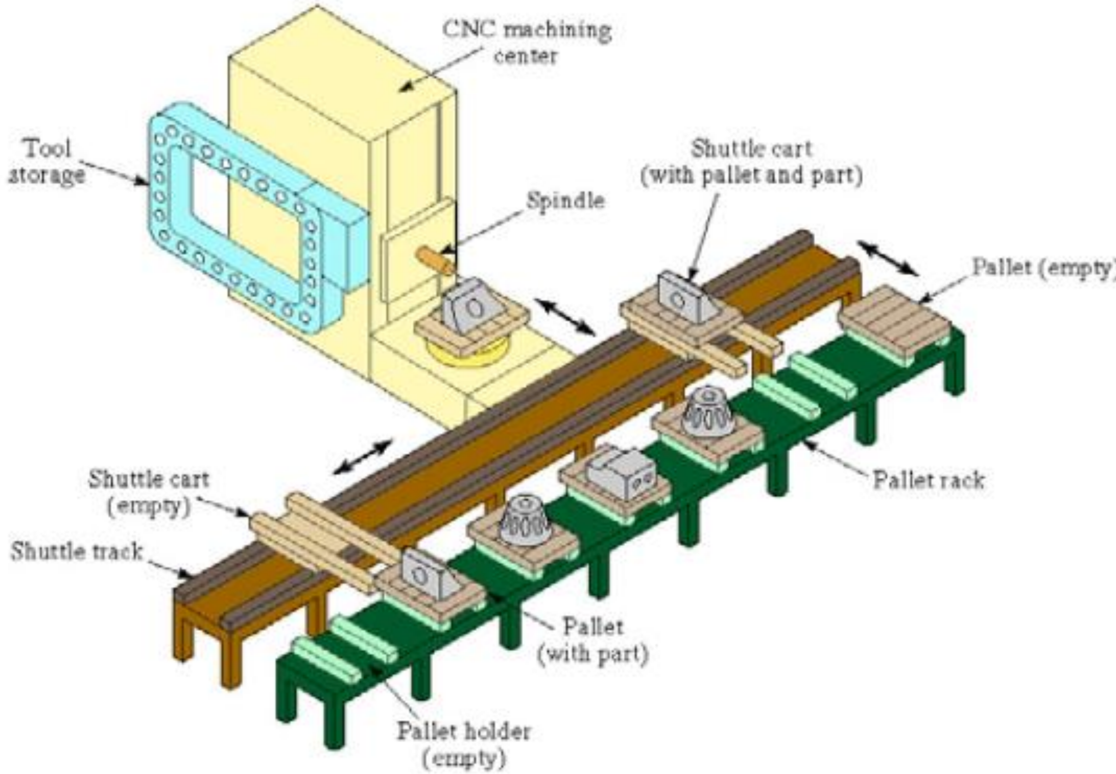
Is the Robotic Work Cell Flexible?

3. <u>Error recovery test</u>
   - Can it operate if one machine breaks down?
     - Example: while repairs are being made on the broken machine, can its work be temporarily reassigned to the other machine?
4. <u>New part test</u>
   - As new part designs are developed, can NC part programs be written off-line and then downloaded to the system for execution?

Types of FMS

- <u>Kinds of operations:</u>
  - Processing vs. assembly
  - Type of processing
    - If machining, rotational vs. non-rotational
- <u>Number of machines (workstations):</u>
  1. Single machine cell (*n* = 1)
  2. Flexible manufacturing cell (*n* = 2 or 3)
  3. Flexible manufacturing system (*n* = 4 or more)

