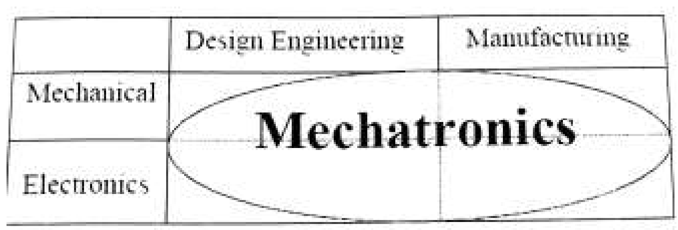
Module-I

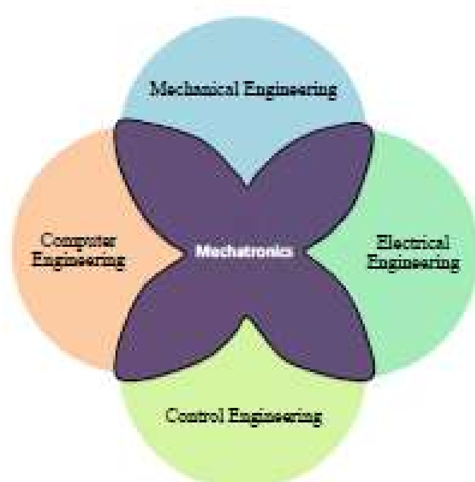
What is "Mechatronics"?

Mechatronics is a concept of Japanese origin (1980's) and can be defined as the application of electronics and computer technology to control the motions of mechanical systems.



Definition of Mechatronics

It is a multidisciplinary approach to product and manufacturing system design (Figure). It involves application of electrical, mechanical, control and computer engineering to develop products, processes and systems with greater flexibility, ease in redesign and ability of reprogramming. It concurrently includes all these disciplines.



Mechatronics: a multi-disciplinary approach

Mechatronics can also be termed as replacement of mechanics with electronics or enhance mechanics with electronics. For example, in modern automobiles, mechanical fuel injection systems are now replaced with electronic fuel injection systems. This replacement made the automobiles more efficient and less pollutant. With the help of microelectronics and sensor technology, mechatronics systems are providing high levels of precision and reliability. It is now possible to move (in x – y plane) the work table of a modern production machine tool in a step of 0.0001 mm. By employment of reprogrammable microcontrollers/microcomputers, it is now easy to add new functions and capabilities to a product or a system. Today's domestic washing machines are "intelligent" and four-wheel passenger automobiles are equipped with safety installations such as air-bags, parking (proximity) sensors, antitheft electronic keys etc.

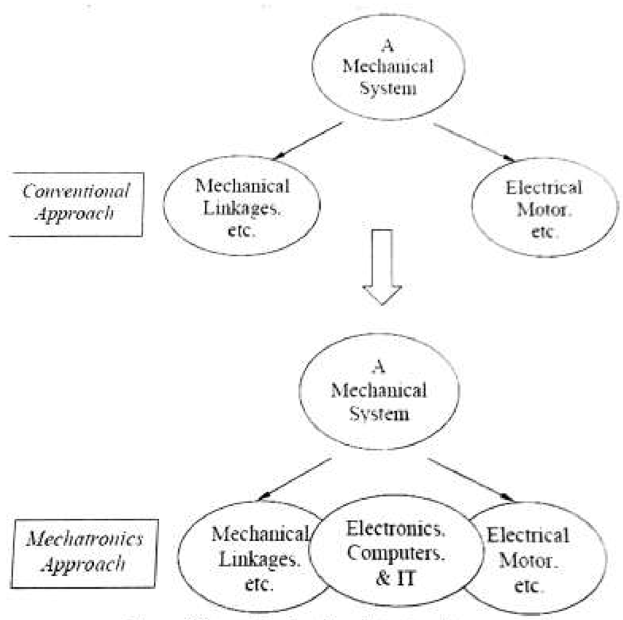


Figure 2 Conventional and mechatronics design approaches.

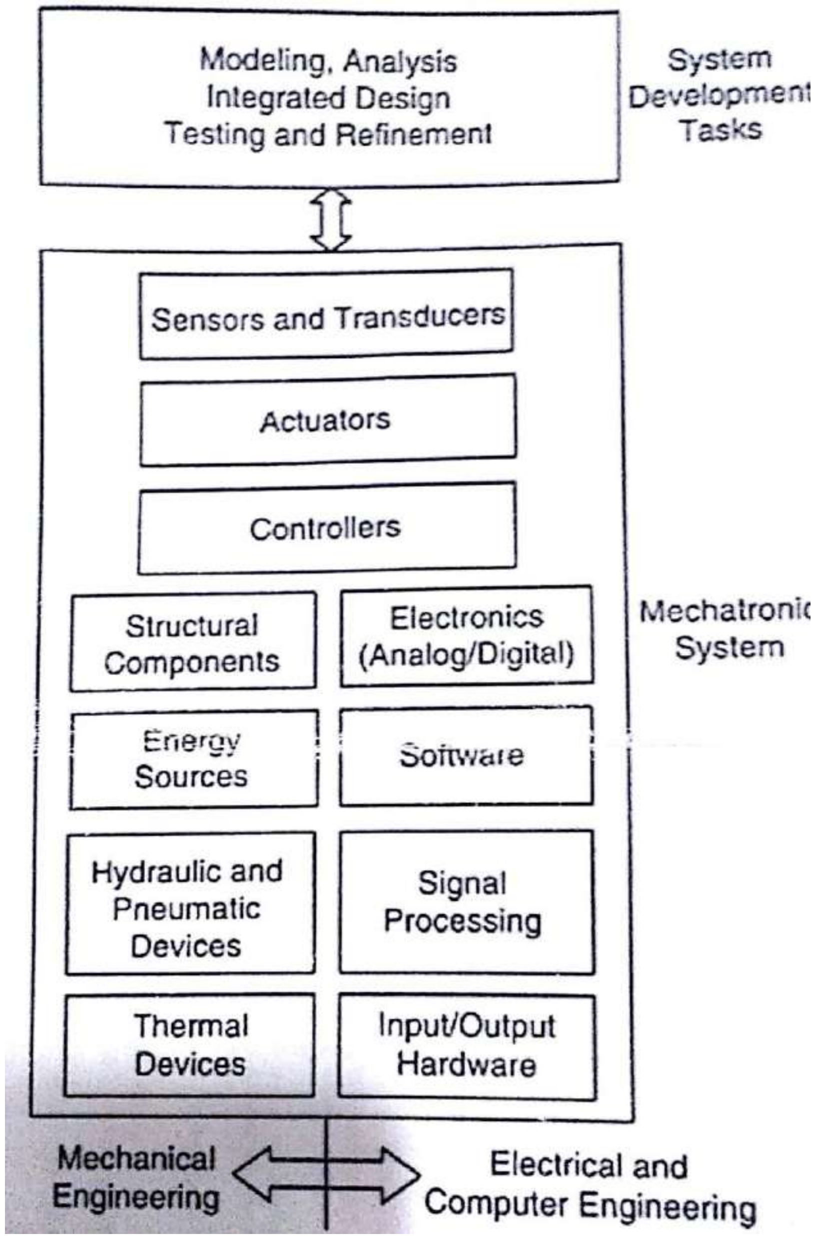
Convectional design	Mechatronics Design
Bulky componentized systems	Compact integrated systems
Complex mechanism; Complex mechanical mechanisms	Simple Mechanism: Replacement of many complex mechanical components and/or systems with electronic, computer and/or software systems
Cable problem	Bus or wireless communication
Simple control • Stiff construction • Feedback control, linear(analog) control • Precision through narrow tolerance • Non measurable quantities changes arbitrarily • Simple monitoring • Fixed abilities	Integration by information processing(software) • elastic construction with damping by electronic feedback • programmable feedback, (nonlinear) digital control • precision through measurement and feedback control • control of non-measurable estimated quantities • supervision over fault diagnosis • learning ability
Centralized processing & control	Hybrid Control: Adaptive and/or Multi-architecture control (e.g., Centralized, Centralized processing & control Decentralized and Distributed)
Constant speed drives	Variable speed drives
Mechanical Systems	Mechanical, Computer, Electronic, Software, and/or Network interface and/or control of physical, chemical, biological and/or neurological systems

APPLICATIONS

Today, mechatronic systems are commonly found in homes, offices, schools, shops, and of course, in industrial applications. Common mechatronic systems include:

Table 2: Applications with product categorization

Product Categorizations	Product Categorizations Examples
Electronic products	Cameras and audio equipment
Consumer Appliances	Refrigerators and Washing machines
Vehicle systems	Automobiles, Aircraft and Trucks
Communication systems	Satellites, Radar equipment and Telephone switches
Onboard control systems	Aerospace, Marine, Weapons and Space systems
Biomedical instrumentation	MRI, CT scan, and Airport security systems
Office equipment	Computers, Printers, copiers, Fax machines
Industrial machinery and equipment	Turbines, Printing presses, Weapon systems
Large scale transportation equipment	Large aircrafts, Locomotives, Mass transit systems



Concept of Mechatronics System

Evolution Level of Mechatronics

1. **Primary Level Mechatronics**: This level incorporates I/O devices such as sensors and actuators that integrates electrical signals with mechanical action at the basic control levels.
   Examples: Electrically controlled fluid valves and relays
2. **Secondary Level Mechantronics**: This level integrates microelectronics into electrically controlled devices.
   Examples: Cassette players
3. **Third Level Mechatronics**: This level incorporates advanced feedback functions into control strategy thereby enhancing the quality in terms of sophistication called smart system.
   - The control strategy includes microelectronics, microprocessor and other ' Application Specific Integrated Circuits' (ASIC)
     Example: Control of Electrical motor used to activate industrial robots, hard disk, CD drives and automatic washing machines.
4. **Fourth Level Mechatronics**: This level incorporates intelligent control in mechatronics system. It introduces intelligence and fault detection and isolation (FDI) capability systems.

Advantages and Disadvantages of Mechatronics system:

Following are the *advantages* and *disadvantages* of mechatronics :

Advantages :

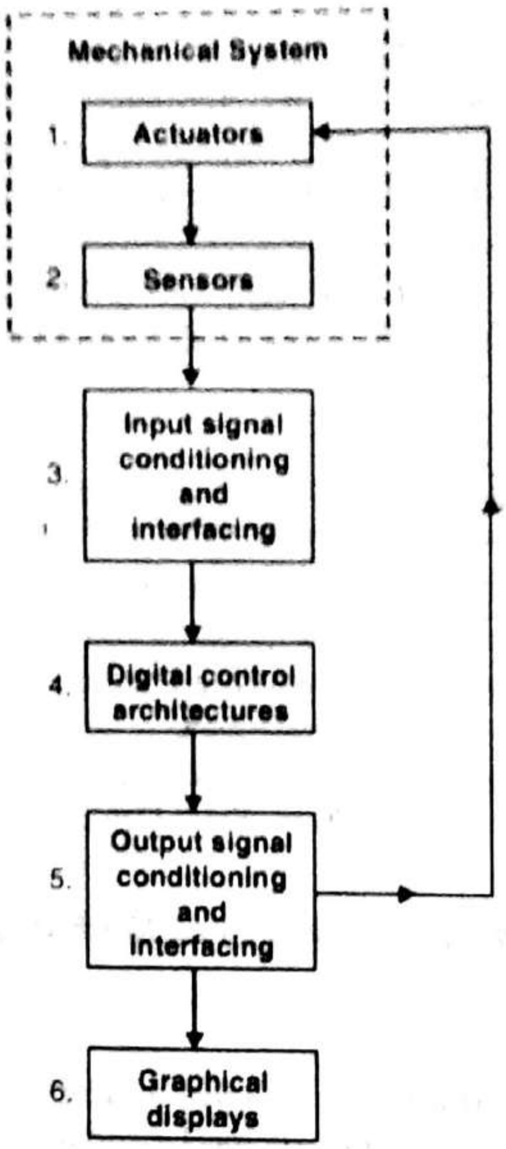
1. The products produced are cost effective and of very good quality.
2. The performance characteristics of mechatronics products are such which are otherwise very difficult to achieve without the synergistic combination.
3. High degree of flexibility.
4. A mechatronics product can be better than just sum of its parts.
5. Greater extent of machine utilisation.
6. Due to the integration of sensors and control systems in a complex system, capital expenses are reduced.
7. Owing to the incorporation of intelligent, self correcting sensory and feedback systems, the *mechatronic approach results in* :
   — greater productivity ;
   — higher quantity and producing reliability.

Disadvantages :

1. High initial cost of the system.
2. Imperative to have knowledge of different engineering fields for design and implementation.
3. Specific problems for various systems will have to be addressed separately and properly.
4. It is expensive to incorporate mechatronics approach to an existing/old system.

Components of Mechatronics system:

The term mechatronics system (sometimes referred to as smart device) encompasses a myriad of devices and systems. Increasingly, microcontrollers are embedded in the elctromechanical devices, creating much more flexibility and control possibilities in system design.

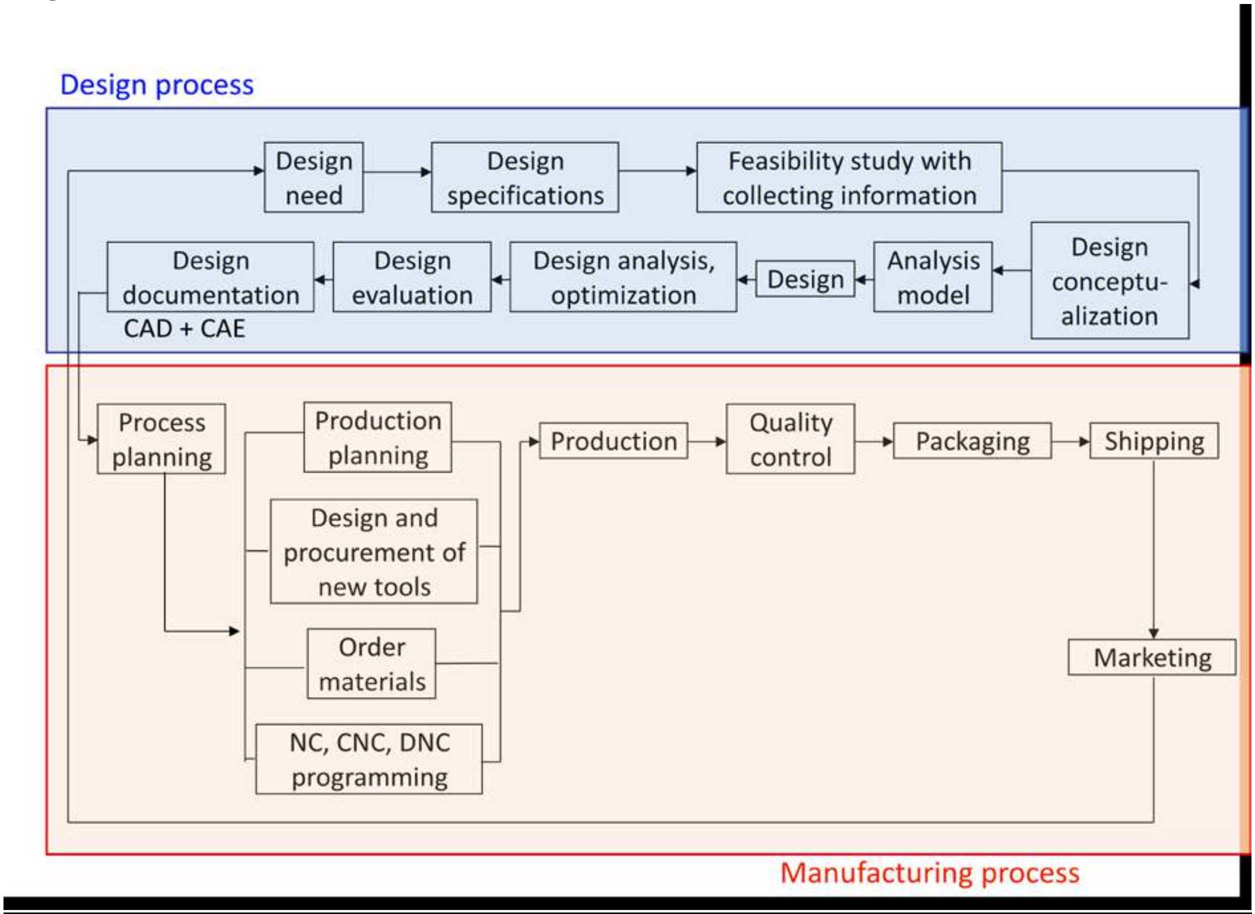


Components of a typical Mechatronics system

- **Actuators:** produce motion or cause some action. Solenoids, voice calls, DC motors, Stepper motor, servomotor, hydraulic, pneumatic.
- **Sensors:** detect the state of the system parameters, inputs and outputs. Switches, potentiometer, photoelctrics, digital encoder, strain gauge, thermocouple, accelerometer etc.

- **Input/output Signal conditioning and interfacing**: provide connection between the control system circuits and the input/output devices. Discrete circuits, amplifiers, filters, A/D, D/A, power transistor etc.
- **Digital devices**: controls the system. Logic circuits, micro controller, SBC, PLC etc
- **Graphic Display**: provide visual feed back to users. LEDs, Digital Displays, LCD, CRT

Importance of Mechatronics in automation:



Operations involved in design and manufacturing of a product

Today's customers are demanding more variety and higher levels of flexibility in the products. Due to these demands and competition in the market, manufacturers are thriving to launch new/modified products to survive. It is reducing the product life as well as lead-time to manufacture a product. It is therefore essential to automate the manufacturing and assembly operations of a product. There are various activities involved in the product manufacturing process. These are shown in figure 1.1.3. These activities can be classified into two groups viz. design and manufacturing activities.

Mechatronics concurrently employs the disciplines of mechanical, electrical, control and computer engineering at the stage of design itself. Mechanical discipline is employed in terms of various machines and mechanisms, where as electrical engineering as various electric prime movers viz. AC/DC, servo motors and other systems is used. Control engineering helps in the development of various electronics-based control systems to enhance or replace the mechanics of the mechanical systems. Computers are widely used to write various softwares to control the control systems; product design and development activities; materials and manufacturing resource planning, record keeping, market survey, and other sales related activities.

Using computer aided design (CAD) / computer aided analysis (CAE) tools, three-dimensional models of products can easily be developed. These models can then be analyzed and can be simulated to study their performances using numerical tools. These numerical tools are being continuously updated or enriched with the real-life performances of the similar kind of products. These exercises provide an approximate idea about performance of the product/system to the design team at the early stage of the product development. Based on the simulation studies, the designs can be modified to achieve better performances. During the conventional design-manufacturing process, the design assessment is generally carried out after the production of first lot of the products. This consumes a lot of time, which leads to longer (in months/years) product development lead-time. Use of CAD–CAE tools saves significant time in comparison with that required in the conventional sequential design process.

CAD-CAE generated final designs are then sent to the production and process planning section. Mechatronics based systems such as computer aided manufacturing (CAM): automatic process planning, automatic part programming, manufacturing resource planning, etc. uses the design data provided by the design team. Based these inputs, various activities will then be planned to achieve the manufacturing targets in terms of quality and quantity with in a stipulated time frame.

Mechatronics based automated systems such as automatic inspection and quality assurance, automatic packaging, record making, and automatic dispatch help to expedite the entire manufacturing operation. These systems certainly ensure a supply better quality, well packed and reliable products in the market. Automation in the machine tools has reduced the human intervention in the machining operation and improved the process efficiency and product quality. Therefore, it is important to study the principles of mechatronics and to learn how to apply them in the automation of a manufacturing system.

Digital Codes:

In digital circuits, each number of piece of information is *defined by an equivalent combination of binary digits. A complete group of these combinations which represent numbers, letters or symbols is called a* **digital code.**

The group of 0s and 1s in the binary number can be thought of as a code representing the decimal numbers. When a decimal number is represented by its equivalent binary number, it is called a *straight binary coding.*

In modern digital equipment, *codes are used to represent and process numerical information.*

Types of codes. The various types of codes are enumerated and briefly discussed below :

1. BCD Code

It is also known as 'natural BCD' and is very convenient for representing decimal digits in digital circuits.

- It consists of four bits from 0000 to 1001 representing the decimal numbers from 0 to 9.1010 to 1111 are don't care conditions since they do not have any meaning in BCD.

2. Excess-3 Code

- The code can be derived from BCD by *adding 3 to each coded number.*
  It is useful when it is desired to obtain the 9's complement of a decimal digit represented by this code. The 9's complement is obtained simply by complementing each bit.
- This code can be *conveniently used for performing substracting operations in digital computers.*

3. Gray Code

- In this code ony one bit changes between any two successive numbers.
- It is mainly *used in the location of angular positions of a rotating shaft.*

4. Octal Code

- The octal system is a 8 base system.
- It uses 3 bits to represent one octal digit.

5. Hexadecimal Code

- The hexadecimal system is a base 16 system.
- It uses four bits to represent one hexadecimal digit.
- The hexadecimal digits are represented as 0 to 9 continued by aphabetical characters from *A* to *F*.

Logic Gates:

General aspects :

A digital circuit with one or more input signals but only output signal is called a **logic gate.**

A *logic gate is an electronic circuit which makes logic decision.*

- Logic gates are the *basic building blocks* from which most of the digital systems are built up. They implement the hardware logic function based on the logical algebra developed by George Boolean which is called *Boolean algebra* in his honour.
  — A unique characteristic of Boolean algebra is that variables used in it can assume only one of the two values *i.e., either 0 or 1.* Hence, every variable is either a 0 or a 1 (Fig. 2.106–limits on TTLIC's).
- Each gate has *distinct graphic symbol and its operation can be described by means of Boolean algebraic function.*

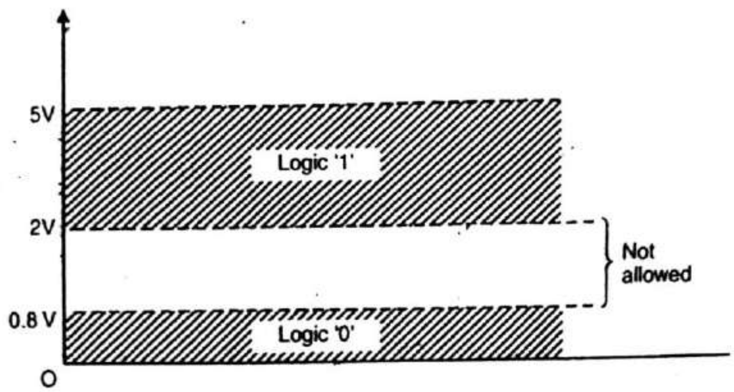


Fig. 2.106. Voltage assignment in a digital system.

- The *table which indicates output of gate for all possible combinations of input is known as a* ***truth table.***
- These gates are available today in the form of various IC families. The *most popular families are :*

(*i*) Transistor-transistor logic (TTL)

(*ii*) Emitter-coupled logic (ECL)

(*iii*) Metal-oxide-semiconductor (MOS)

(*iv*) Complementary metal-oxide-semiconductor (CMOS).

Applications of logic gates :

The following are the *fields of application of logic gates :*

1. Calculators and computers.
2. Digital measuring techniques.
3. Digital processing of communications.
4. Musical instruments.
5. Games and domestic appliances, etc.
6. The logic gates are also employed for decision making in *automatic control of machines and various industrial processes and for building more complex devices such as binary counters* etc.

Positive and negative logic :

The number symbols 0 and 1 represent, in computing systems, two possible states of a circuit or device. It does not make any difference if these two states are referred to as

'ON' and 'OFF', 'Closed' and 'Open', 'High' and 'Low', 'Plus' and 'Minus' or 'True' and 'False' depending upon the situations. The main point is they must be symbolized by *two opposite conditions*. In *positive logic* a '**1**' *represents* : an '*ON circuit*' ; a '*Closed switch*'; a '*High voltage*', a *Plus sign*', '*True statement*'. *Consequently*, a **0** *represent* : an 'OFF circuit' ; an '*Open switch*', a '*Low voltage*' ; a '*Minus sign*', a 'False statement'.

In negative logic, the just opposite conditions prevail.

Example. A digital system has two voltage levels of 0 V and 5 V. If we say that symbol 1 stands for 5 V and symbol 0 for 0 V, then we have *positive logic system*. If on the other hand, we decide that a 1 should represent 0 V and 0 should represent 5 V, then we will get negative logic system.

Main point is that in '*positve logic*' the ***more positive*** of the two voltage levels represents the 1 while in '*negative logic*' the ***more negative*** voltage represents the 1.

Types of Logic Gates : Refer to table 2.4 (page 126)

In the *complex circuits*, the following *six* different digital electronics gates are used as *basic elements* :

1. NOT Gate
2. NAND Gate
3. AND Gate
4. OR Gate
5. NOR Gate
6. XOR Gate.

— A truth table has 2^n rows. It gives in each of its row m outputs for a given combination of n inputs.

1. NOT Gate :

- *Not operation means that the output is the complement of input*. If input is logic '1', the output is logic '0' and if input is logic '0', the output is logic '1'.
- Fig. 2.107 shows the *symbol of NOT Gate*. It is generally represented by a *triangle followed by a bubble* (or a bubble followed by a triangle).
- NOT gate is *used when an output is desired to be complement of the input*.
- If all inputs of NAND gates are joined it shall act as NOT gate.
- NOT gate is also *called 'inverting logic circuit*. It is also *called a 'complementing circuit'*.

2. **NAND Gate :**

- A NAND gate can said to be *basic building block* of the *all digital TTL logic gates and other digital circuits*.
- It is represented by the symbol shown in Fig. 2.108.
- Its *unique property is that output is high '1' if any of the input is at low '0' logic level.*

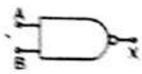
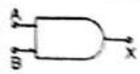
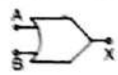
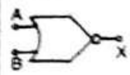
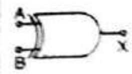
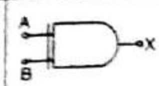
Let us consider two inputs with the states A and B at the NAND gate. The answer (output) $X=\overline{A.B}$. Bar denotes a NOT log operation on A.B. The meaning of A.B, called AND operation, is given in 3 below.

3. **AND Gate :**

- *A NAND gate followed by a NOT gate gives us AND gate.*
- It is represented by a symbol in Fig. 2.109. Its symbol differs from NAND only by *omission of a bubble* (*circle*).
- Its *unique property is that its output is '0' unless all the inputs to it are at the logic 1's.*
- A two inputs, AND gate has $X = A.B$. *Dot* between the two states indicates 'AND' logic operation using these.

4. **OR Gate :**

- An 'OR' operation means that the *output is '0' only if all the inputs are '0s'*.
- It is represented by a symbol shown in Fig. 2.110.

Logic	NOT	NAND	AND	OR	NOR	EXOR	COINCIDENCE
Symbol	 Fig. 2.107	 Fig. 2.108	 Fig. 2.109	 Fig. 2.110	 Fig. 2.111	 Fig. 2.112	 Fig. 2.113
Boolean expression	$X = \overline{A}$	$X = \overline{A \cdot B}$	$X = A.B$	$X = A + B$	$X = \overline{A + B}$	$X =$ $A.\overline{B} + \overline{A}.B$ $= A \oplus B$	$X = \overline{A}.\overline{B} + A.B$
Truth table	A X 0 1 1 0	A B X 0 0 1 0 1 1 1 0 1 1 1 0	A B X 0 0 0 0 1 0 1 0 0 1 1 1	A B X 0 0 0 0 1 1 1 0 1 1 1 1	A B X 0 0 1 0 1 0 1 0 0 1 1 0	A B X 0 0 1 0 1 1 1 0 1 1 1 0	A B X 0 0 1 0 1 0 1 0 0 1 1 1
Definition	Output available – when there is no input.	Output available – to all states except when all the inputs are available.	Output available– when all inputs available.	Output available– when only one or more inputs available.	Output available– when no input is available.	Output available– when the inputs are *not* identical.	Output available– to those states when the inputs are identical.

Module-II

Sensors and Transducers: An introduction to sensors and Transducers, use of sensor and transducer for specific purpose in mechatronics. Transducer signal conditioning and Devices for Data conversion programmable controllers. ;

Sensors and transducers

Measurement is an important subsystem of a mechatronics system. Its main function is to collect the information on system status and to feed it to the micro-processor(s) for controlling the whole system.

Measurement system comprises of sensors, transducers and signal processing devices. Today a wide variety of these elements and devices are available in the market.

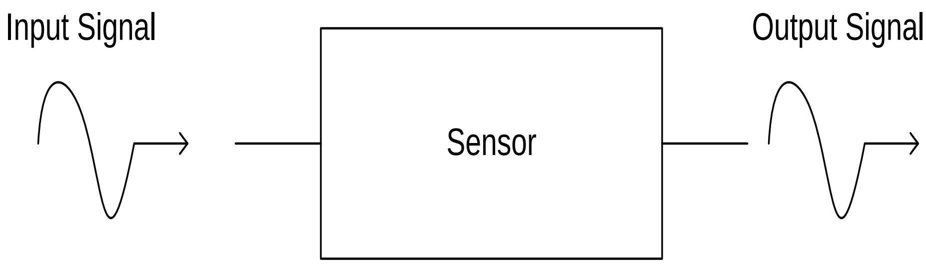
For a mechatronics system designer it is quite difficult to choose suitable sensors/transducers for the desired application(s). It is therefore essential to learn the principle of working of commonly used sensors/transducers.

Sensors in manufacturing are basically employed to automatically carry out the production operations as well as process monitoring activities. Sensor technology has the following important advantages in transforming a conventional manufacturing unit into a modern one.

- Sensors alarm the system operators about the failure of any of the sub units of manufacturing system. It helps operators to reduce the downtime of complete manufacturing system by carrying out the preventative measures.
- Reduces requirement of skilled and experienced labors.
- Ultra-precision in product quality can be achieved.

Sensor

It is defined as an element which produces signal relating to the quantity being measured. According to the Instrument Society of America, sensor can be defined as "*A device which provides a usable output in response to a specified measurand.*" Here, the output is usually an 'electrical quantity' and measurand is a 'physical quantity, property or condition which is to be measured'. Thus in the case of, say, a variable inductance displacement element, the quantity being measured is displacement and the sensor transforms an input of displacement into a change in inductance.



Sensors are also called detectors.

Need for Sensors

- Sensors are omnipresent. They embedded in our bodies, automobiles, airplanes, cellular telephones, radios, chemical plants, industrial plants and countless other applications.
- Without the use of sensors, there would be no automation

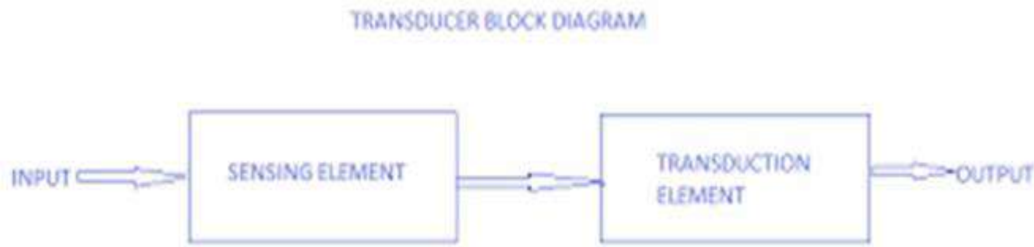
Transducer

It is defined as an element when subjected to some physical change experiences a related change or an element which converts a specified measurand into a usable output by using a transduction principle. It can also be defined as a device that converts a signal from one form of energy to another form.

A wire of Constantan alloy (copper-nickel 55-45% alloy) can be called as a sensor because variation in mechanical displacement (tension or compression) can be sensed as change in electric resistance. This wire becomes a transducer with appropriate electrodes and input-output mechanism attached to it. Thus we can say that 'sensors are transducers'.

Basic elements of transducer

- There are basically two elements which constructs a transducer and they are
- A sensing ELEMENT



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Sensor/transducers specifications

Transducers or measurement systems are not perfect systems. Mechatronics design engineer must know the capability and shortcoming of a transducer or measurement system to properly assess its performance. There are a number of performance related parameters of a transducer or measurement system. These parameters are called as sensor specifications.

Sensor specifications inform the user to the about deviations from the ideal behavior of the sensors. Following are the various specifications of a sensor/transducer system.

1. Range

The range of a sensor indicates the limits between which the input can vary. For example, a thermocouple for the measurement of temperature might have a range of 25-225 °C.

2. Span

The span is difference between the maximum and minimum values of the input. Thus, the above-mentioned thermocouple will have a span of 200 °C.

3. Error

Error is the difference between the result of the measurement and the true value of the quantity being measured. A sensor might give a displacement reading of 29.8 mm, when the actual displacement had been 30 mm, then the error is –0.2 mm.

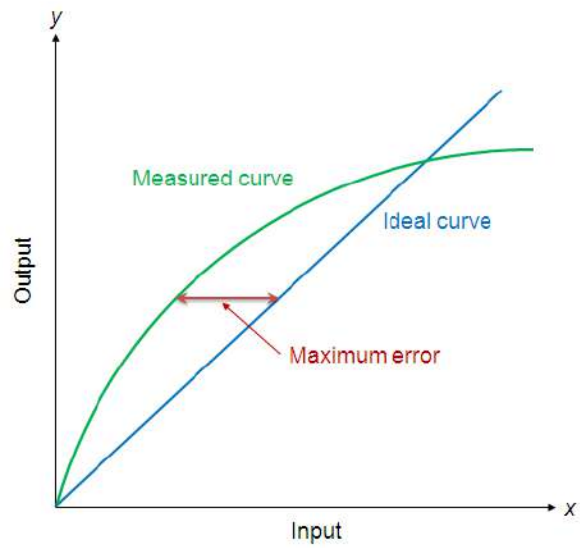
4. Accuracy

The accuracy defines the closeness of the agreement between the actual measurement result and a true value of the measurand. It is often expressed as a percentage of the full range output or full–scale deflection. A piezoelectric transducer used to evaluate dynamic pressure phenomena associated with explosions, pulsations, or dynamic pressure conditions in motors, rocket engines, compressors, and other pressurized devices is capable to detect pressures between 0.1 and 10,000 psig (0.7 KPa to 70 MPa). If it is specified with the accuracy of about ±1% full scale, then the reading given can be expected to be within ± 0.7 MPa.

5. Sensitivity

Sensitivity of a sensor is defined as the ratio of change in output value of a sensor to the per unit change in input value that causes the output change. For example, a general purpose thermocouple may have a sensitivity of 41 μV/°C.

6. Nonlinearity



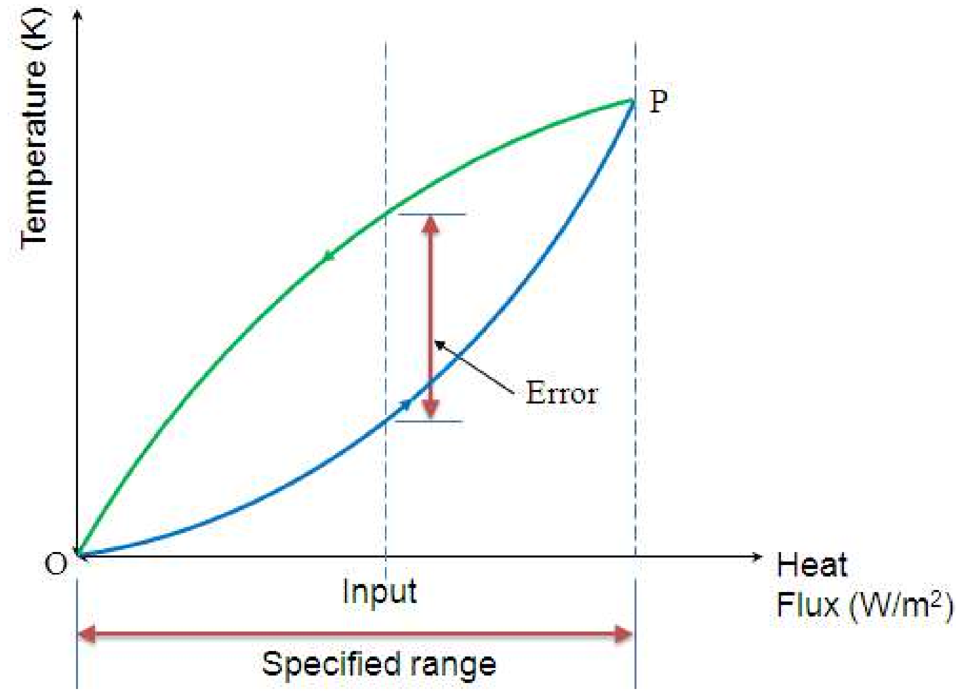
Non-linearity error

The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve. Figure above shows a somewhat exaggerated relationship between the ideal, or least squares fit, line and the actual measured or *calibration* line. Linearity is often specified in terms of *percentage of nonlinearity,* which is defined as:

Nonlinearity (%) = Maximum deviation in input ⁄ Maximum full scale input (1)

The static nonlinearity defined by Equation (1) is dependent upon environmental factors, including temperature, vibration, acoustic noise level, and humidity. Therefore it is important to know under what conditions the specification is valid.