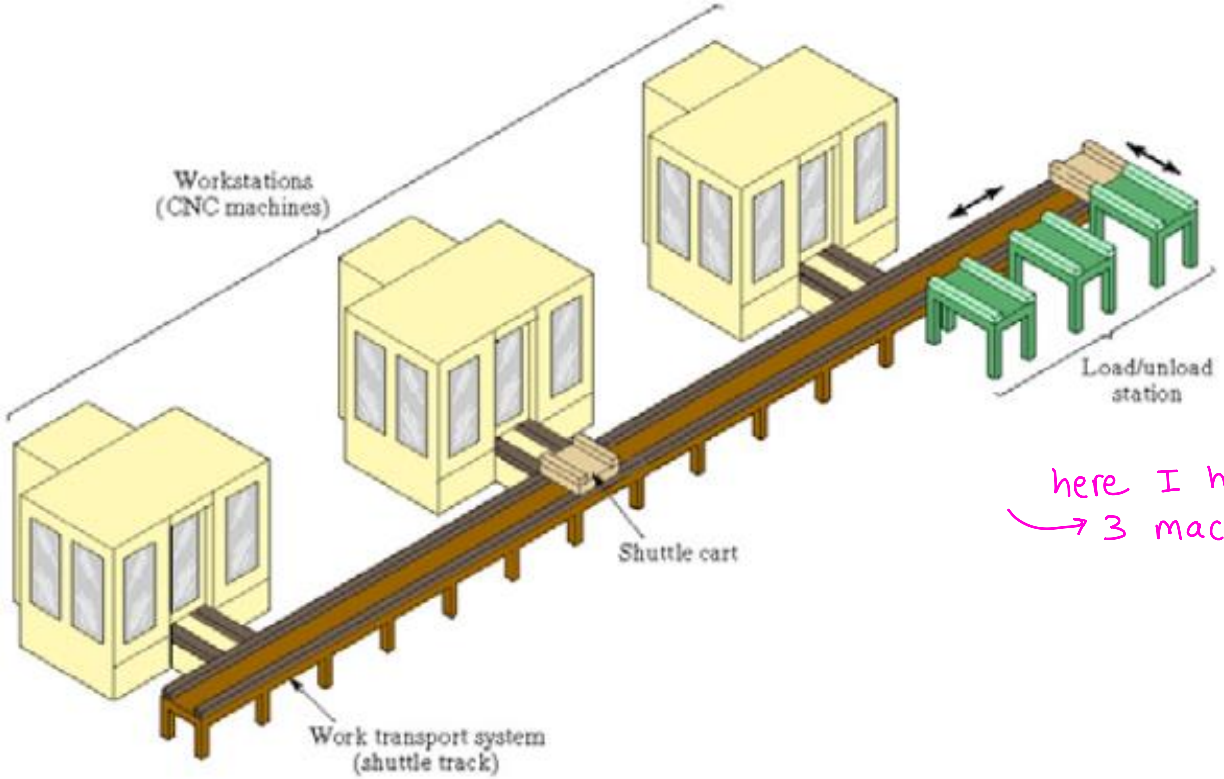
Single-Machine Manufacturing Cell



A single-machine CNC machining cell (photo courtesy of Cincinnati Milacron)

Flexible Manufacturing Cell

n= 2 or 3



here I have
3 machines

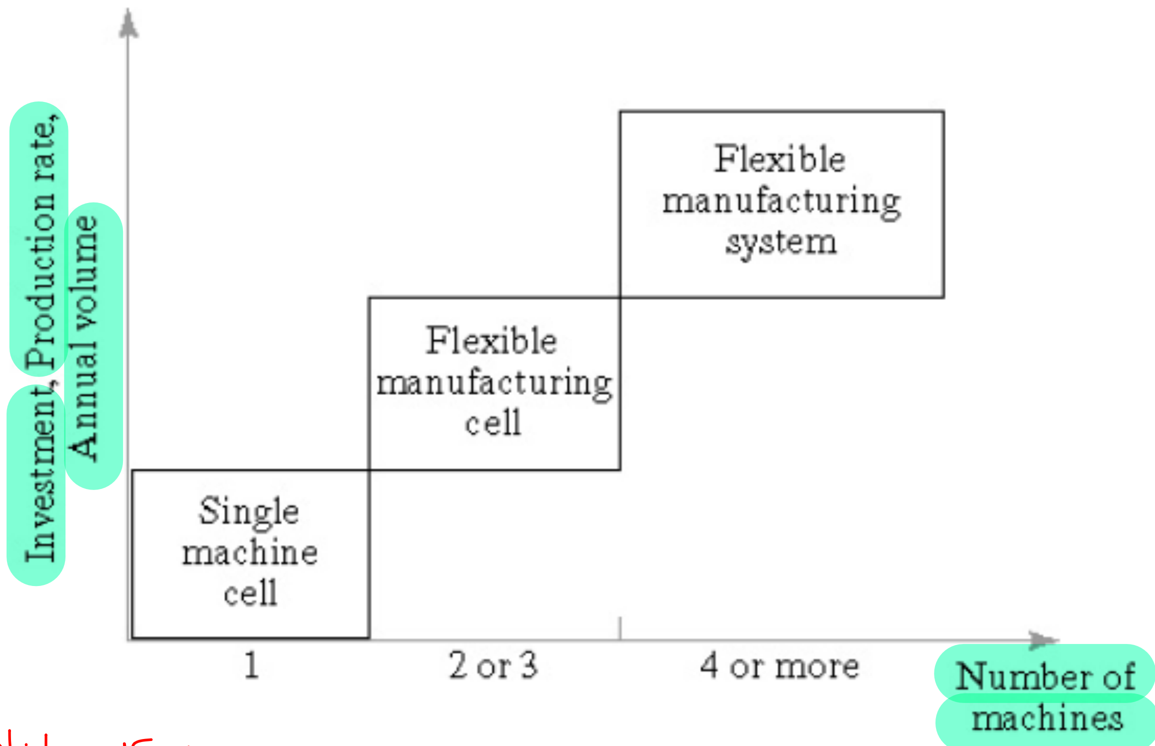
2

A two-machine flexible manufacturing cell for machining (photo courtesy of Cincinnati Milacron)

$n > 4 \rightarrow$ FMS system

A five-machine flexible manufacturing system for machining (photo courtesy of Cincinnati Milacron)

Features of the Three Categories



* كل ما زاد عدد ال (Machines)

كل ما زاد ال (Annual volume)