7. Hysteresis



Hysteresis error curve

The hysteresis is an error of a sensor, which is defined as the maximum difference in output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter. Figure above shows the hysteresis error might have occurred during measurement of temperature using a thermocouple. The hysteresis error value is normally specified as a positive or negative percentage of the specified input range.

8. Resolution

Resolution is the smallest detectable incremental change of input parameter that can be detected in the output signal. Resolution can be expressed either as a proportion of the full-scale reading or in absolute terms. For example, if a LVDT sensor measures a displacement up to 20 mm and it provides an output as a number between 1 and 100 then the resolution of the sensor device is 0.2 mm.

9. Stability

Stability is the ability of a sensor device to give same output when used to measure a constant input over a period of time. The term 'drift' is used to indicate the change in output that occurs over a period of time. It is expressed as the percentage of full range output.

10.Dead band/time

The dead band or dead space of a transducer is the range of input values for which there is no output. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.

11.Repeatability

It specifies the ability of a sensor to give same output for repeated applications of same input value. It is usually expressed as a percentage of the full range output:

Repeatability = (maximum – minimum values given) X 100 ⁄ full range (2)

12.Response time

Response time describes the speed of change in the output on a step-wise change of the measurand. It is always specified with an indication of input step and the output range for which the response time is defined.

Classification of sensors

Sensors can be classified into various groups according to the factors such as measurand, application fields, conversion principle, energy domain of the measurand and thermodynamic considerations. These general classifications of sensors are well described in the references

Detail classification of sensors in view of their applications in manufacturing is as follows.

A. Displacement, position and proximity sensors

- Potentiometer
- Strain-gauged element
- Capacitive element
- Differential transformers
- Eddy current proximity sensors
- Inductive proximity switch

• Optical encoders
• Pneumatic sensors
• Proximity switches (magnetic)
• Hall effect sensors

B. Velocity and motion

• Incremental encoder
• Tachogenerator
• Pyroelectric sensors

C. Force

• Strain gauge load cell

D. Fluid pressure

• Diaphragm pressure gauge
• Capsules, bellows, pressure tubes
• Piezoelectric sensors
• Tactile sensor

E. Liquid flow

• Orifice plate
• Turbine meter

F. Liquid level

• Floats
• Differential pressure

G. Temperature

• Bimetallic strips
• Resistance temperature detectors
• Thermistors
• Thermo-diodes and transistors
• Thermocouples
• Light sensors
• Photo diodes
• Photo resistors
• Photo transistor

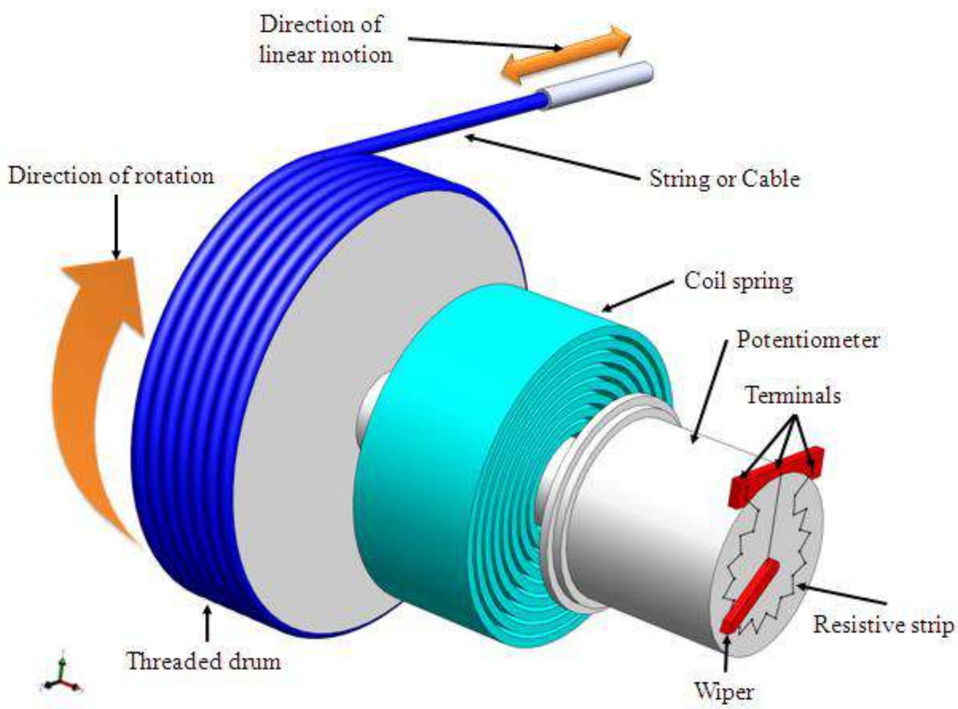
Displacement and position sensors

Displacement sensors are basically used for the measurement of movement of an object. Position sensors are employed to determine the position of an object in relation to some reference point.

Proximity sensors are a type of position sensor and are used to trace when an object has moved with in particular critical distance of a transducer.

Displacement sensors

1. Potentiometer Sensors



Schematic of a potentiometer sensor for measurement of linear displacement

Figure above shows the construction of a rotary type potentiometer sensor employed to measure the linear displacement. The potentiometer can be of linear or angular type. It works on the principle of conversion of mechanical displacement into an electrical signal. The sensor has a resistive element and a sliding contact (wiper). The slider moves along this conductive body, acting as a movable electric contact.

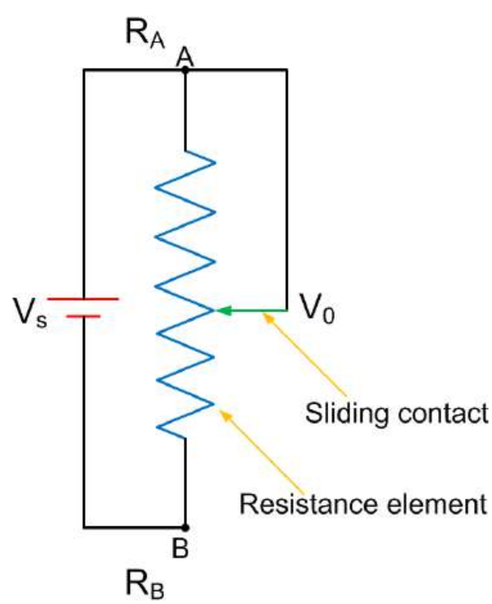
The object of whose displacement is to be measured is connected to the slider by using

- a rotating shaft (for angular displacement)
- a moving rod (for linear displacement)

• a cable that is kept stretched during operation

The resistive element is a wire wound track or conductive plastic. The track comprises of large number of closely packed turns of a resistive wire. Conductive plastic is made up of plastic resin embedded with the carbon powder. Wire wound track has a resolution of the order of ± 0.01 % while the conductive plastic may have the resolution of about 0.1 μm.

During the sensing operation, a voltage *Vs* is applied across the resistive element. A voltage divider circuit is formed when slider comes into contact with the wire. The output voltage (*VA*) is measured as shown in the figure below. The output voltage is proportional to the displacement of the slider over the wire. Then the output parameter displacement is calibrated against the output voltage *VA.*



Potentiometer: electric circuit

Applications of potentiometer

These sensors are primarily used in the control systems with a feedback loop to ensure that the moving member or component reaches its commanded position.

These are typically used on machine-tool controls, elevators, liquid-level assemblies, forklift trucks, automobile throttle controls. In manufacturing, these are used in control of injection molding machines, woodworking machinery, printing, spraying, robotics, etc. These are also used in computer-controlled monitoring of sports equipment.

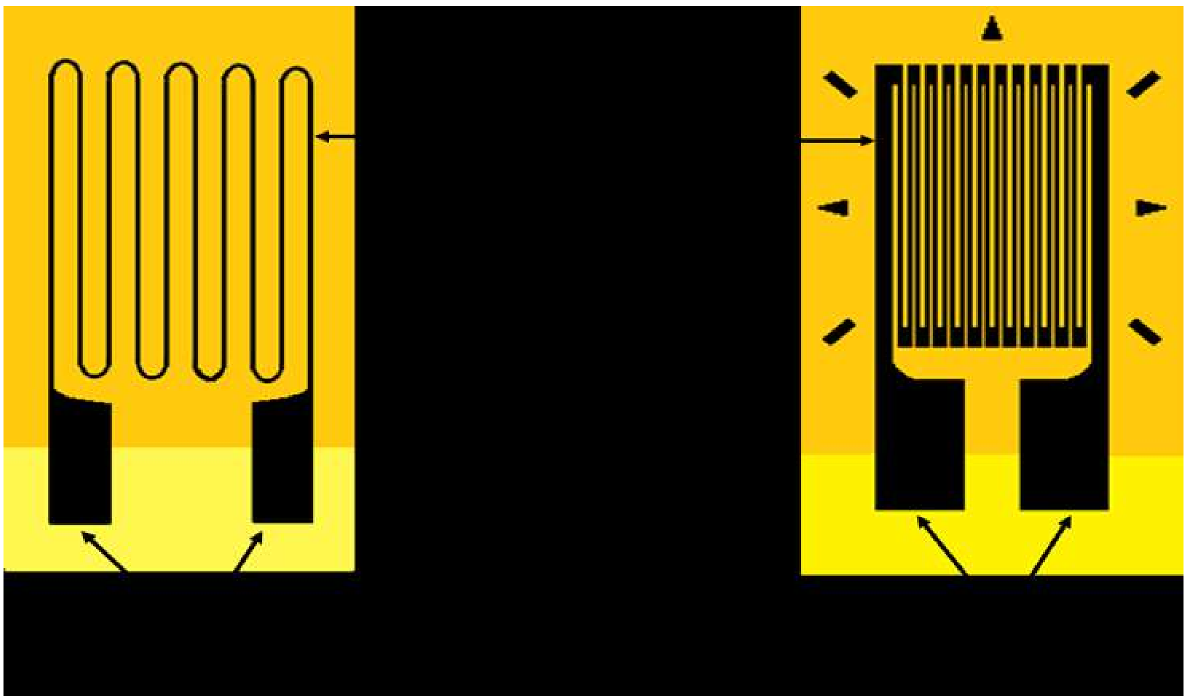
Strain Gauges

The strain in an element is a ratio of change in length in the direction of applied load to the original length of an element. The strain changes the resistance *R* of the element. Therefore, we can say,

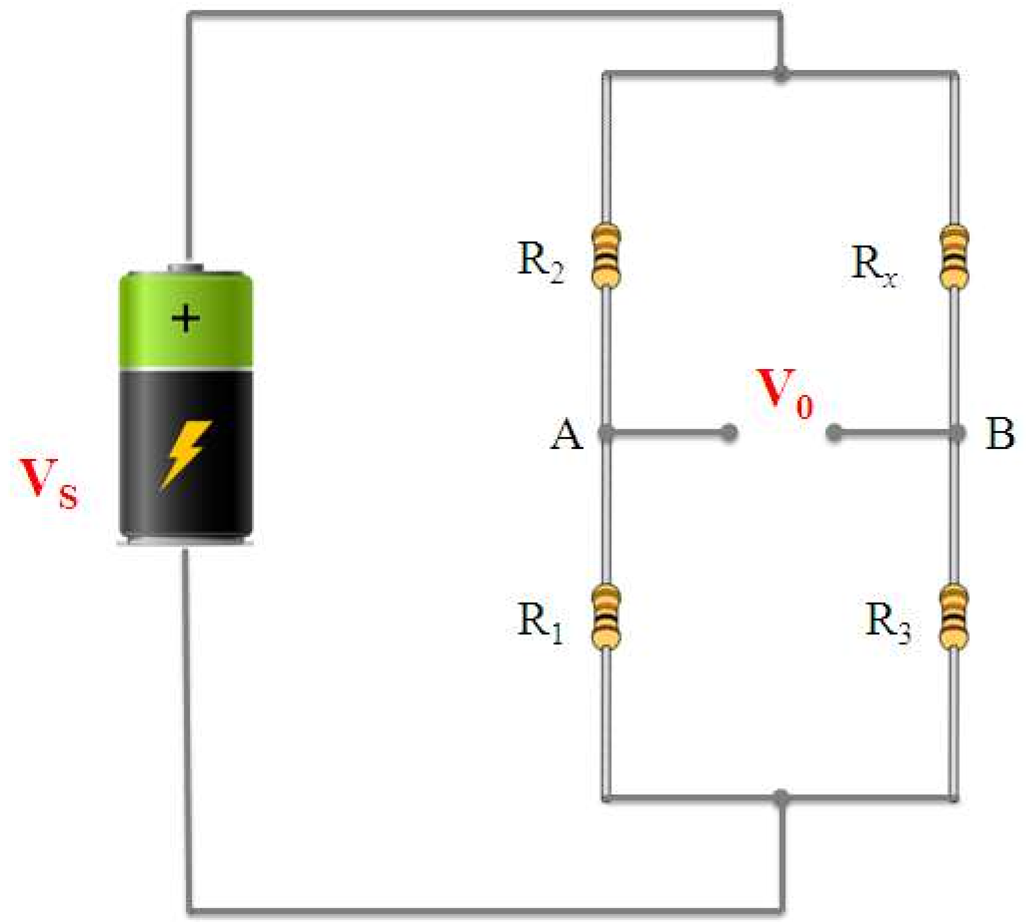
$\Delta R/R \propto \varepsilon$;

$\Delta R/R = G\,\varepsilon$ (2.2.5)

where G is the constant of proportionality and is called as gauge factor. In general, the value of G is considered in between 2 to 4 and the resistances are taken of the order of 100 Ω.



A pattern of resistive foils



Whetstone's bridge

Resistance strain gauge follows the principle of change in resistance as per the equation 2.2.5. It comprises of a pattern of resistive foil arranged as shown in Figure 2.2.3. These foils are made of Constantan alloy (copper-nickel 55-45% alloy) and are bonded to a backing material plastic (ployimide), epoxy or glass fiber reinforced epoxy. The strain gauges are secured to the workpiece by using epoxy or Cyanoacrylate cement Eastman 910 SL. As the workpiece undergoes change in its shape due to external loading, the resistance of strain gauge element changes. This change in resistance can be detected by a using a Wheatstone's resistance bridge as shown in Figure 2.2.4. In the balanced bridge we can have a relation,

$$R2/ R1 = Rx / R3$$

where *Rx* is resistance of strain gauge element, R2 is balancing/adjustable resistor, *R1* and *R3* are known constant value resistors. The measured deformation or displacement by the stain gauge is calibrated against change in resistance of adjustable resistor *R2* which makes the voltage across nodes A and B equal to zero.

Applications of strain gauges

Strain gauges are widely used in experimental stress analysis and diagnosis on machines and failure analysis. They are basically used for multi-axial stress fatigue testing, proof testing, residual stress and vibration measurement, torque measurement, bending and deflection measurement, compression and tension measurement and strain measurement.

Strain gauges are primarily used as sensors for machine tools and safety in automotives. In particular, they are employed for force measurement in machine tools, hydraulic or pneumatic press and as impact sensors in aerospace vehicles.

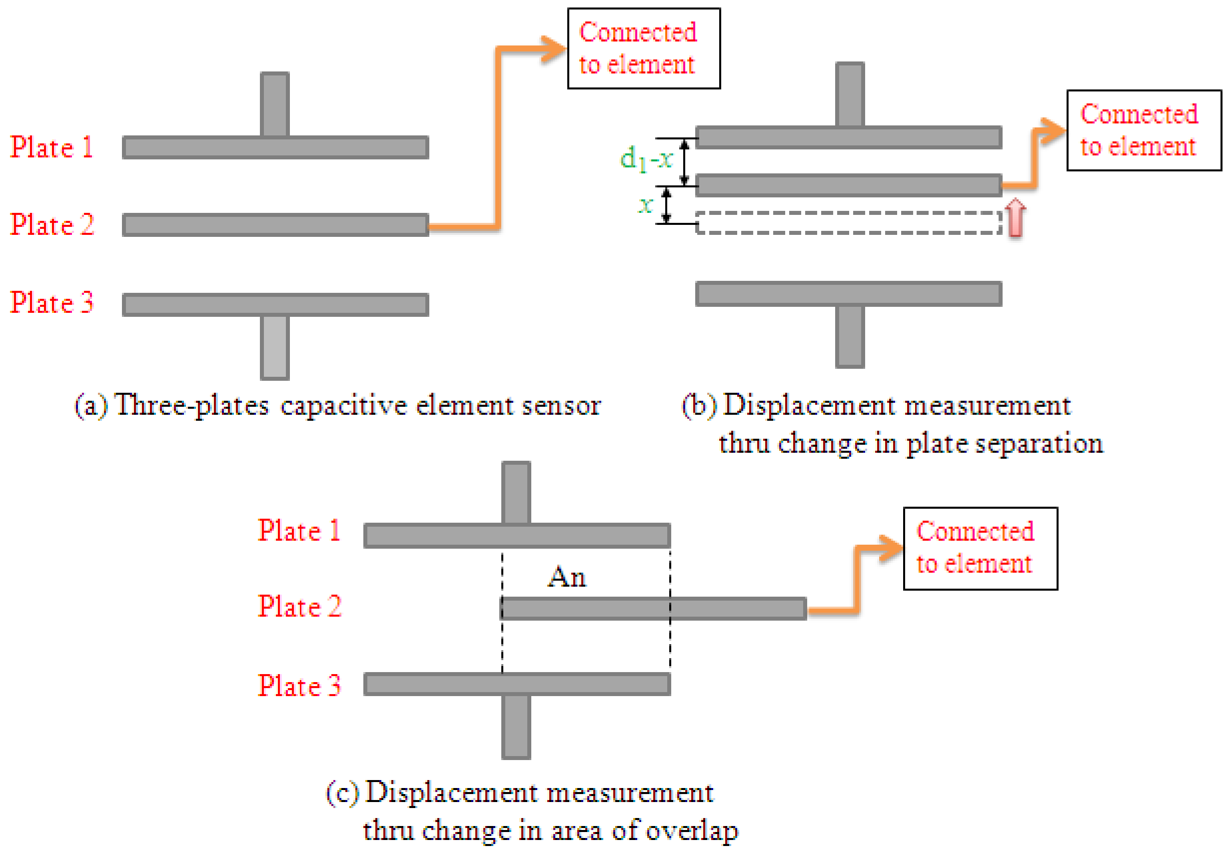
Capacitive element based sensor

Capacitive sensor is of non-contact type sensor and is primarily used to measure the linear displacements from few millimeters to hundreds of millimeters. It comprises of three plates, with the upper pair forming one capacitor and the lower pair another. The linear displacement might take in two forms:

a. one of the plates is moved by the displacement so that the plate separation changes

b. area of overlap changes due to the displacement.

Figure below shows the schematic of three-plate capacitive element sensor and displacement measurement of a mechanical element connected to the plate 2.



Displacement measurement using capacitive element sensor

The capacitance C of a parallel plate capacitor is given by,

$C = \varepsilon_r \varepsilon_o A / d$

where ε_r is the relative permittivity of the dielectric between the plates, εo permittivity of free space, *A* area of overlap between two plates and *d* the plate separation.

As the central plate moves near to top plate or bottom one due to the movement of the element /workpiece of which displacement is to be measured, separation in between the plate changes. This can be given as,

$C_1 = (\varepsilon_r \varepsilon_o A) / (d + x)$

$C_2 = (\varepsilon_r \varepsilon_o A) / (d – x)$

When C_1 and C_2 are connected to a Wheatsone's bridge, then the resulting out-of-balance voltage would be in proportional to displacement x.

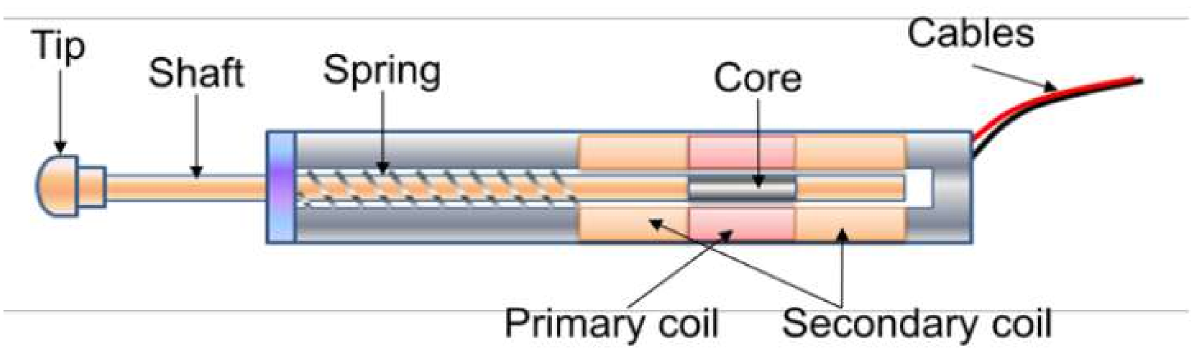
Capacitive elements can also be used as proximity sensor. The approach of the object towards the sensor plate is used for induction of change in plate separation. This changes the capacitance which is used to detect the object.

Applications of capacitive element sensors

• Feed hopper level monitoring
• Small vessel pump control
• Grease level monitoring
• Level control of liquids
• Metrology applications o to measure shape errors in the part being produced
o to analyze and optimize the rotation of spindles in various machine tools such as surface grinders, lathes, milling machines, and air bearing spindles by measuring errors in the machine tools themselves

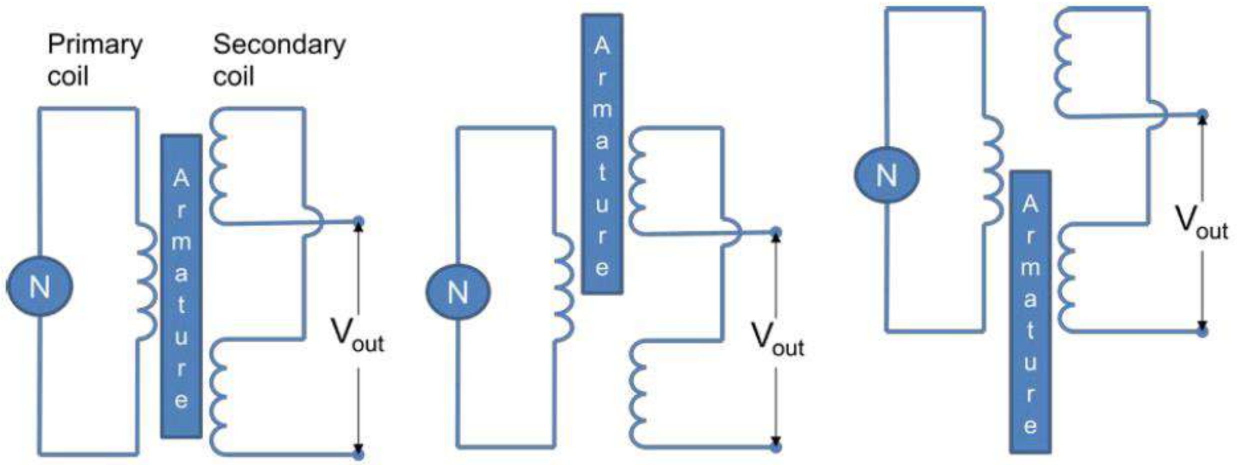
• Assembly line testing o to test assembled parts for uniformity, thickness or other design features
o to detect the presence or absence of a certain component, such as glue etc.

Linear variable differential transformer (LVDT)



Construction of a LVDT sensor

Linear variable differential transformer (LVDT) is a primary transducer used for measurement of linear displacement with an input range of about ± 2 to ± 400 mm in general. It has non-linearity error ± 0.25% of full range. Figure 2.2.6 shows the construction of a LVDT sensor. It has three coils symmetrically spaced along an insulated tube. The central coil is primary coil and the other two are secondary coils. Secondary coils are connected in series in such a way that their outputs oppose each other. A magnetic core attached to the element of which displacement is to be monitored is placed inside the insulated tube.



Working of LVDT sensor

Due to an alternating voltage input to the primary coil, alternating electro-magnetic forces (emfs) are generated in secondary coils. When the magnetic core is centrally placed with its half portion in each of the secondary coil regions then the resultant voltage is zero. If the core is displaced from the central position as shown in Figure 2.2.7, say, more in secondary coil 1 than in coil 2, then more emf is generated in one coil i.e. coil 1 than the other, and there is a resultant voltage from the coils. If the magnetic core is further displaced, then the value of resultant voltage increases in proportion with the displacement. With the help of signal processing devices such as low pass filters and demodulators, precise displacement can be measured by using LVDT sensors.

LVDT exhibits good repeatability and reproducibility. It is generally used as an absolute position sensor. Since there is no contact or sliding between the constituent elements of the sensor, it is highly reliable. These sensors are completely sealed and are widely used in Servomechanisms, automated measurement in machine tools.

A rotary variable differential transformer (RVDT) can be used for the measurement of rotation. Readers are suggested to prepare a report on principle of working and construction of RVDT sensor.

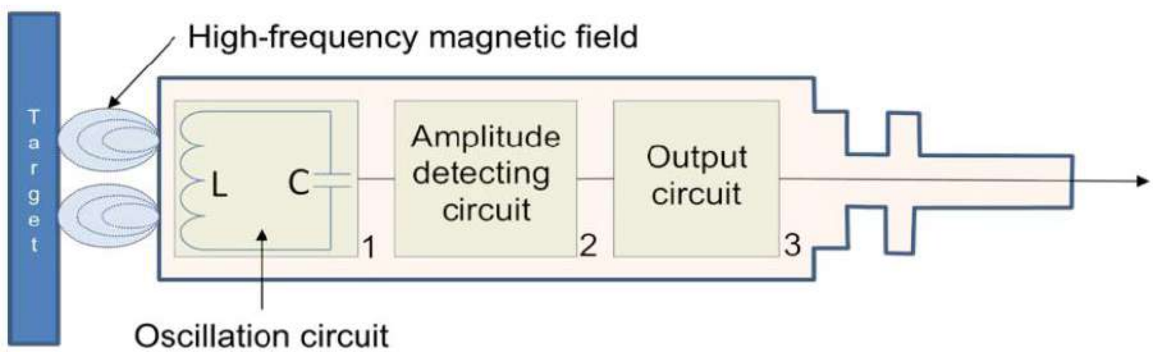
Applications of LVDT sensors

- Measurement of spool position in a wide range of servo valve applications
- To provide displacement feedback for hydraulic cylinders
- To control weight and thickness of medicinal products viz. tablets or pills

• For automatic inspection of final dimensions of products being packed for dispatch
• To measure distance between the approaching metals during Friction welding process
• To continuously monitor fluid level as part of leak detection system
• To detect the number of currency bills dispensed by an ATM

Displacement, position and proximity sensors

Eddy current proximity sensors



Schematic of Inductive Proximity Sensor

Eddy current proximity sensors are used to detect non-magnetic but conductive materials. They comprise of a coil, an oscillator, a detector and a triggering circuit. Figure 2.3.1 shows the construction of eddy current proximity switch. When an alternating current is passed thru this coil, an alternative magnetic field is generated. If a metal object comes in the close proximity of the coil, then eddy currents are induced in the object due to the magnetic field. These eddy currents create their own magnetic field which distorts the magnetic field responsible for their generation. As a result, impedance of the coil changes and so the amplitude of alternating current. This can be used to trigger a switch at some pre-determined level of change in current.

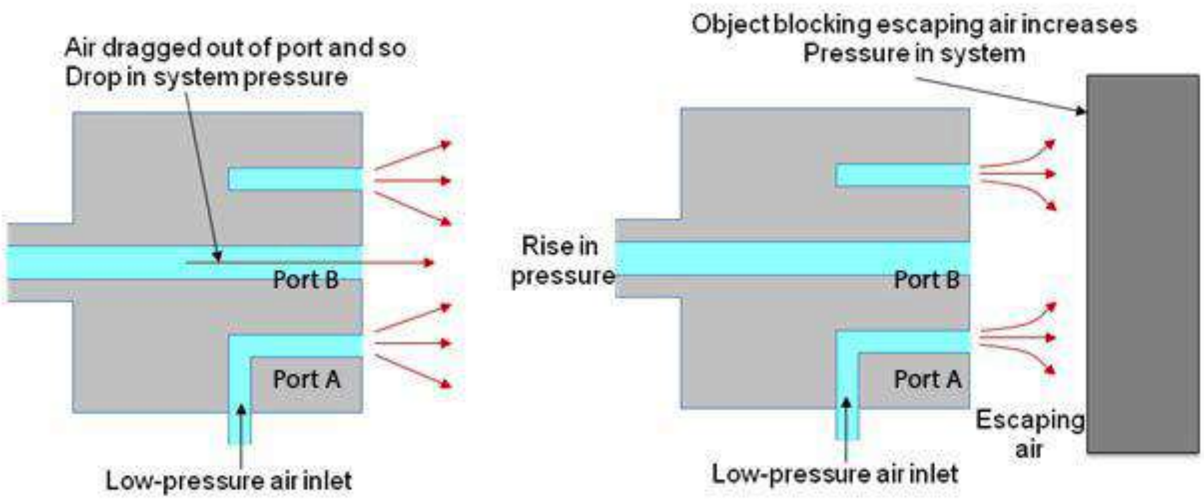
Eddy current sensors are relatively inexpensive, available in small in size, highly reliable and have high sensitivity for small displacements.

Applications of eddy current proximity sensors

• Automation requiring precise location
• Machine tool monitoring

• Final assembly of precision equipment such as disk drives
• Measuring the dynamics of a continuously moving target, such as a vibrating element,
• Drive shaft monitoring
• Vibration measurements

Pneumatic Sensors



Working of Pneumatic Sensors

Pneumatic sensors are used to measure the displacement as well as to sense the proximity of an object close to it. The displacement and proximity are transformed into change in air pressure. Figure 2.3.4 shows a schematic of construction and working of such a sensor. It comprises of three ports. Low pressure air is allowed to escape through port A. In the absence of any obstacle / object, this low pressure air escapes and in doing so, reduces the pressure in the port B. However when an object obstructs the low pressure air (Port A), there is rise in pressure in output port B. This rise in pressure is calibrated to measure the displacement or to trigger a switch. These sensors are used in robotics, pneumatics and for tooling in CNC machine tools.

Proximity Switches

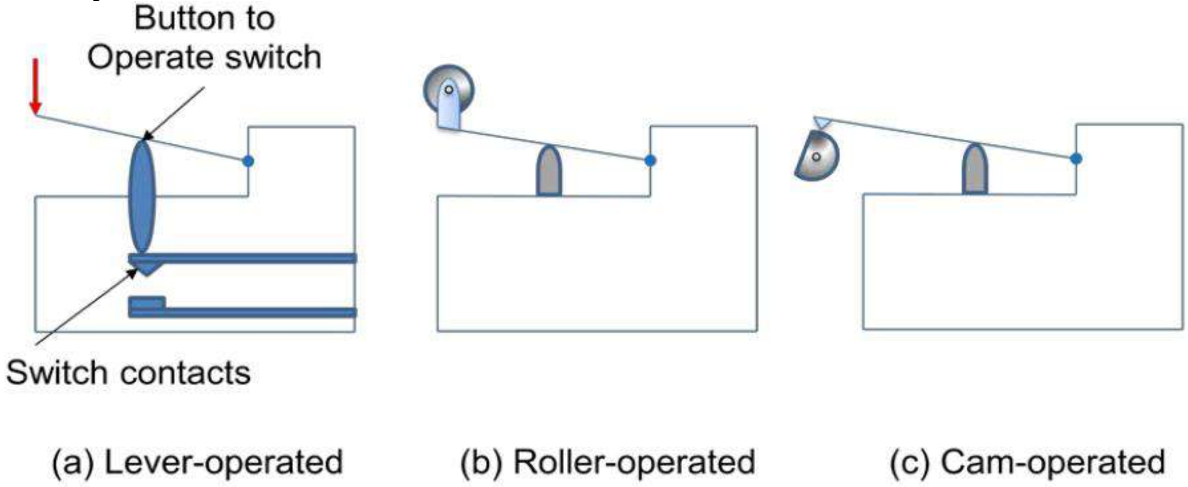
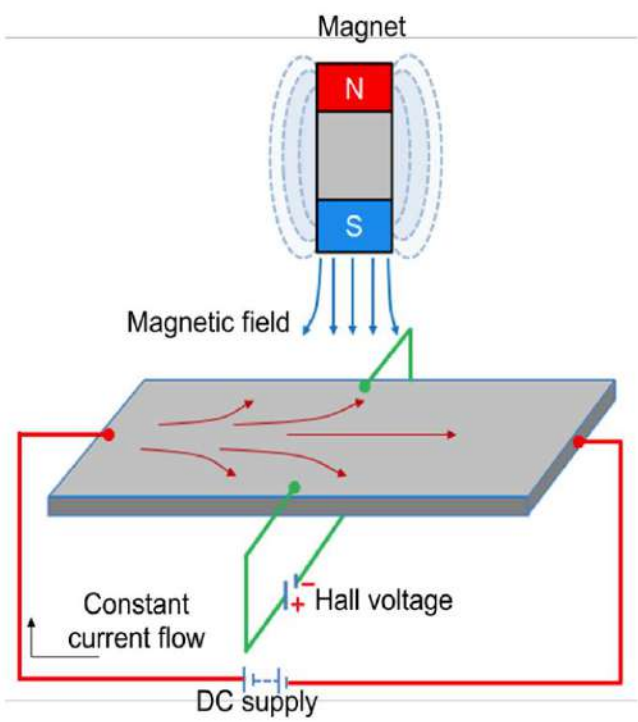


Figure above shows a number of configurations of contact-type proximity switch being used in manufacturing automation. These are small electrical switches which require physical contact and a small operating force to close the contacts. They are basically employed on conveyor systems to detect the presence of an item on the conveyor belt.

Hall effect sensor



Principle of working of Hall effect sensor

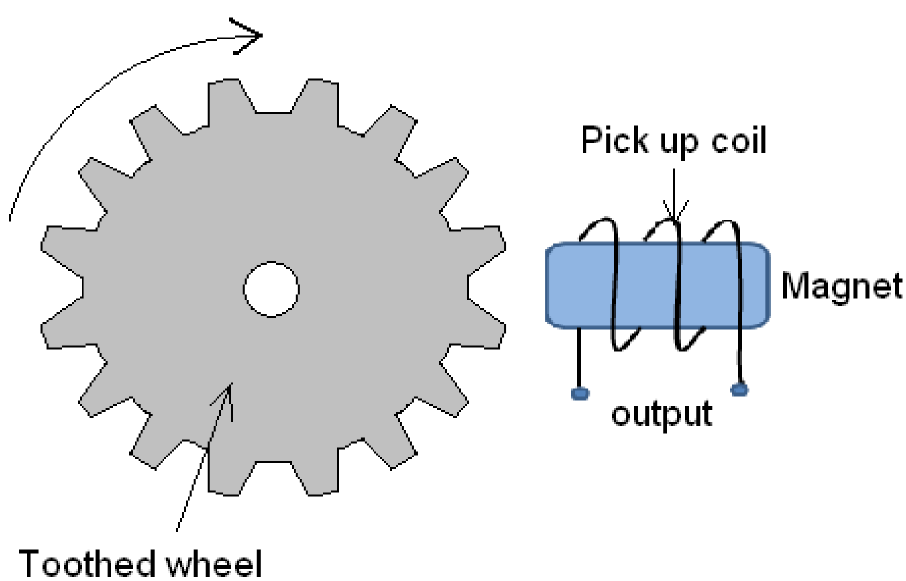
Figure above shows the principle of working of Hall effect sensor. Hall effect sensors work on the principle that when a beam of charge particles passes through a magnetic field, forces act on the particles and the current beam is deflected from its straight line path. Thus one side of the disc will become negatively charged and the other side will be of positive charge. This charge separation generates a potential difference which is the measure of distance of magnetic field from the disc carrying current.

The typical application of Hall effect sensor is the measurement of fluid level in a container. The container comprises of a float with a permanent magnet attached at its top. An electric circuit with a current carrying disc is mounted in the casing. When the fluid level increases, the magnet will come close to the disc and a potential difference generates. This voltage triggers a switch to stop the fluid to come inside the container.

These sensors are used for the measurement of displacement and the detection of position of an object. Hall effect sensors need necessary signal conditioning circuitry. They can be operated at 100 kHz. Their non-contact nature of operation, good immunity to environment contaminants and ability to sustain in severe conditions make them quite popular in industrial automation.