FMS Types
Level of Flexibility

1. *Dedicated FMS*

cells are fixed
أو انه صعب اغير الترتيب تبعهم

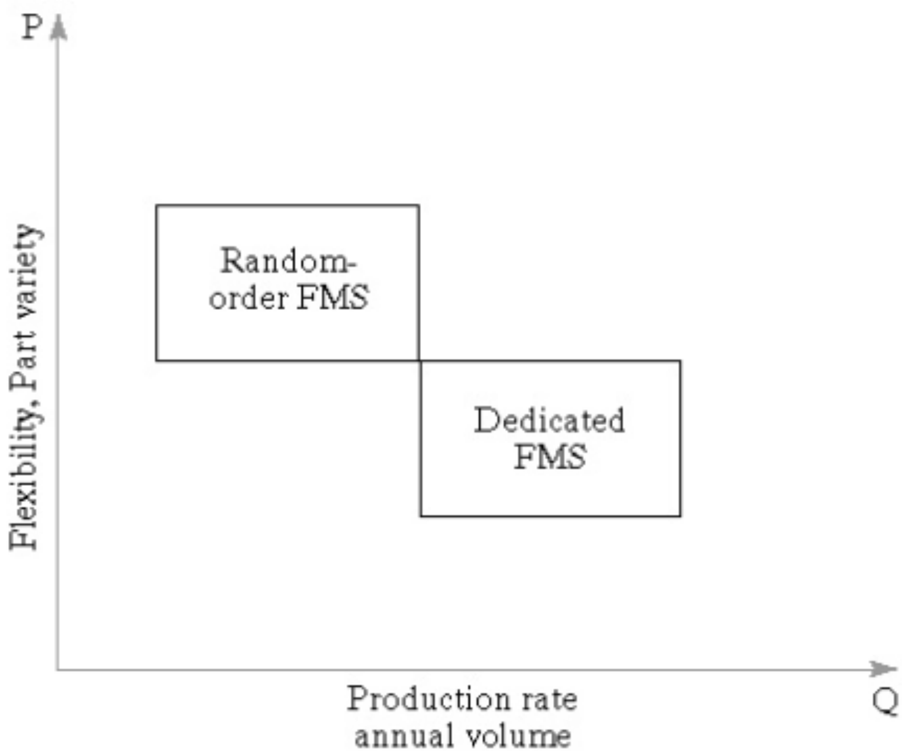
- Designed to produce a limited variety of part styles
- The complete universe of parts to be made on the system is known in advance
- Part family likely based on product commonality rather than geometric similarity

2. *Random-order FMS*

Flexibility
أعلى من ال dedicated

- Appropriate for large part families
- New part designs and engineering changes will be introduced
- Production schedule is subject to daily changes

Dedicated vs. Random-Order FMSs



FMS Components

1. Workstations
2. Material handling and storage system
3. Computer control system
4. Human labor

Workstations

- *Load and unload station(s)*
  - Factory interface with FMS
  - Manual or automated
  - Includes communication interface with worker to specify parts to load, fixtures needed, etc.
- *CNC machine tools in a machining type system*
  - CNC machining centers
  - Milling machine modules
  - Turning modules
- *Assembly machines*

Material Handling and Storage

- *Functions:*
  - Random, independent movement of parts between stations
  - Capability to handle a variety of part styles
    - Standard pallet fixture base
    - Workholding fixture can be adapted
  - Temporary storage
  - Convenient access for loading and unloading
  - Compatibility with computer control

Material Handling Equipment

- Primary handling system establishes basic FMS layout
- Secondary handling system –

  Functions:

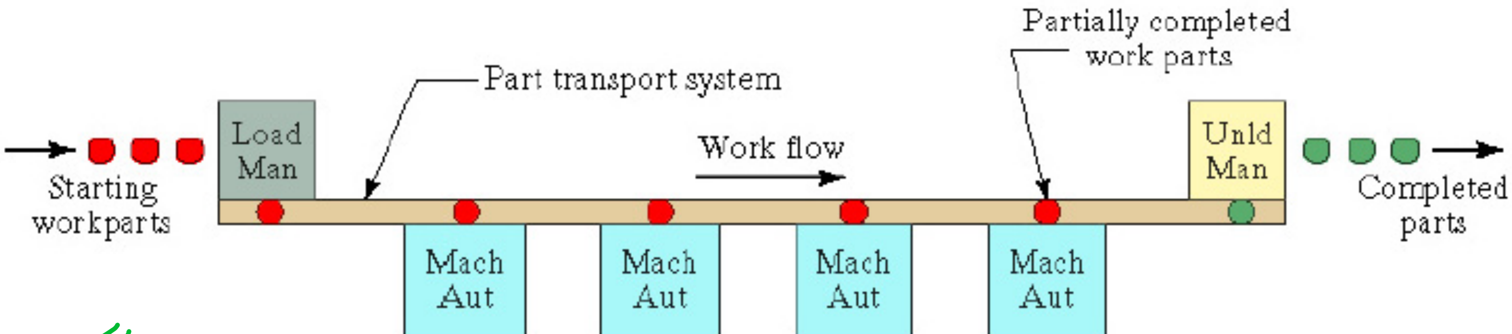
  - Transfers work from primary handling system to workstations
  - Position and locate part with sufficient accuracy and repeatability for the operation
  - Reorient part to present correct surface for processing
  - Buffer storage to maximize machine utilization