Velocity, motion, force and pressure sensors

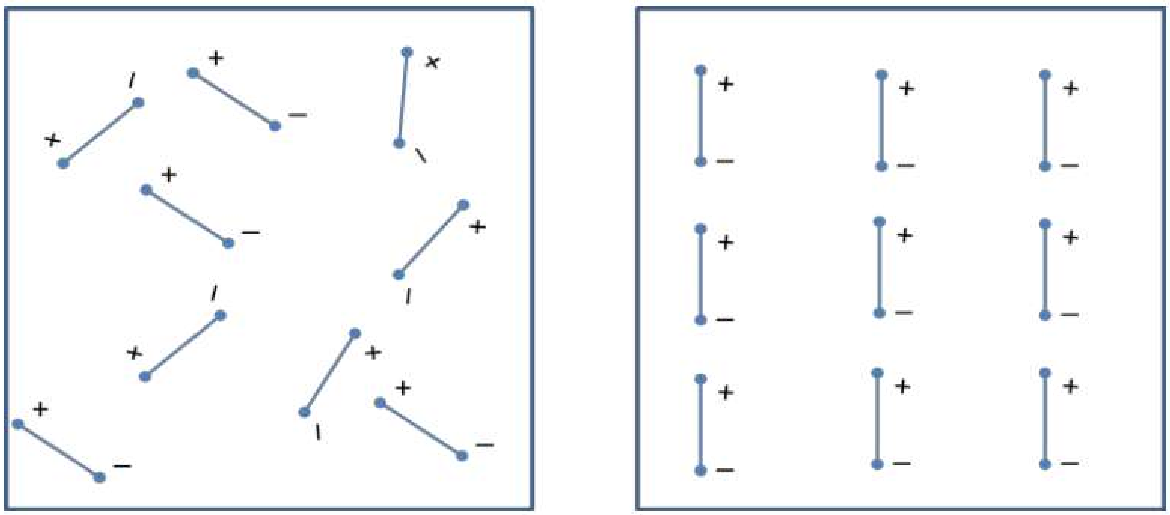
Tachogenerator



Principle of working of Techogenerator

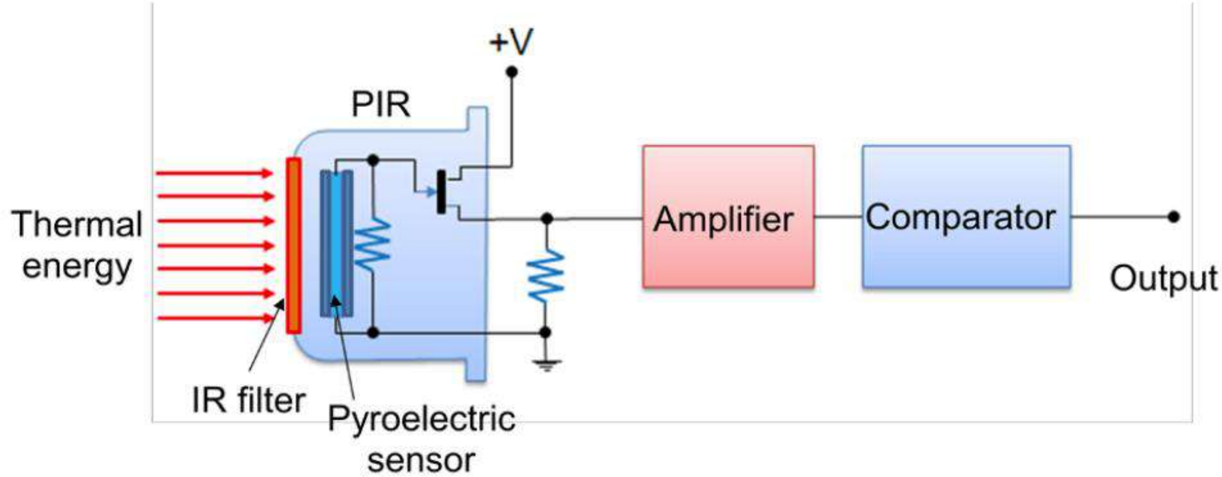
Tachogenerator works on the principle of variable reluctance. It consists of an assembly of a toothed wheel and a magnetic circuit as shown in figure 2.4.1. Toothed wheel is mounted on the shaft or the element of which angular motion is to be measured. Magnetic circuit comprising of a coil wound on a ferromagnetic material core. As the wheel rotates, the air gap between wheel tooth and magnetic core changes which results in cyclic change in flux linked with the coil. The alternating emf generated is the measure of angular motion. A pulse shaping signal conditioner is used to transform the output into a number of pulses which can be counted by a counter.

Pyroelectric sensors



Principle of pyroelectricity

These sensors work on the principle of *pyroelectricity*, which states that a crystal material such as Lithium tantalite generates charge in response to heat flow. In presence of an electric field, when such a crystal material heats up, its electrical dipoles line up as shown in figure 2.4.3. This is called as polarization. On cooling, the material retains its polarization. In absence of electric field, when this polarized material is subjected to infrared irradiation, its polarization reduces. This phenomenon is the measure of detection of movement of an object.



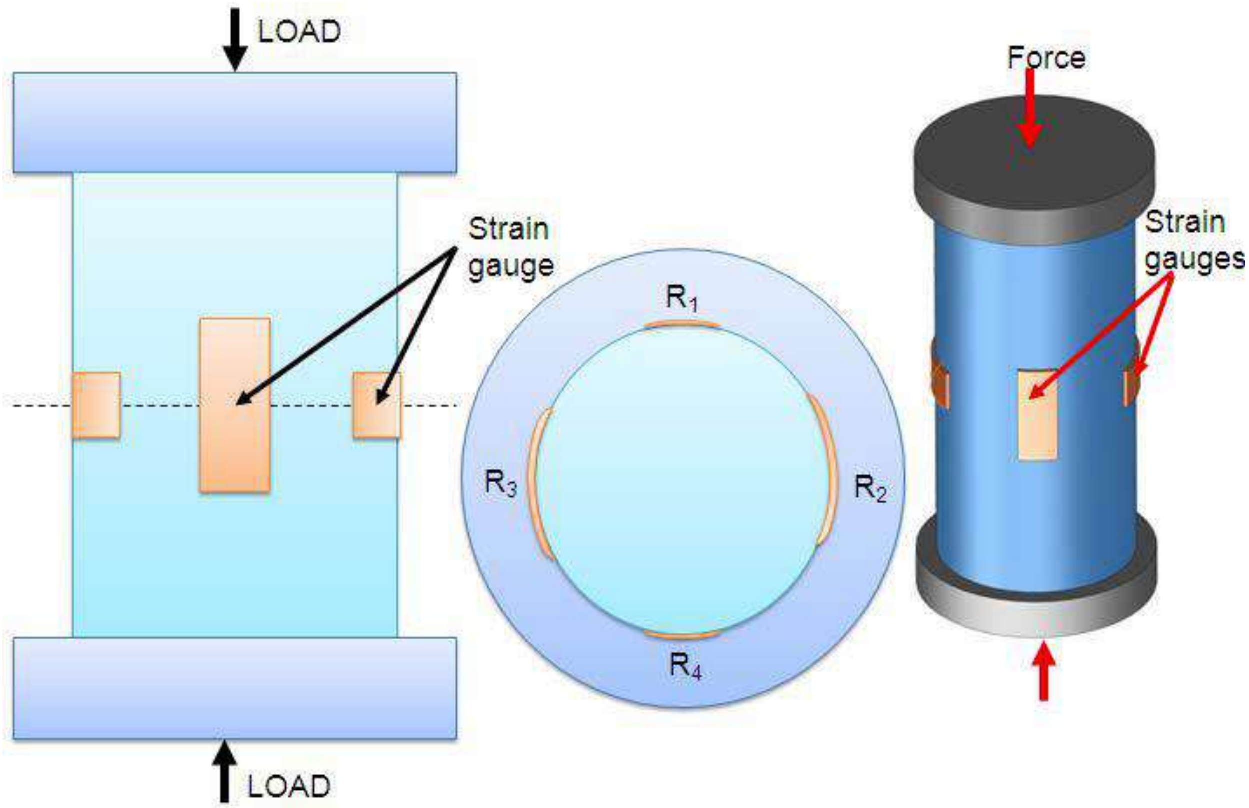
Construction and working a Pyroelectric sensor

Pyroelectric sensor comprises of a thick element of polarized material coated with thin film electrodes on opposite faces as shown in figure 2.4.4. Initially the electrodes are in electrical equilibrium with the polarized material. On incident of infra red, the material heats up and reduces its polarization. This leads to charge imbalance at the interface of crystal and electrodes. To balance this disequilibrium, measurement circuit supplies the charge, which is calibrated against the detection of an object or its movement.

Applications of Pyroelectric sensors

- Intrusion detector
- Optothermal detector
- Pollution detector
- Position sensor
- Solar cell studies
- Engine analysis

Strain Gauge as force Sensor



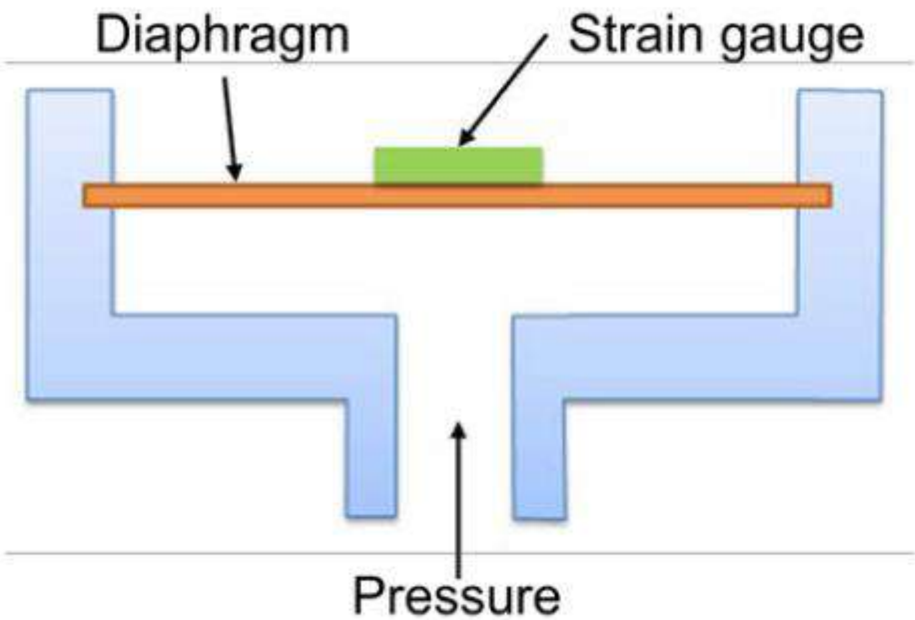
Strain gauge based Load cell

Strain gauge based sensors work on the principle of change in electrical resistance. When, a mechanical element subjects to a tension or a compression the electric resistance of the material changes. This is used to measure the force acted upon the element.

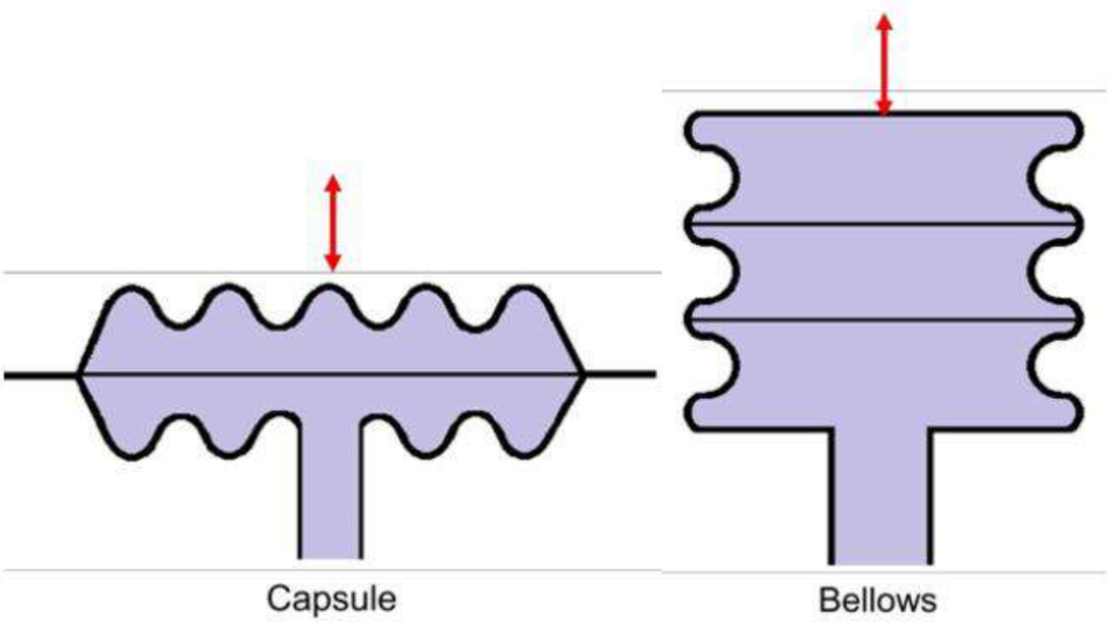
Figure above shows a strain gauge load cell. It comprises of cylindrical tube to which strain gauges are attached. A load applied on the top collar of the cylinder compress the strain gauge element which changes its electrical resistance. Generally strain gauges are used to measure forces up to 10 MN. The non-linearity and repeatability errors of this transducer are ±0.03% and ±0.02% respectively.

Fluid pressure

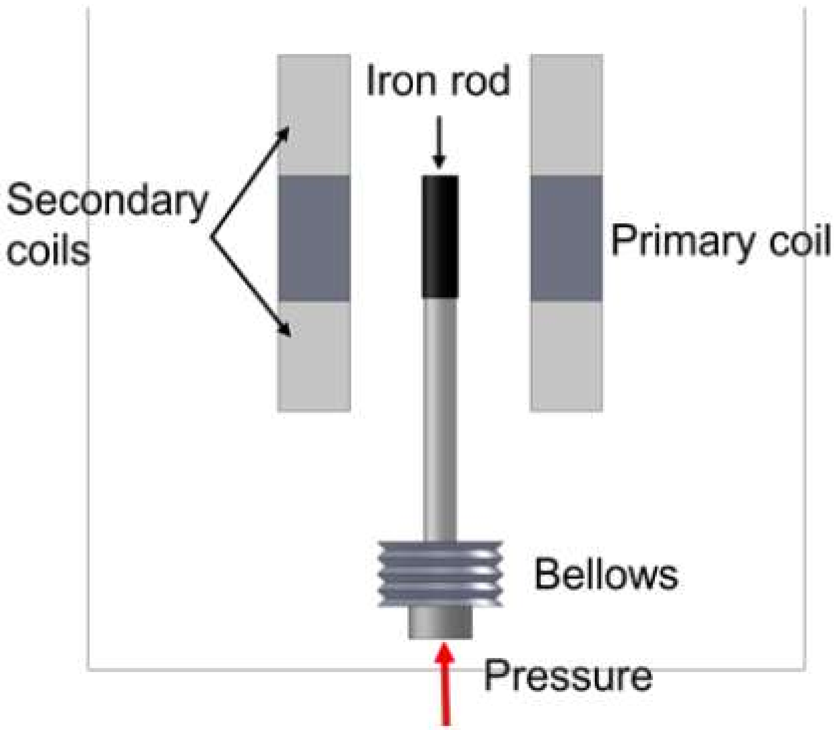
Chemical, petroleum, power industry often need to monitor fluid pressure. Various types of instruments such as diaphragms, capsules, and bellows are used to monitor the fluid pressure. Specially designed strain gauges doped in diaphragms are generally used to measure the inlet manifold pressure in applications such as automobiles. A typical arrangement of strain gauges on a diaphragm is shown in figure 2.4.6. Application of pressurized fluid displaces the diaphragm. This displacement is measured by the stain gauges in terms of radial and/or lateral strains. These strain gauges are connected to form the arms of a Wheatstone bridge.



A diaphragm



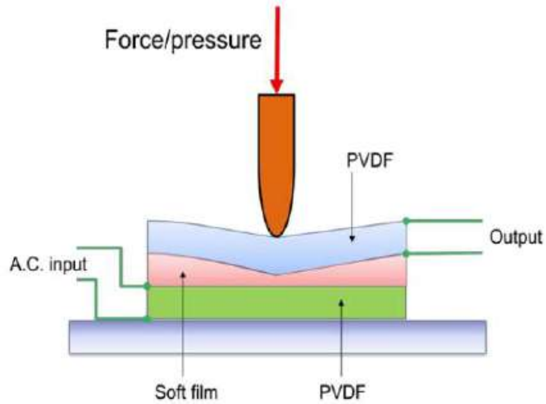
Schematic of Capsule and Bellow



Bellow with a LVDT

Capsule is formed by combining two corrugated diaphragms. It has enhanced sensitivity in comparison with that of diaphragms. Figure 2.4.7 shows a schematic of a Capsule and a Bellow. A stack of capsules is called as 'Bellows'. Bellows with a LVDT sensor measures the fluid pressure in terms of change in resultant voltage across the secondary coils of LVDT. Figure above shows a typical arrangement of the same.

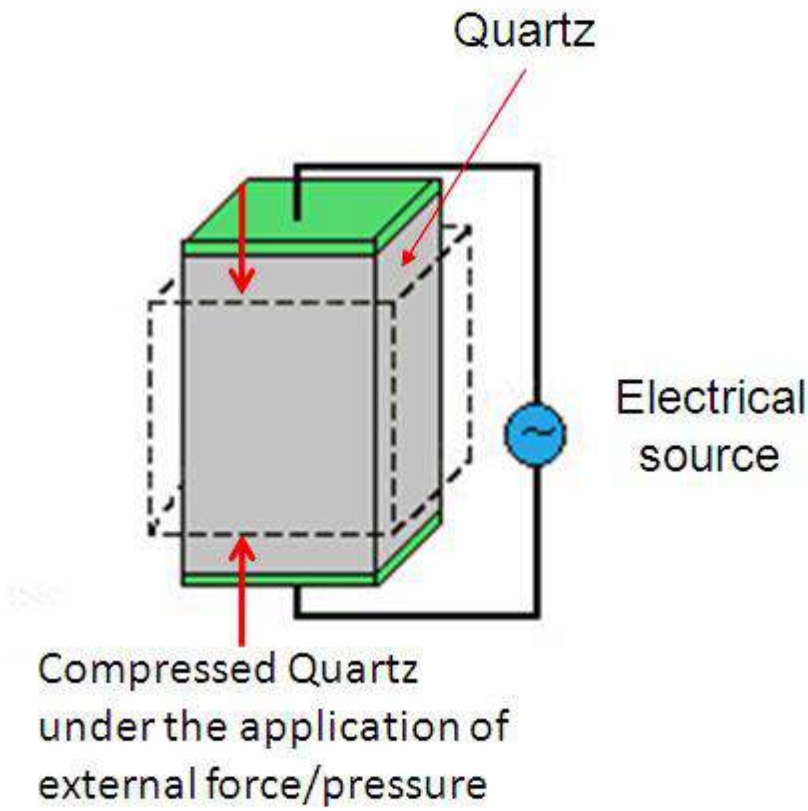
Tactile sensors



Schematic of a tactile sensor

In general, tactile sensors are used to sense the contact of fingertips of a robot with an object. They are also used in manufacturing of ‘touch display’ screens of visual display units (VDUs) of CNC machine tools. Figure 2.4.9 shows the construction of piezo-electric polyvinylidene fluoride (PVDF) based tactile sensor. It has two PVDF layers separated by a soft film which transmits the vibrations. An alternating current is applied to lower PVDF layer which generates vibrations due to reverse piezoelectric effect. These vibrations are transmitted to the upper PVDF layer via soft film. These vibrations cause alternating voltage across the upper PVDF layer. When some pressure is applied on the upper PVDF layer the vibrations gets affected and the output voltage changes. This triggers a switch or an action in robots or touch displays.

Piezoelectric sensor



Principle of working of Piezoelectric sensor

Piezoelectric sensor is used for the measurement of pressure, acceleration and dynamic-forces such as oscillation, impact, or high speed compression or tension. It contains piezoelectric ionic crystal materials such as Quartz (Figure). On application of force or pressure these materials get stretched or compressed. During this process, the charge over the material changes and redistributes. One face of the material becomes positively charged and the other negatively charged. The net charge q on the surface is proportional to the amount x by which the charges have been displaced. The displacement is proportion to force. Therefore we can write,

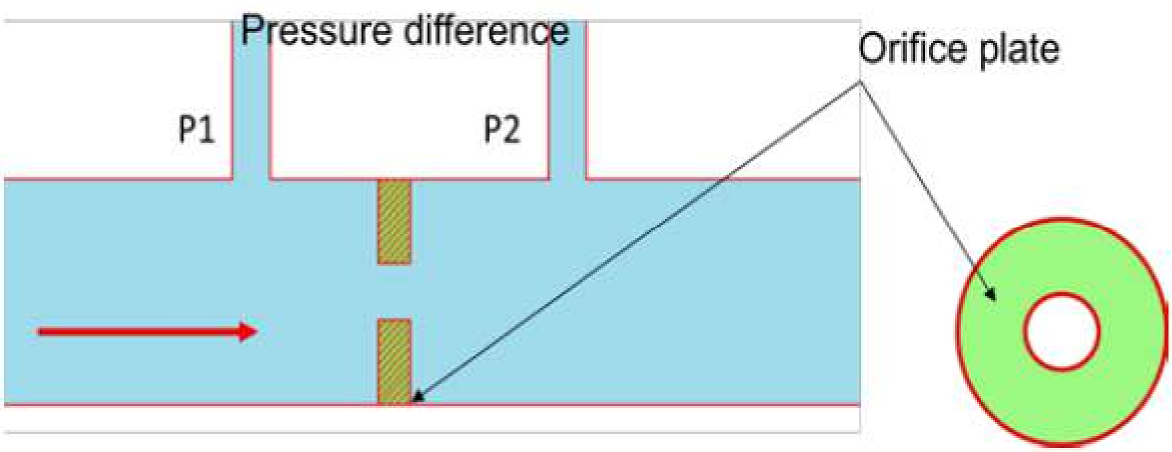
$$q = kx = SF$$

where k is constant and S is a constant termed the charge sensitivity.

Liquid flow

Liquid flow is generally measured by applying the Bernoulli's principle of fluid flow through a constriction. The quantity of fluid flow is computed by using the pressure drop measured. The fluid flow volume is proportional to square root of pressure difference at the two ends of the constriction. There are various types of fluid flow measurement devices being used in manufacturing automation such as Orifice plate, Turbine meter etc.

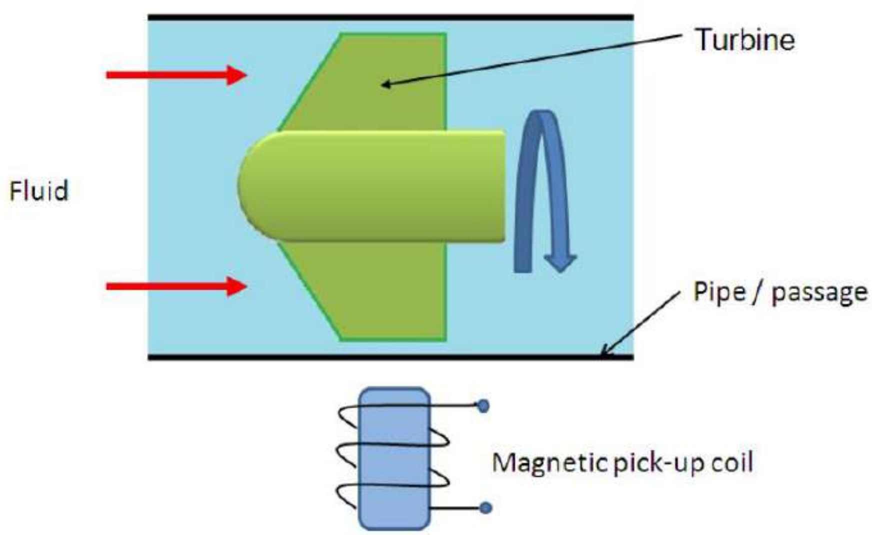
Orifice Plate



Orifice Plate

Figure above shows a schematic of Orifice plate device. It has a disc with a hole at its center, through which the fluid flows. The pressure difference is measured between a point equal to the diameter of the tube upstream and a point equal to the half the diameter downstream. Orifice plate is inexpensive and simple in construction with no moving parts. It exhibits nonlinear behavior and does not work with slurries. It has accuracy of ± 1.5%.

Turbine meter



Schematic of turbine meter

Turbine flow meter has an accuracy of ±0.3%. It has a multi blade rotor mounted centrally in the pipe along which the flow is to be measured. Figure 2.4.12 shows the typical arrangement of the rotor and a magnetic pick up coil. The fluid flow rotates the rotor. Accordingly the magnetic pick up coil counts the number of magnetic pulses generated due to the distortion of magnetic field by the rotor blades. The angular velocity is proportional to the number of pulses and fluid flow is proportional to angular velocity.

8. Fluid level

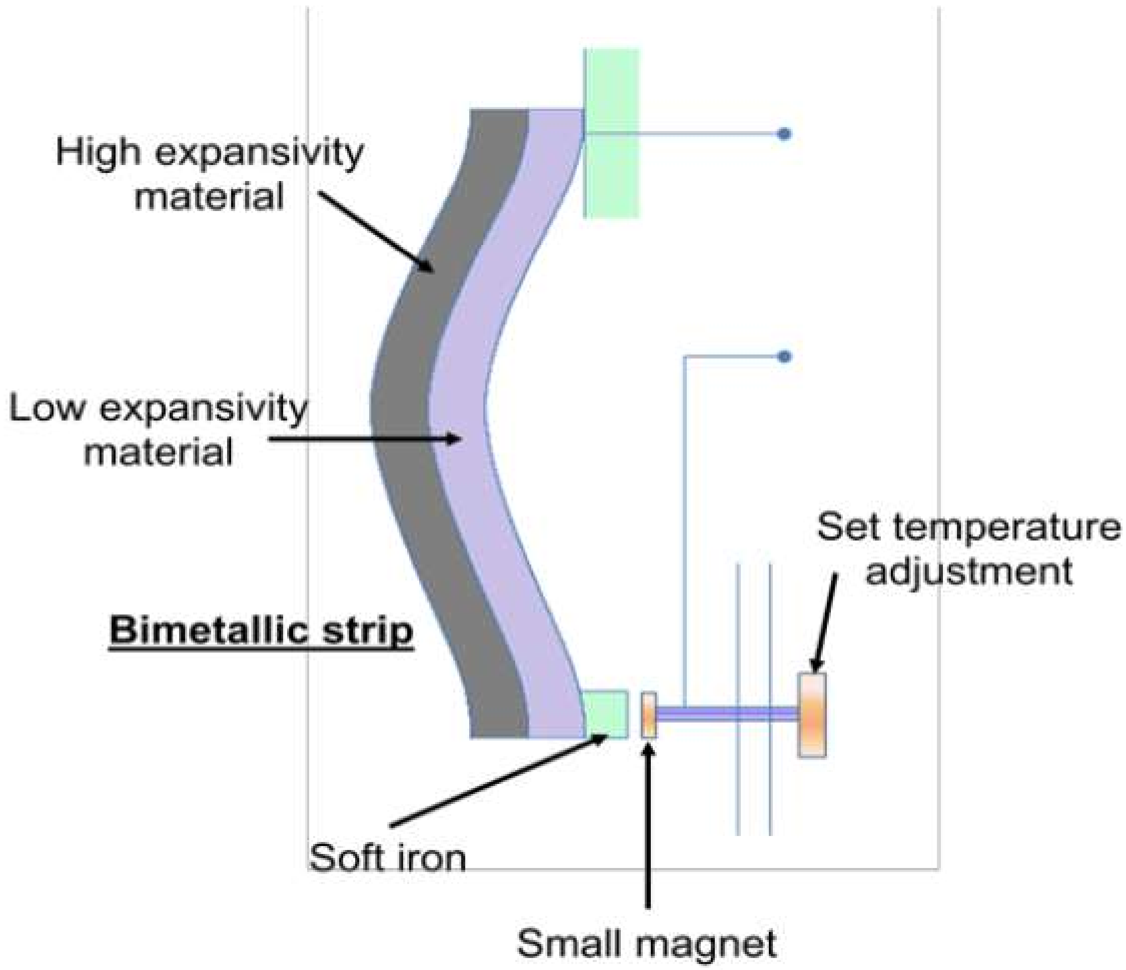
The level of liquid in a vessel or container can be measured,
a. directly by monitoring the position of liquid surface
b. indirectly by measuring some variable related to the height.

Direct measurements involve the use of floats however the indirect methods employ load cells. Potentiometers or LVDT sensors can be used along with the floats to measure the height of fluid column. Force sensed by the load cells is proportional to the height of fluid column.

Temperature and light sensors

Temperature conveys the state of a mechanical system in terms of expansion or contraction of solids, liquids or gases, change in electrical resistance of conductors, semiconductors and thermoelectric emfs. Temperature sensors such as bimetallic strips, thermocouples, thermistors are widely used in monitoring of manufacturing processes such as casting, molding, metal cutting etc. The construction details and principle of working of some of the temperature sensors are discussed in following sections.

1. Bimetallic strips



Construction and working of Bi-metallic strip

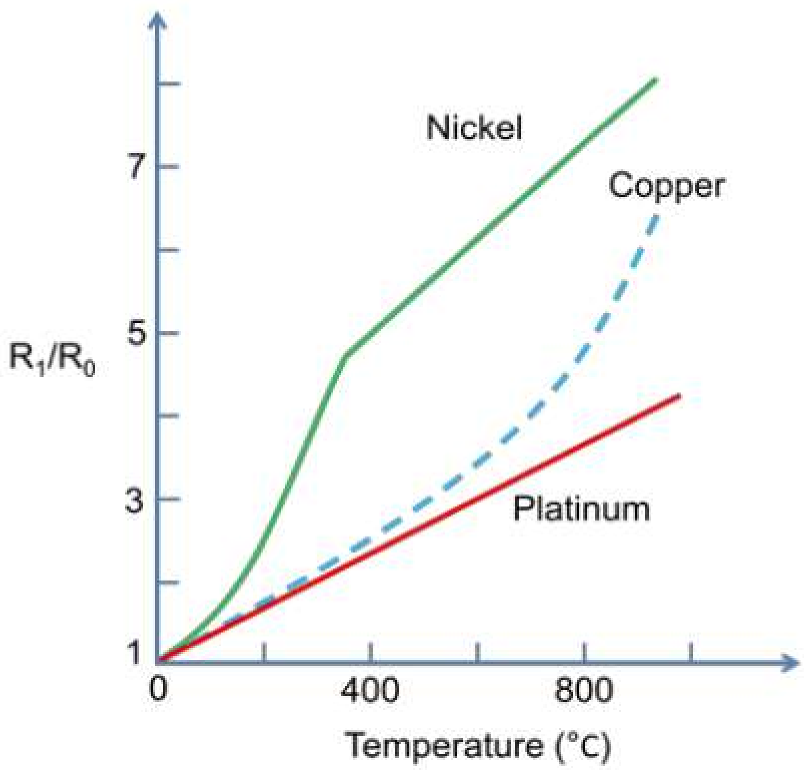
Bimetallic strips are used as thermal switch in controlling the temperature or heat in a manufacturing process or system. It contains two different metal strips bonded together. The metals have different coefficients of expansion. On heating the strips bend into curved strips with the metal with higher coefficient of expansion on the outside of the curve. Figure 2.5.1 shows a typical arrangement of a bimetallic strip used with a setting-up magnet. As the strips bend, the soft iron comes in closer proximity of the small magnet and further touches. Then the electric circuit completes and generates an alarm. In this way bimetallic strips help to protect the desired application from heating above the pre-set value of temperature.

2. Resistance temperature detectors (RTDs)

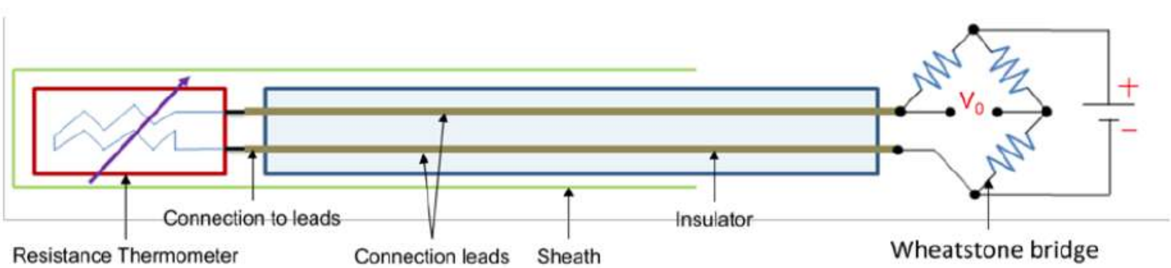
RTDs work on the principle that the electric resistance of a metal changes due to change in its temperature. On heating up metals, their resistance increases and follows a linear relationship as shown in Figure 2.5.2. The correlation is

Rt = R0 (1 + αT) (2.5.1)

where *Rt* is the resistance at temperature *T* (ºC) and *R0* is the temperature at 0ºC and *α* is the constant for the metal termed as temperature coefficient of resistance. The sensor is usually made to have a resistance of 100 Ω at 0 °C



Behavior of RTD materials



Construction of a Resistance temperature detector (RTD)

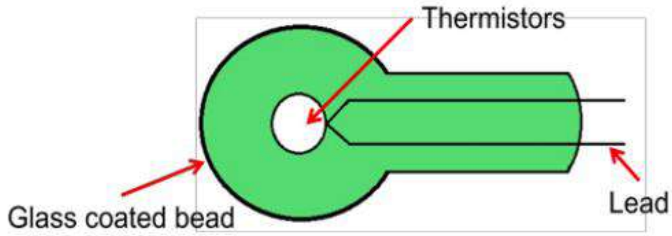
Figure above shows the construction of a RTD. It has a resistor element connected to a Wheatstone bridge. The element and the connection leads are insulated and protected by a sheath. A small amount of current is continuously passing though the coil. As the temperature changes the resistance of the coil changes which is detected at the Wheatstone bridge.RTDs are used in the form of thin films, wire wound or coil. They are generally made of metals such as platinum, nickel or nickel-copper alloys. Platinum wire held by a high-temperature glass adhesive in a ceramic tube is used to measure the temperature in a metal furnace. Other applications are:

- Air conditioning and refrigeration servicing
- Food Processing
- Stoves and grills
- Textile production
- Plastics processing
- Petrochemical processing
- Micro electronics
- Air, gas and liquid temperature measurement in pipes and tanks
- Exhaust gas temperature measurement

3. Thermistors

Thermistors follow the principle of decrease in resistance with increasing temperature. The material used in thermistor is generally a semiconductor material such as a sintered metal oxide (mixtures of metal oxides, chromium, cobalt, iron, manganese and nickel) or doped polycrystalline ceramic containing barium titanate ($BaTiO_3$) and other compounds. As the temperature of semiconductor material increases the number of electrons able to move about increases which results in more current in the material and reduced resistance. Thermistors are rugged and small in dimensions. They exhibit nonlinear response characteristics.

Thermistors are available in the form of a bead (pressed disc), probe or chip. Figure 2.5.4 shows the construction of a bead type thermistor. It has a small bead of dimension from 0.5 mm to 5 mm coated with ceramic or glass material. The bead is connected to an electric circuit through two leads. To protect from the environment, the leads are contained in a stainless steel tube.



Schematic of a thermistorApplications of Thermistors

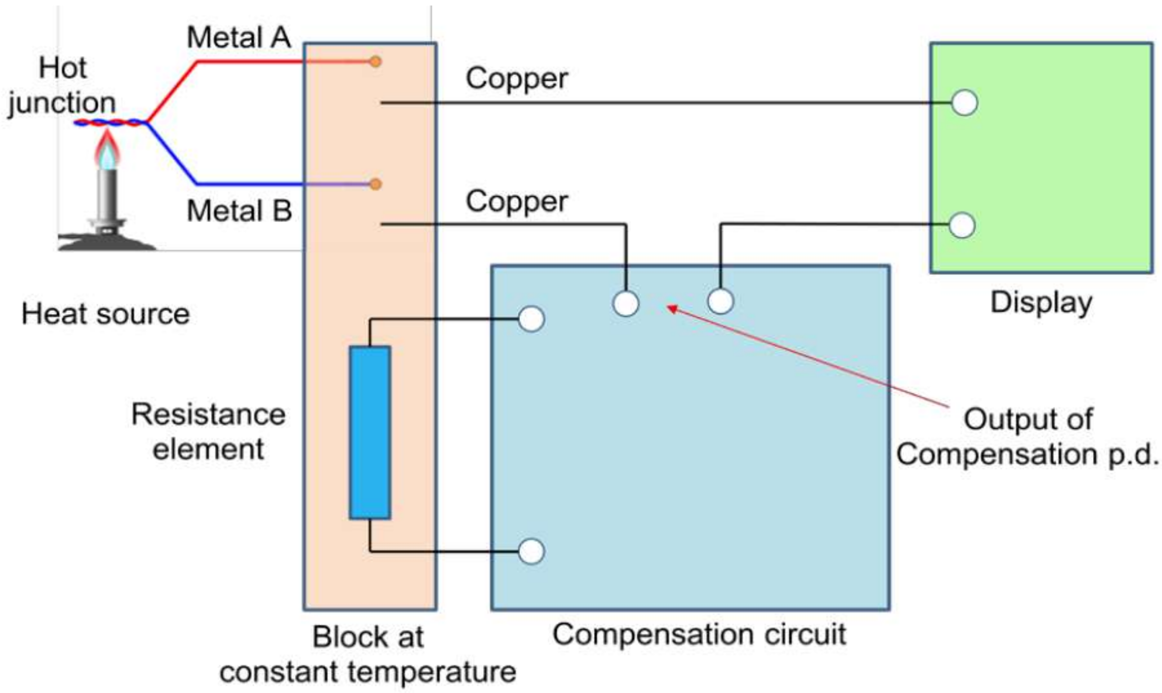
• To monitor the coolant temperature and/or oil temperature inside the engine
• To monitor the temperature of an incubator
• Thermistors are used in modern digital thermostats
• To monitor the temperature of battery packs while charging
• To monitor temperature of hot ends of 3D printers
• To maintain correct temperature in the food handling and processing industry equipments
• To control the operations of consumer appliances such as toasters, coffee makers, refrigerators, freezers, hair dryers, etc.