Five Types of FMS Layouts

يعتمدو على
مقدار الـFlexibility التي احتاجها
درجة تعقيد الـproduct

- The layout of the FMS is established by the material handling system
- Five basic types of FMS layouts
  1. In-line
  2. Loop
  3. Ladder
  4. Open field
  5. Robot-centered cell

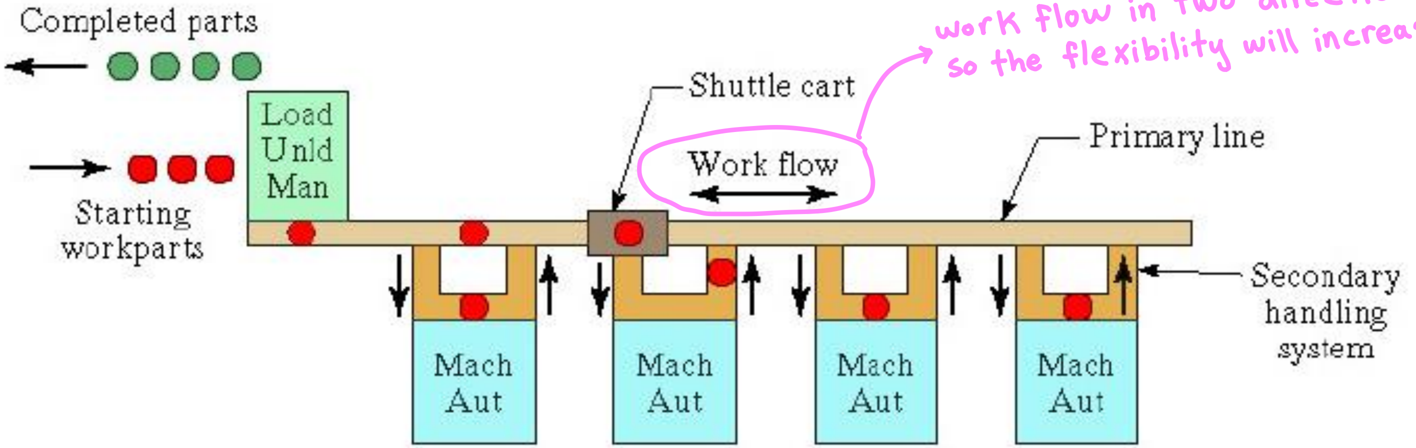
FMS In-Line Layout



غالباً يستخدم في ال Dedicated systems

- Straight line flow, well-defined processing sequence similar for all work units
- Work flow is from left to right through the same workstations
- No secondary handling system

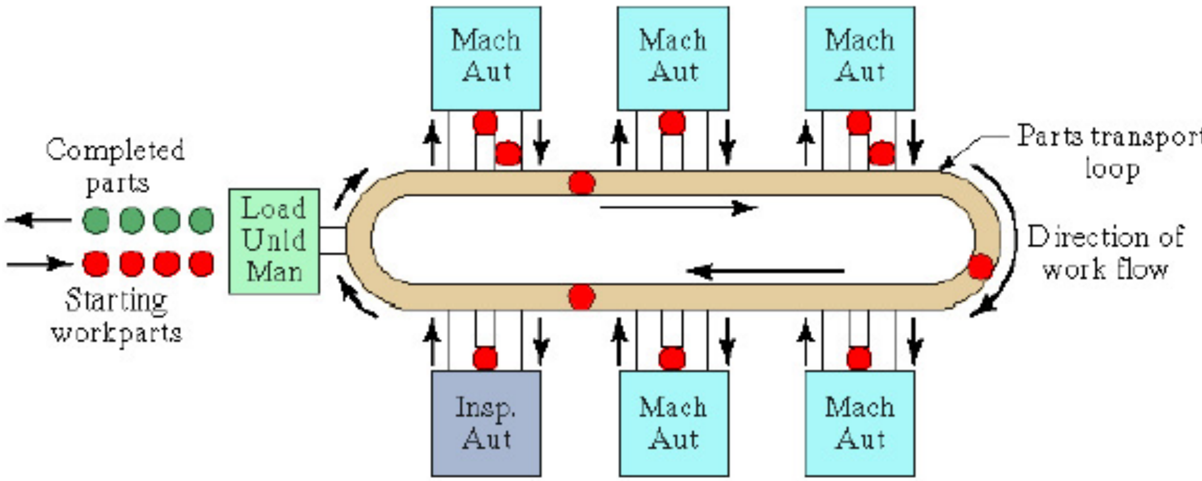
FMS In-Line Layout



work flow in two directions so the flexibility will increase

- Linear transfer system with secondary parts handling system at each workstation to facilitate flow in two directions