4. Thermocouple

Thermocouple works on the fact that when a junction of dissimilar metals heated, it produces an electric potential related to temperature. As per Thomas Seebeck (1821), when two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, then there is a continuous current which flows in the thermoelectric circuit. Figure 2.5.5 shows the schematic of thermocouple circuit. The net open circuit voltage (the Seebeck voltage) is a function of junction temperature and composition of two metals. It is given by,

$\Delta VAB = \alpha \, \Delta T$ (2.5.2)

where α, the Seebeck coefficient, is the constant of proportionality.



Schematic of thermocouple circuit

Generally, Chromel (90% nickel and 10% chromium)–Alumel (95% nickel, 2% manganese, 2% aluminium and 1% silicon) are used in the manufacture of a thermocouple. Table 2.5.1 shows the various other materials, their combinations and application temperature ranges.

Materials	Range (°C)	(μV/°C)
Platinum 30% rhodium/platinum 6% rhodium	0 to 1800	3
Chromel/constantan	-200 to 1000	63
Iron/constantan	-200 to 900	53
Chromel/alumel	-200 to 1300	41
Nirosil/nisil	-200 to 1300	28
Platinum/platinum 13% rhodium	0 to 1400	6
Platinum/platinum 10% rhodium	0 to 1400	6
Copper/constantan	-200 to 400	43

Thermo couple material and Temperature range

Applications of Thermocouples

• To monitor temperatures and chemistry throughout the steel making process

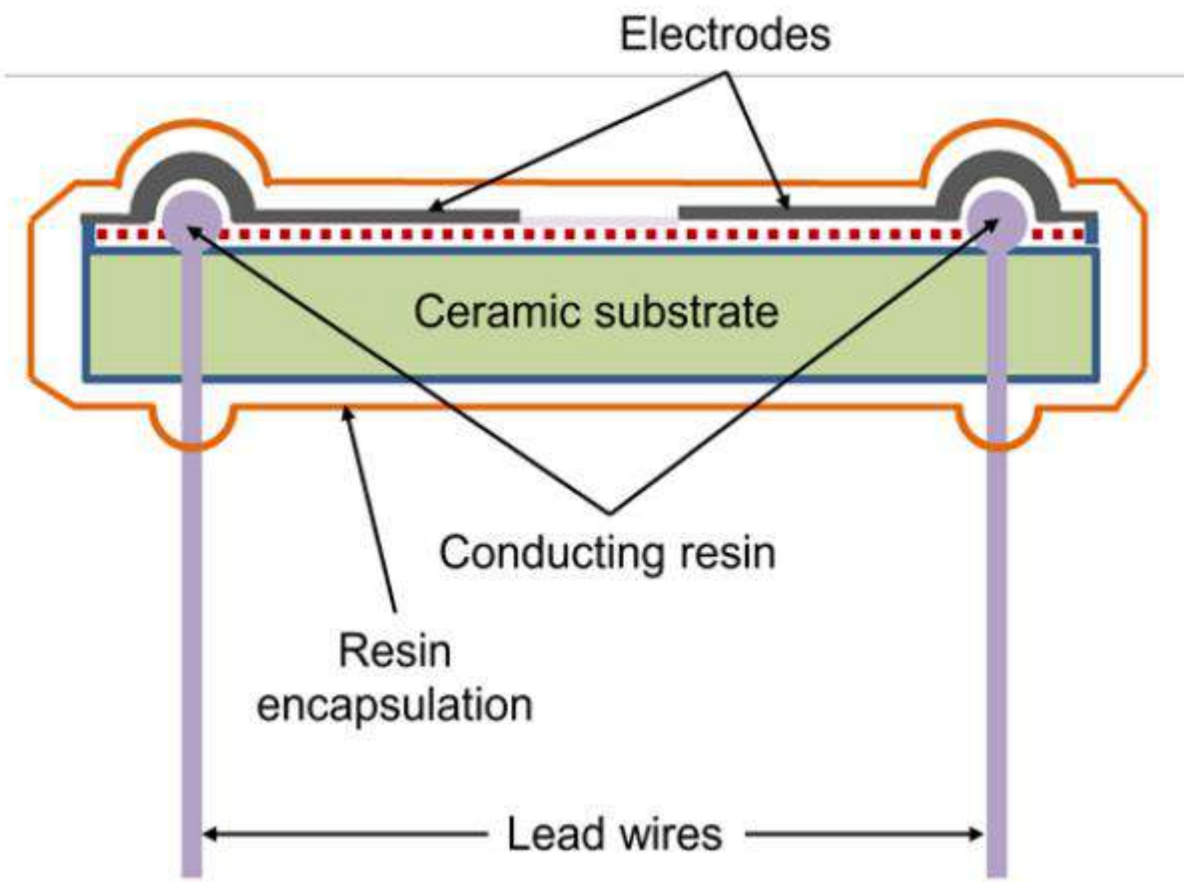
• Testing temperatures associated with process plants e.g. chemical production and petroleum refineries
• Testing of heating appliance safety
• Temperature profiling in ovens, furnaces and kilns
• Temperature measurement of gas turbine and engine exhausts
• Monitoring of temperatures throughout the production and smelting process in the steel, iron and aluminum industry

Light sensors

A light sensor is a device that is used to detect light. There are different types of light sensors such as photocell/photoresistor and photo diodes being used in manufacturing and other industrial applications.

Photoresistor is also called as light dependent resistor (LDR). It has a resistor whose resistance decreases with increasing incident light intensity. It is made of a high resistance semiconductor material, cadmium sulfide (CdS). The resistance of a CdS photoresistor varies inversely to the amount of light incident upon it. Photoresistor follows the principle of photoconductivity which results from the generation of mobile carriers when photons are absorbed by the semiconductor material.

Figure 2.5.6 shows the construction of a photo resistor. The CdS resistor coil is mounted on a ceramic substrate. This assembly is encapsulated by a resin material. The sensitive coil electrodes are connected to the control system though lead wires. On incidence of high intensity light on the electrodes, the resistance of resistor coil decreases which will be used further to generate the appropriate signal by the microprocessor via lead wires.



Construction of a photo resistor

Photoresistors are used in science and in almost any branch of industry for control, safety, amusement, sound reproduction, inspection and measurement.

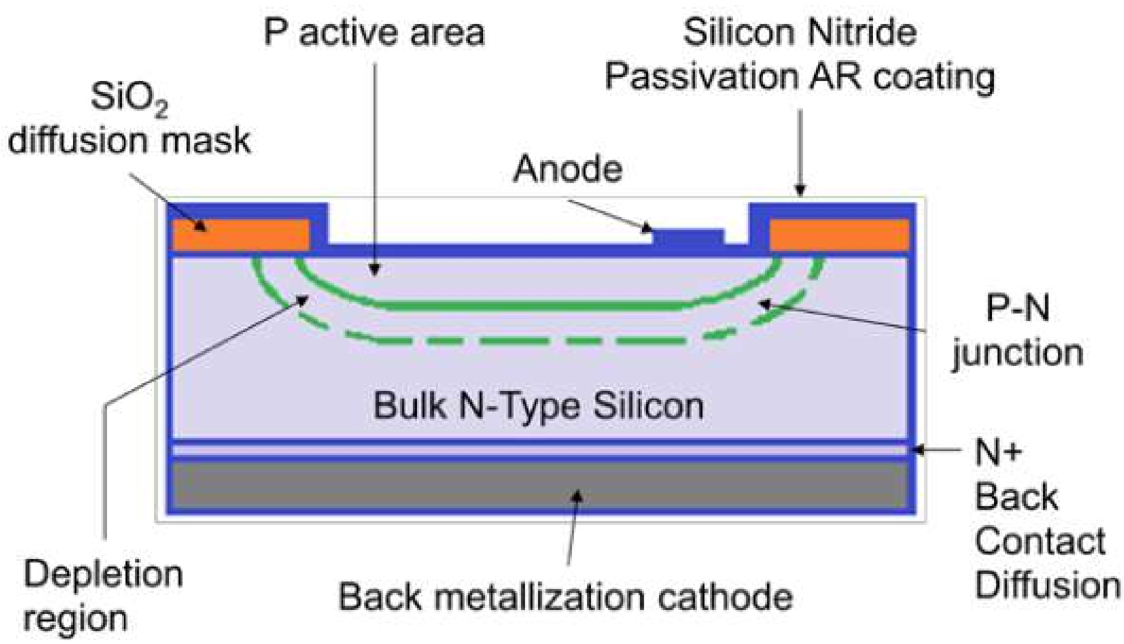
Applications of photo resistor

- Computers, wireless phones, and televisions, use ambient light sensors to automatically control the brightness of a screen
- Barcode scanners used in retailer locations work using light sensor technology
- In space and robotics: for controlled and guided motions of vehicles and robots. The light sensor enables a robot to detect light. Robots can be programmed to have a specific reaction if a certain amount of light is detected.
- Auto Flash for camera
- Industrial process control

Photo diodes

Photodiode is a solid-state device which converts incident light into an electric current. It is made of Silicon. It consists of a shallow diffused p-n junction, normally a p-on-n configuration. When photons of energy greater than 1.1eV (the bandgap of silicon) fall on the device, they are absorbed and electron-hole pairs are created. The depth at which the photons are absorbed depends upon their energy. The lower the energy of the photons, the deeper they are absorbed. Then the electron-hole pairs drift apart. When the minority carriers reach the junction, they are swept across by the electric field and an electric current establishes

Photodiodes are one of the types of photodetector, which convert light into either current or voltage. These are regular semiconductor diodes except that they may be either exposed to detect vacuum UV or X-rays or packaged with an opening or optical fiber connection to allow light to reach the sensitive part of the device.



Construction of photo diode detector

Figure 2.5.7 shows the construction of Photo diode detector. It is constructed from single crystal silicon wafers. It is a p-n junction device. The upper layer is p layer. It is very thin and formed by thermal diffusion or ion implantation of doping material such as boron. Depletion region is narrow and is sandwiched between p layer and bulk n type layer of silicon. Light irradiates at front surface, anode, while the back surface is cathode. The incidence of light on anode generates a flow of electron across the p-n junction which is the measure of light intensity.

Applications of photo diodes

Camera: Light Meters, Automatic Shutter Control, Auto-focus, Photographic Flash Control

Medical: CAT Scanners - X ray Detection, Pulse Oximeters, Blood Particle Analyzers

Industry

- Bar Code Scanners
- Light Pens
- Brightness Controls
- Encoders
- Position Sensors
- Surveying Instruments
- Copiers - Density of Toner

Safety Equipment

- Smoke Detectors
- Flame Monitors
- Security Inspection Equipment - Airport X ray
- Intruder Alert - Security System

Automotive

- Headlight Dimmer
- Twilight Detectors
- Climate Control - Sunlight Detector

Communications

- Fiber Optic Links
- Optical Communications
- Optical Remote Control

Module-III

Signals, systems and Actuating Devices: Introduction to signals, systems and control system, representation, linearization of nonlinear systems, time Delays, measures of system performance, types of actuating devices selection. ;

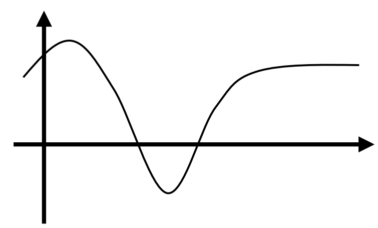
SIGNAL:

- One can note that what is really being received through sensor and what is being directed to the actuator is simply the 'signal'.
- A signal is a time varying quantity conveying some information.
- The transducer output is simply the 'signal' and the actuator input is also 'signal'.
- Examples of signal include:
    - Electrical signals

  - Voltages and currents in a circuit
- Acoustic signals
  - Acoustic pressure (sound) over time
- Mechanical signals
  - Velocity of a car over time
- Video signals
  - Intensity level of a pixel (camera, video) over time

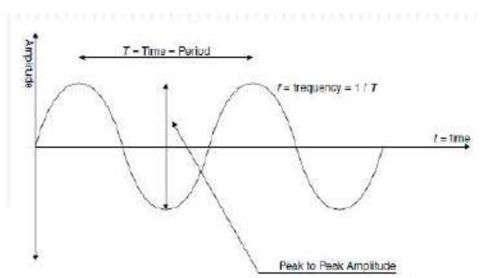
How is a Signal Represented?

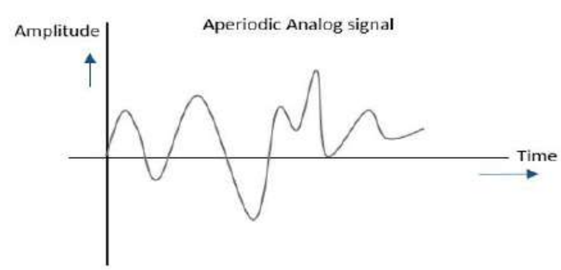
- Mathematically, signals are represented as a function of one or more **independent variables**.
- For instance a black & white video signal intensity is dependent on *x*, *y* coordinates and time *tf*(*x*,*y*,*t*)



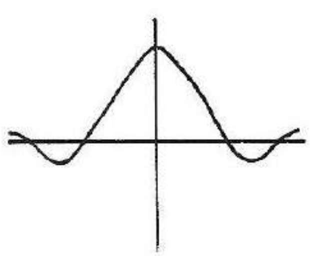
<u>Types of Signals</u>

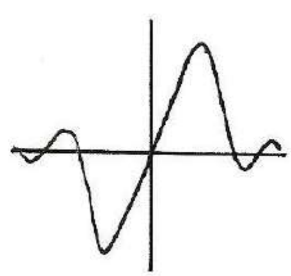
- **Periodicsignals**: a signal is periodic if it repeats itself after a fixed period *T*, i.E. *X*(*t*) = *x*(*t*+*t*) for all *t*. A sin(*t*) signal is periodic.



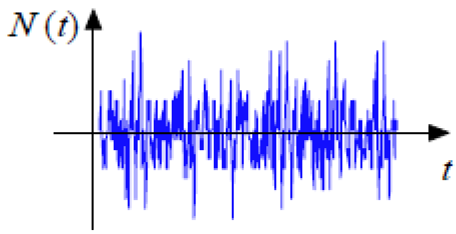


- **Even and odd signals**: a signal is even if *x*(-*t*) = x(*t*) (i.E. It can be reflected in the axis at zero). A signal is odd if *x*(-*t*) = -*x*(*t*). Examples are cos(*t*) and sin(*t*) signals, respectively.

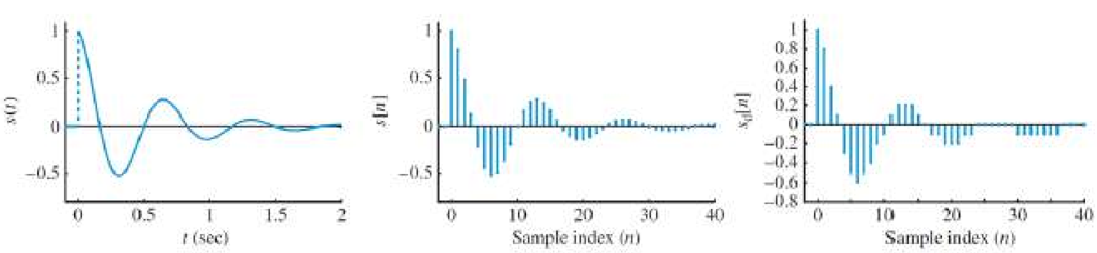




- **Deterministic signal**: completely predictable, can be a deterministic function of the variables.
  – E.g., sin(t)., cos(t)…
- **Random signal**: cannot predict the future values of the signal exactly; evolves uncertainties. Can only be described with statistical observations, the probability of the value at certain position.
  – E.g., noise, vibration, stock market…



- **Continuous-time signal**
  It defined in the continuous time period. It is a function of a continuous independent variable. Note that the "continuous" refers to the variable *t*. The amplitude could be either continuous or discontinuous.
- **Digital signal**
  Digital signal is the signal that is both discrete in time, and quantized in amplitude.
- **Discrete-time signal**
  It defined only at a discrete set of values of independent variables. It can be obtained by sampling the continuous signal. Digital signal processing requires a discrete-time signal representation.



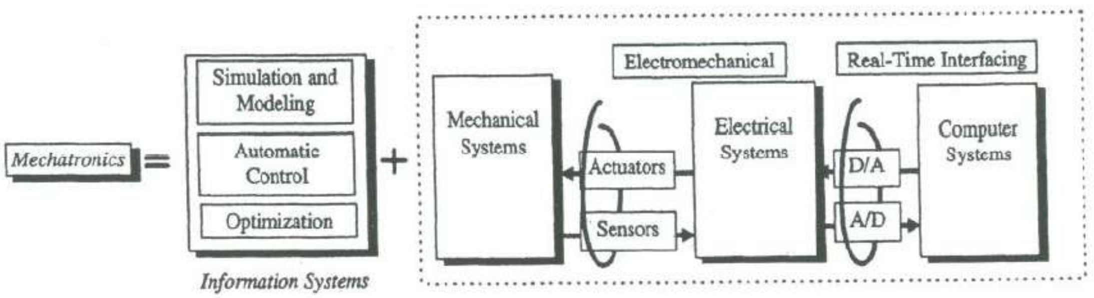
Why signal processing?

- A signal is composed is composed of many components.

- Analysis that are being carried out is to know the amplitude, frequency, and phase of the components either at a particular point of time and/or in an interval.
- In order to take advantage of processing power of modern digital processors or computers, it is necessary to convert the real world analog signals in to an appropriate form, which can be stored and processed by the use of digital systems and devices.
- Efficient make use of information, e.g. amplify or filter out information, detect patterns, different domain information
- Better transmission and processing, e.g. distortions, prevent interference

SYSTEM:

- A system (or plant) is a naturally occurring or man-made entity which transforms cause(or inputs) into effects(or outputs).
- System behaviour can be modified by interactions with other systems.