FMS Loop Layout

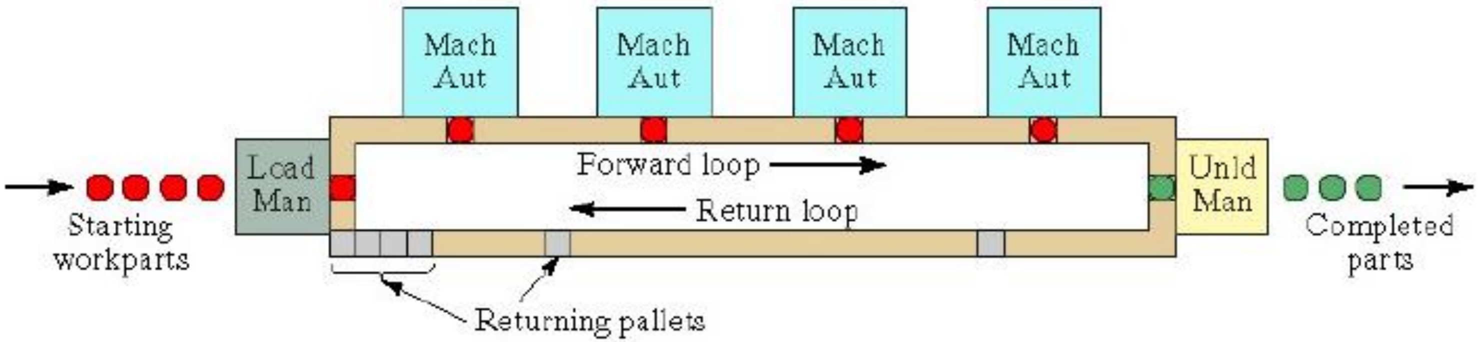


ممكن استخدامها
اذا كان الproduct
أكثر تعقيداً

عدد ال machines ↑
تعقيد ال product ↑

- One direction flow, but variations in processing sequence possible for different part types
- Secondary handling system at each workstation

FMS Rectangular Layout



- Rectangular layout allows recirculation of pallets back to the first station in the sequence after unloading at the final station

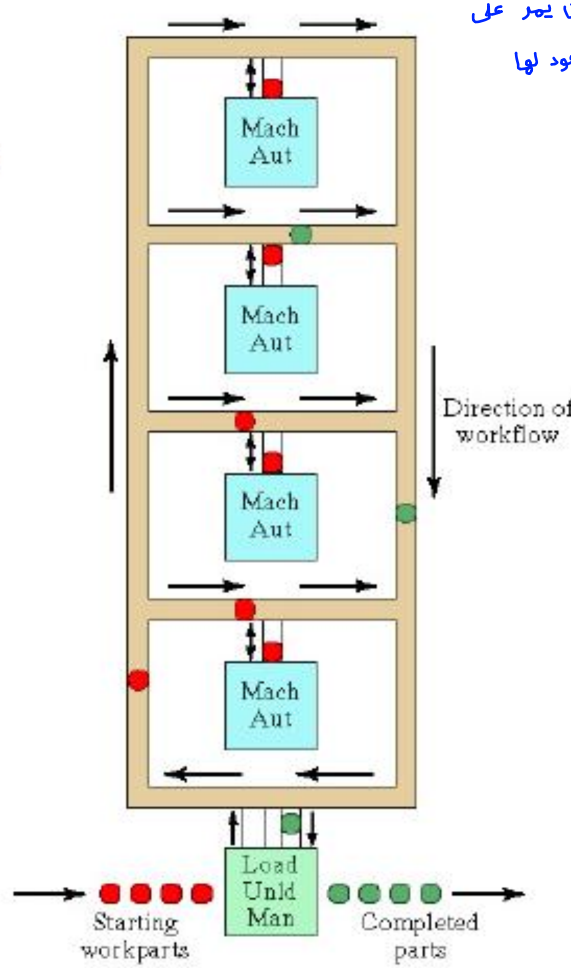
FMS Ladder Layout

أعلى Flexibility

كونه ال product ممكن يمر على

أكثر من workstation و يعود لها

- Loop with rungs to allow greater variation in processing sequence



FMS Open Field Layout

Flexibility

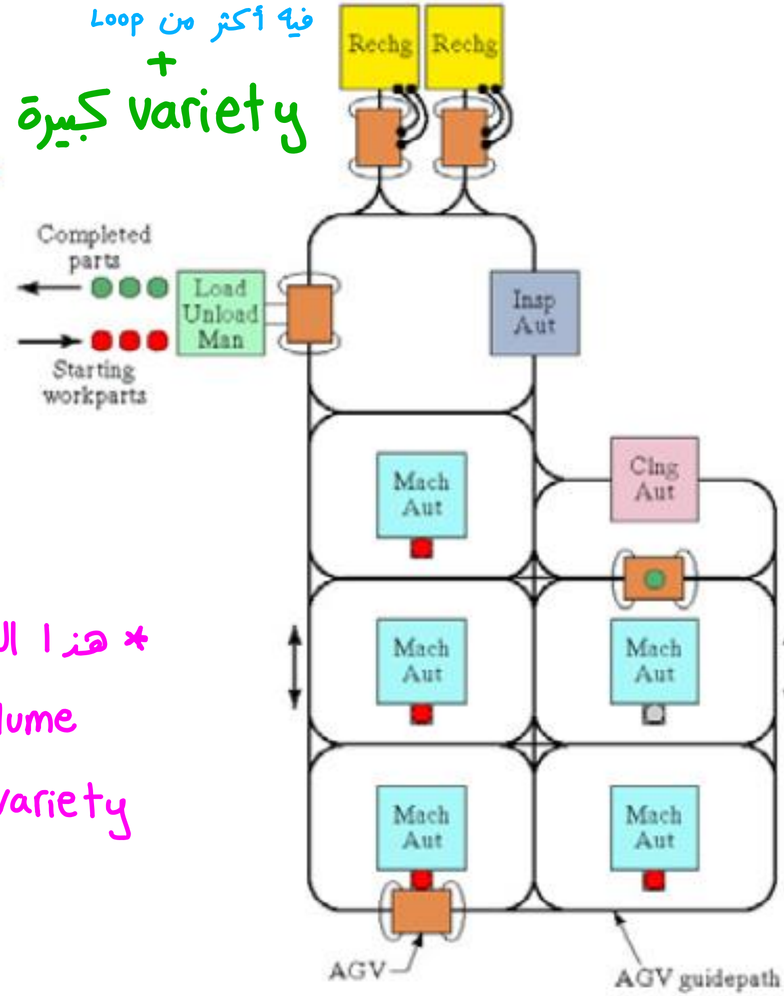
أعلى أكثر

لأنه الـLadder الواحد يوجد

فيه أكثر من Loop

+

variety كبيرة



- Multiple loops and ladders, suitable for large part families

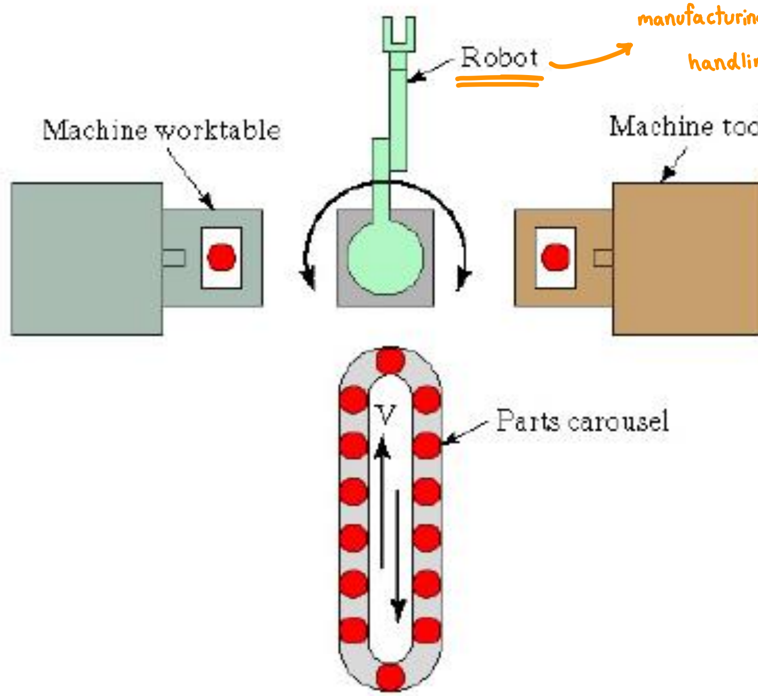
* هذا النظام بيعطيني

Large Annual Volume

Large Product variety

Robot-Centered Cell

- Suited to the handling of rotational parts and turning operations



اما ال manufacturing

او ال handling

FMS Computer Functions

1. *Workstation control*
   - Individual stations require controls, usually computerized
2. *Distribution of control instructions to workstations*
   - Central intelligence required to coordinate processing at individual stations
3. *Production control*
   - Product mix, machine scheduling, and other planning functions

FMS Computer Functions

4. *Traffic control*
   - Management of the primary handling system to move parts between workstations
5. *Shuttle control*
   - Coordination of secondary handling system with primary handling system
6. *Workpiece monitoring*
   - Monitoring the status of each part in the system

FMS Computer Functions

7. *Tool control*
   - Tool location
     - Keeping track of each tool in the system
   - Tool life monitoring
     - Monitoring usage of each cutting tool and determining when to replace worn tools
8. *Performance monitoring and reporting*
   - Availability, utilization, production piece counts, etc.
9. *Diagnostics*
   - Diagnose malfunction causes and recommend repairs

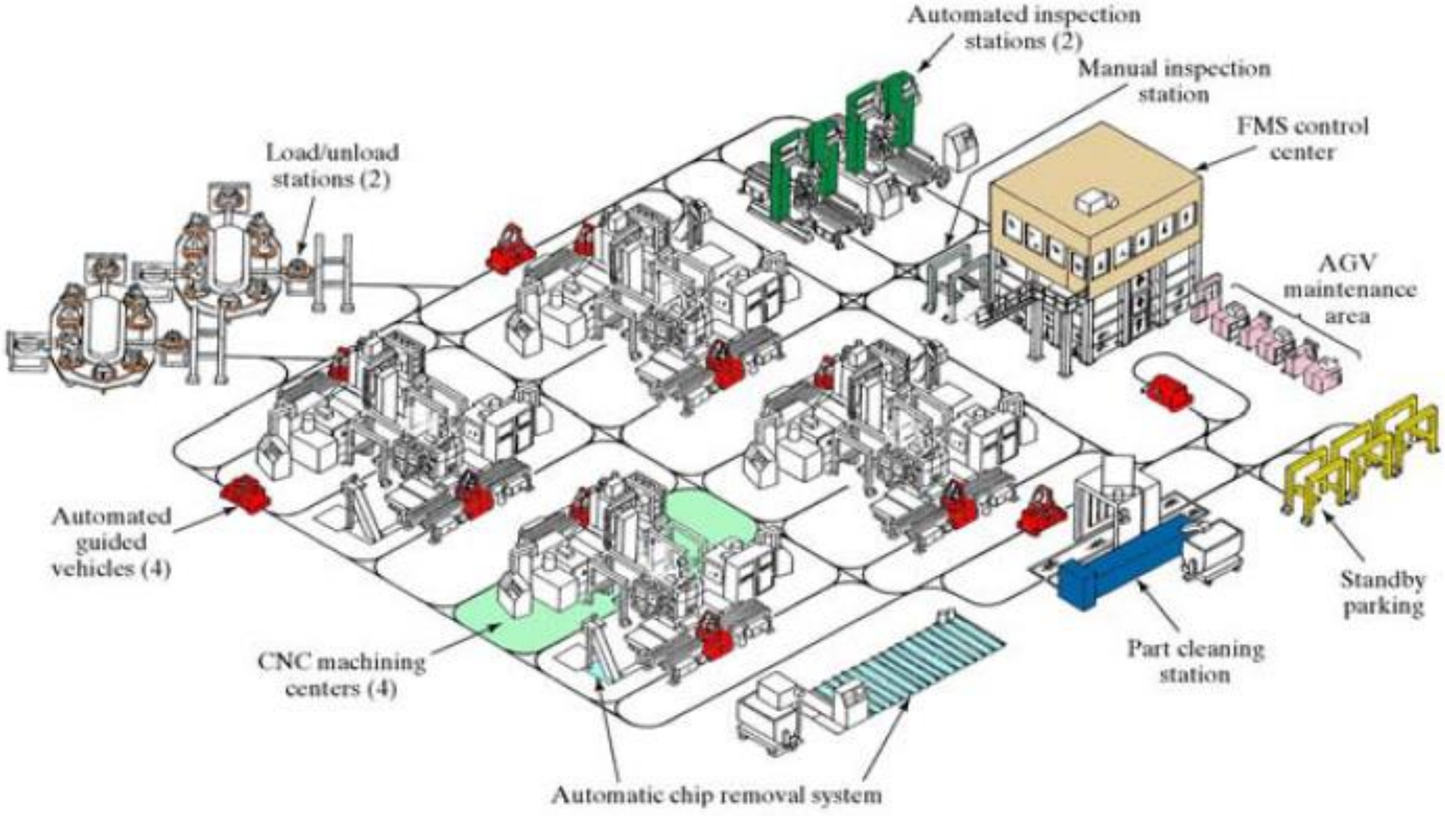
Duties Performed by Human Labor

- Loading and unloading parts from the system
- Changing and setting cutting tools
- Maintenance and repair of equipment
- NC part programming
- Programming and operating the computer system
- Overall management of the system

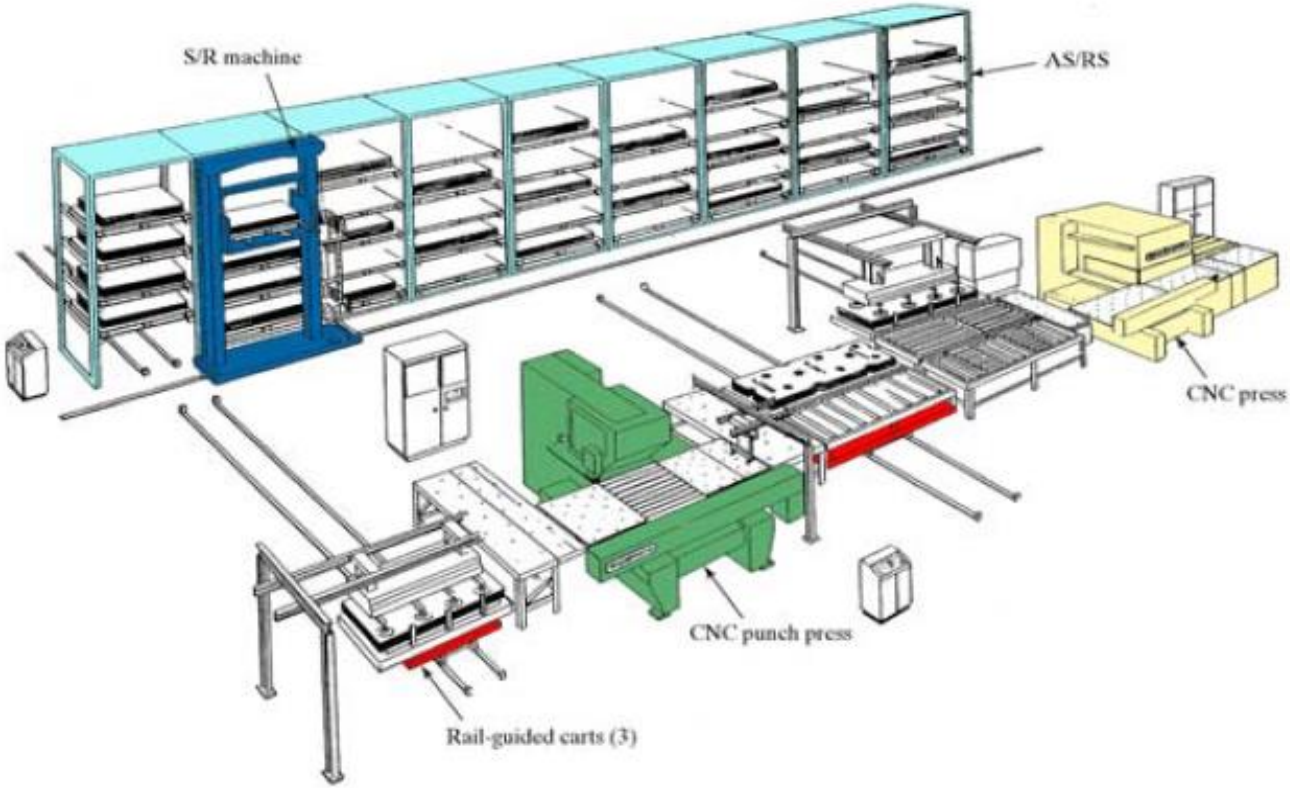
FMS Applications

- Machining – most common application of FMS technology
- Assembly
- Inspection
- Sheet metal processing (punching, shearing, bending, and forming)
- Forging

FMS at Chance-Vought Aircraft (courtesy of Cincinnati Milacron)



FMS for Sheet Metal Fabrication



FMS Benefits

- Increased machine utilization
  - Reasons:
    - 24 hour operation likely to justify investment
    - Automatic tool changing
    - Automatic pallet changing at stations
    - Queues of parts at stations to maximize utilization
    - Dynamic scheduling of production to account for changes in demand
- Fewer machines required
- Reduction in factory floor space required

FMS Benefits

- Greater responsiveness to change
- Reduced inventory requirements
  - Different parts produced continuously rather than in batches
- Lower manufacturing lead times
- Reduced labor requirements
- Higher productivity
- Opportunity for unattended production
  - Machines run overnight ("lights out operation")

4 Additional slides
from the recorded Lecture

FMS Planning and Design Issues

- Part family considerations
  - Defining the part family of families to be processed
    - Based on part similarity
    - Based on product commonality
- Processing requirements
  - Determine types of processing equipment required
- Physical characteristics of workparts
  - Size and weight determine size of processing equipment and material handling equipment

FMS Planning and Design Issues

- Production volume
  - Annual quantities determined number of machines required
- Types of workstations
- Variations in process routings
- Work-in-process and storage capacity
- Tooling
- Pallet fixtures

FMS Operational Issues

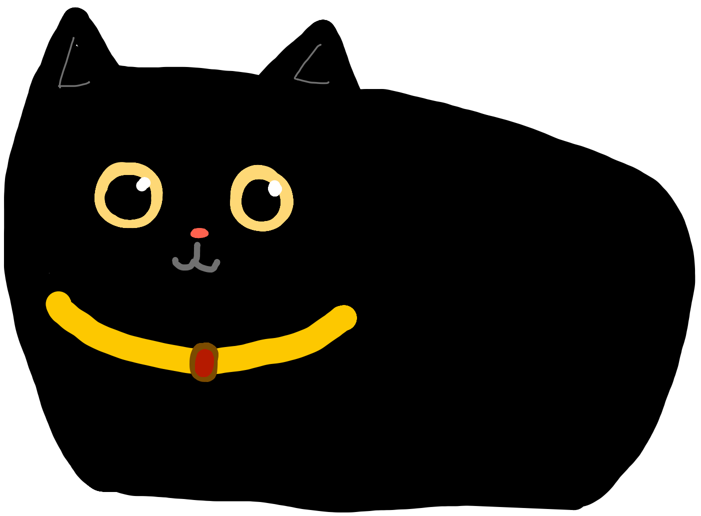
- Scheduling and dispatching
  - Launching parts into the system at appropriate times
- Machine loading
  - Deciding what operations and associated tooling at each workstation
- Part routing
  - Selecting routes to be followed by each part

FMS Operational Issues

- Part grouping
  - Which parts should be on the system at one time
- Tool management
  - When to change tools
- Pallet and fixture allocation
  - Limits on fixture types may limit part types that can be processed

Videos

https://www.youtube.com/watch?v=PDSmRPh6TaM&t=3s
https://www.youtube.com/watch?v=Br2eEpiiwvU&t=1s
https://www.youtube.com/watch?v=UzDT9Ev4DDU



ملخص للمادة

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