- A cd player takes the signal on the cd and transforms it into a signal sent to the loud speaker.

CONTROL SYSTEM:

A control system is a collection of components that is designed to drive a given system (plant) with a given input to a desired output.

In a control system there is an interconnection between the constituent components. These components may be electrical, mechanical, hydraulic, pneumatic, etc.

- Modification of the behaviour of a system such that a desired behaviour is achieved is called control.
- Controls are implemented by attaching a controller or compensator to the plant. The resulting combined system is called a control system.

- Control systems incorporate either human or machine controllers. When the controller is machine based, it is called automatic control.
- Within any control system there are variables and functions.
- Variables can be either constant or may vary with respect to some independent variable.
    - Constant variables are called *parameters.*
    - Varying variables are called **signals**.

Basic function of a control system are:

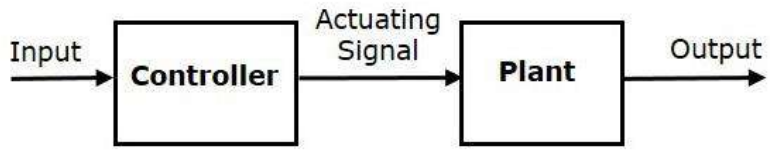
- To minimise the error between the actual and desired output.
- To minimise the time response to load changes in the system.

Requirement of a control system:

- Stability: for any change in the input signal, the output of the system reads or makes its response at a reasonable value.
- Accuracy: the closeness of the measured value to the true value is known as accuracy.
- Response: the quickness with which an instrument responds to a change in the output signal is known as response.
- Sensitivity: The sensitivity measures how much change is caused in the output bysmall changes to the reference input.

CLASSIFICATION OF CONTROL SYSTEM:

OPEN LOOP CONTROL SYSTEM

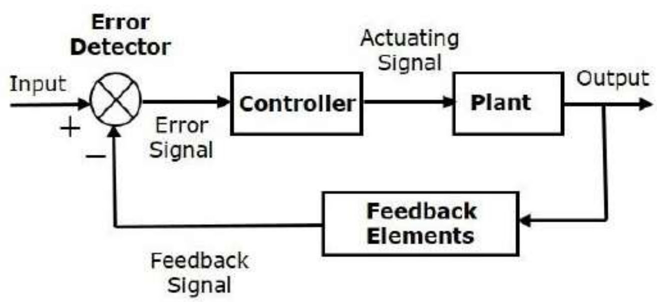


The term open-loop comes from the fact that the fact that the output only depends on the inputs. This is a complete system by itself. The control system takes the input from the controller in order to produce output by the action of the plant. The relation between the input and output are mentioned in terms of transfer function, which is defined as the ratio between the Laplace transform of the output and the Laplace transform of the input. If the output is proportional to the input, the plant is called a linear system.

In a basic open-loop control system the controller takes the reference input called setpoint and outputs a control signal to the plant or process. This configuration is also called feed-forward open-loop control system. The controller is designed and turned using accurate model of the plant. Any inaccuracy in the system model results discrepancy in the desired output response.

1.1.1 <u>CLOSED LOOP CONTROL SYSTEM</u>

A closed-loop control system, on the other hand, uses input as well



as some portion of the output to regulate the output. Closed-loop systems are also called feedback control system. In feedback control the variable required to be controlled is measured. This measurement is compared with a given setpoint. If the error results, the controller takes this error and decides what action should be taken to compensate to remove the error. Errors occur when an operator changes the setpoint intentionally or when a process load changes the process variable accidentally. The error could be positive or negative.

ACTUATOR

What is an Actuator?

- An actuator is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve. In simple terms, it is a "mover".
- An actuator requires a control signal and a source of energy. The control signal is relatively low energy and may be electric voltage or current,

pneumatic or hydraulic pressure, or even human power. Its main energy source may be an electric current, hydraulic fluid pressure, or pneumatic pressure. When it receives a control signal, an actuator responds by converting the signal's energy into mechanical motion.

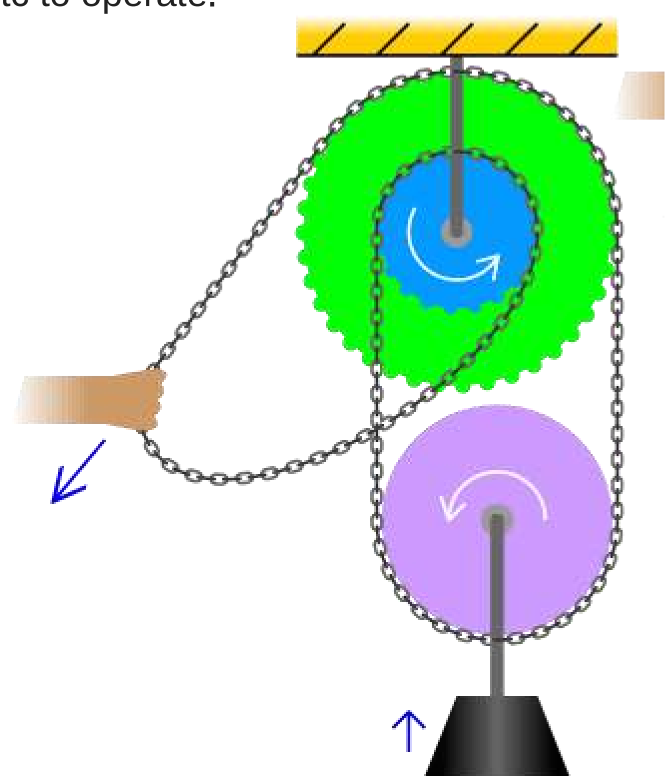
- An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple (a fixed mechanical or electronic system), software-based (e.g. a printer driver, robot control system), a human, or any other input.

Different Types of Actuators

- Mechanical Actuator
- Pneumatic Actuator
- Hydraulic Actuator
- Electrical Actuator
- Hybrid Actuator

Mechanical Actuator:

In mechanical actuators normally a rotary motion is converted into linear motion to perform an operation. Such actuator normally involves gears, rails, pulley, chain, springs etc to operate.



A basic example of a mechanical actuator is chain block hoisting weight in which mechanical motion of chain over the sprocket is utilized to lift a rated load.

Pneumatic Actuator:

Pneumatic energy is most commonly used for actuators used for main engine controls. In this type, compressed air at high pressure is used which converts this energy into either linear or rotary motion.

A pneumatic actuator converts energy formed by vacuum or compressed air at high pressure into either linear or rotary motion. Pneumatic energy is desirable for main engine controls because it can quickly respond in starting and stopping as the power source does not need to be stored in reserve for operation. Moreover, pneumatic actuators are safer, cheaper, and often more reliable and powerful than other actuators.

Pneumatic actuators enable considerable forces to be produced from relatively small pressure changes. These forces are often used with valves to move diaphragms to affect the flow of liquid through the valve.

Hydraulic Actuator:

Unlike air, liquid cannot be compressed and hence hydraulics generates higher energy than any other system. All systems involving high loads are operated by hydraulic actuators in which oil pressure is applied on mechanical actuator to give an output in terms of rotary or linear motion.

A hydraulic actuator consists of cylinder or fluid motor that uses hydraulic power to facilitate mechanical operation. The mechanical motion gives an output in terms of linear, rotatory or oscillatory motion. As liquids are nearly impossible to compress, a hydraulic actuator can exert a large force. The drawback of this approach is its limited acceleration.

The hydraulic cylinder consists of a hollow cylindrical tube along which a piston can slide. The term *single acting* is used when the fluid pressure is applied to just one side of the piston. The piston can move in only one direction, a spring being frequently used to give the piston a return stroke. The term *double acting* is used when pressure is applied on each side of the piston; any difference in pressure between the two sides of the piston moves the piston to one side or the other.

Electrical Actuator:

It is one of the cleanest and readily available forms of actuating system as it does not involve oil; as there is no need to compress air, hence no extra machinery. Electrical energy is always available on ship. The electrical energy is used to actuate a mechanical system using magnetic field i.e. EMF. Basic example are electrical motor operated valve and magnetic valve actuator or solenoid valve.

An electric actuator is powered by a motor that converts electrical energy into mechanical torque. The electrical energy is used to actuate equipment such as multi-turn valves. Additionally, a brake is typically installed above the motor to prevent the media from opening valve. If no brake is installed, the actuator will uncover the opened valve and rotate it back to its closed position. If this continues to happen, the motor and actuator will eventually become damaged.[6] It is one of the cleanest and most readily available forms of actuator because it does not directly involve oil or other fossil fuels.

Hybrid Actuators:

These are mixture of some of the above systems which control the mechanical part of the system. Common example is a thermo hydraulic Electronic actuator used in operating valves in hot water system, wherein hot water liquid is used along with electronic system acting as control for the valve

Examples of actuators

- Comb drive
- Digital micromirror device
- Electric motor
- Electroactive polymer
- Hydraulic cylinder
- Piezoelectric actuator
- Pneumatic actuator
- Screw jack
- Servomechanism
- Solenoid
- Stepper motor
- Shape-memory alloy
- Hydraulic actuators

Performance metrics

Performance metrics or actuators include speed, acceleration, and force (alternatively, angular speed, angular acceleration, and torque), as well as energy efficiency and considerations such as mass, volume, operating conditions, and durability, among others.

- **Force**

When considering force in actuators for applications, two main metrics should be considered. These two are static and dynamic loads. Static load is the force capability of the actuator while not in motion. Conversely, the dynamic load of the actuator is the force capability while in motion.

- Speed

Speed should be considered primarily at a no-load pace, since the speed will invariably decrease as the load amount increases. The rate the speed will decrease will directly correlate with the amount of force and the initial speed.

- **Operating conditions**

Actuators are commonly rated using the standard IP Code rating system. Those that are rated for dangerous environments will have a higher IP rating than those for personal or common industrial use.

- **Durability**

This will be determined by each individual manufacturer, depending on usage and quality.

ACTUATING DEVICES

Actuating devices in access control systems directly reduce or give access towards different areas of controlled territory or the object. Steered latches, locks, turnstiles of different variants, elevators, entrance security cabins, automatic gates and lots of others are used as actuating devices. Control of actuating devices is fulfilled by the controllers of access control system. The selection of actuating device depends upon the object's type, upon the equipment's service conditions, specifics of the mode and upon security requirements on the object. Depending upon these and some other factors the variant of actuating devices' access control system can differ a lot.

- **Electromechanical locks and latches**

Electromechanical locks and latches operate quite simply. In electromechanical catchers the electromagnet is used, which under tension drags the locking device enabling opening of the door. In powerful locks of vault type special electric drive is used for opening-closing of the locking pins. If building object is planned to be equipped by the access control system electromechanical locks should be better used as actuating devices. In case of fitting put of the operating object electromechanical latches should be better chosen, which can be utilized alongside with already installed locking devices.

- **Electromagnetic locks**

Electromagnetic lock is a powerful magnet installed on the doorframe and a metal plate fixed on the door. The electromagnet is supplied by electric hold-on current; it attracts and holds the door with the plate.

Electromagnets used in electromagnet locks can have retentivity power up to one ton and more. While door-open signal injection electromagnet power is switched off and the door can be freely opened. Doors with electromagnetic locks should be by all means equipped by the door closers for resetting into initial position.

- **Turnstiles**

Turnstile is a revolute system for access control to the secured territory. Turnstiles thanks to their construction have high throughput efficiency; that is why they are installed in places of mass pass onto enclosed territory – checkpoints, railway/metro line stations and i.e. In ordinary state the turnstile blocks the passage, while open-passage signal injection the turnstile can freely rotate about its axis enabling the pass onto the territory of the object.

There are half- and full-length turnstiles. Half-length turnstiles can be got over, that is why they are used on the objects with low and moderate security requirements and are installed in direct closeness to the watchpost. For important objects full-length turnstiles should be better used, they thoroughly block the passage ability to the territory.

- **Entrance security cabins**

Entrance security cabins like turnstiles are intended for installation in places of mass pass to the secured territory, but entrance security cabins supply intensified security level having at the same time lower flow capacity. Entrance security cabin of a tambour type is the premises with two doors among which only one can remain open.

After entrance to the security cabin, the first door closes and only after controller's access admittance signal the second door opens. Entrance security cabin of the tambour type meets high security requirements but has minimal flow capacity – 8/12 persons per minute.

To increase throughput capacity entrance security cabins of rotary type are used; one rotary door is used in them, reminding turnstile by its construction. Rotary entrance security cabins can meet high security requirements, at the same time their flow capacity is two times higher than entrance security cabins of tambour type-18/22 persons per minute.

To increase efficiency of entrance security cabins variety of certain devices - input metal detectors for weapons disclosure and weighing systems, averting simultaneous passage of more than one person are used in their construction. Entrance security cabins are manufactured of armor-coated glass or of the metal.

- **Elevators**

Elevators are also used as one of the variants of actuating devices in access control systems. Elevator is an entrance security cabin by its essence from which a person can get only to those floors where he has access authorization. Elevator's stop on another floors and door opening is forbidden by access control system.

- **Automatic gates and turnstiles**

Automatic **gates and turnstiles** are used for limitation of free automobile transport movement. Automatic turnstiles of different constructions as well as automatic gates of various versions – swinging, sliding, upward acting gates and roller shutters are used for this purpose. On the ordinary objects gates or turnstiles are enough means for transport's encroachment restriction to the enclosed territory. On the objects with high security level anti-ram barriers for emergency automobile braking are used further to the gates and turnstiles.

- Other examples
- Video surveillance systems
- Perimeter security systems
- Alarm systems
- Access control systems
  - Actuating devices
  - Controllers
  - Entryphones
  - Keys and readers

Real time interfacing: Introduction, Element of a Data Acquisition and control system, overview of the I/O process. Installation of the I/O card and software.

Real time interface

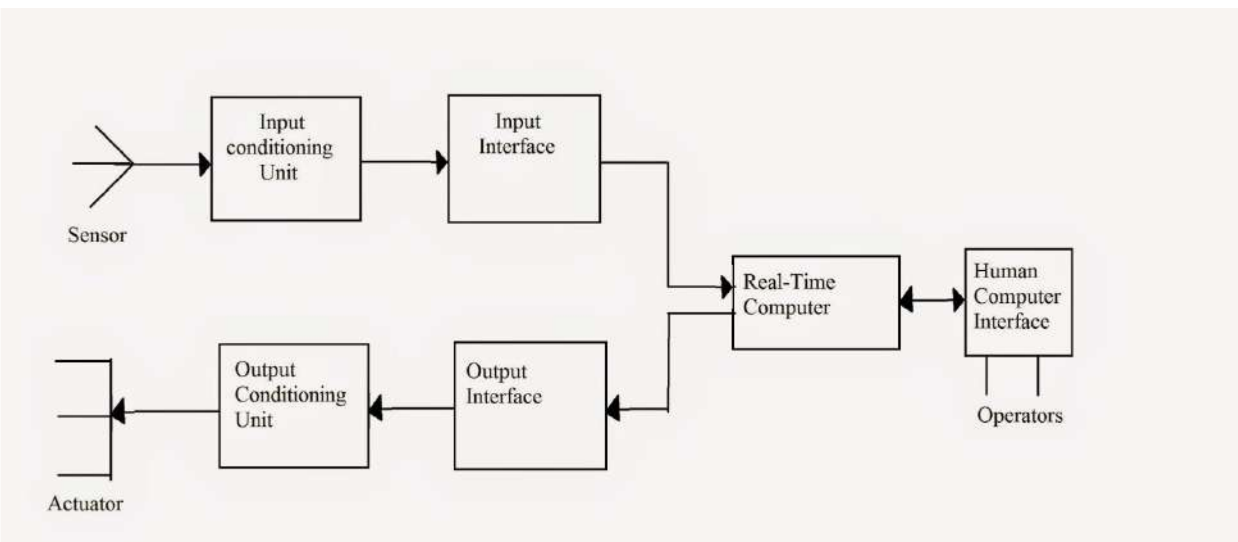
- What is real time?

- Real-time is a quantitative notion of time. Real-time is measured using a physical (real) clock.

- In contrast to real time, logical time (also known as virtual time) deals with a qualitative notion of time and is expressed using event ordering relations such as before, after, sometimes, eventually, precedes, succeeds, etc.

- A system is called a real-time system, when we need quantitative expression of time (i.e. real-time) to describe the behavior of the system.

Basic model of RTI



- **<u>Sensor:</u>** converts some physical characteristic of its environment into electrical signals. An example of a sensor is a photo-voltaic cell which converts light energy into electrical energy. A wide variety of temperature and pressure sensors are also used. A temperature sensor typically operates based on the principle of a thermocouple.

- **Actuator:** Device that takes its inputs from the output interface of a computer and converts these electrical signals into some physical actions on its environment.

  Physical actions :- motion, change of thermal, electrical, pneumatic, or physical characteristics of some objects.

  Eg:- motor

  Signal Conditioning Units:

  Electrical signals produced by a computer can rarely be used to directly drive an actuator. The computer signals usually need conditioning before they can be used by the actuator. This is termed output conditioning. Input conditioning is required to be carried out on sensor signals before they can be accepted by the computer.

  -Important types of conditioning carried out on raw signals generated by sensors and digital signals generated by computers

  1. Voltage amplifier
  2. Voltage level shifting
  3. Frequency range shifting and filtering
  4. Signal mode conversion

- **Interface Unit:** Normally commands from the CPU are delivered to the actuator through an output interface. An output interface converts the stored voltage into analog form and then outputs this to the actuator circuitry. This of course would require the value generated to be written on a register

Characteristics

- Time constraints
- New Correctness Criterion
- Embedded
- Safety-Criticality
- Concurrency
- Distributed and Feedback Structure
- Task criticality
- Custom hardware
- Reactive
- Stability
- Exception handling

Types of real time task

- A real-time task can be classified into
  - ✓ Hard real-time task
  - ✓ Soft real-time task
  - ✓ Firm real-time task

Hard Real-Time Tasks

A hard real-time task is one that is constrained to produce its results within certain predefined time bounds. The system is considered to have failed whenever any of its hard real-time tasks does not produce its required results before the specified time bound.

Firm Real-Time Tasks

Every firm real-time task is associated with some predefined deadline before which it is required to produce its results. 1.7.3. Soft Real-Time Tasks

Soft real-time tasks also have time bounds associated with them. However, unlike hard and firm real-time tasks, the timing constraints on soft real-time tasks are not expressed as absolute values. Instead, the constraints are expressed either in terms of the average response times required.

Applications

- Industrial Applications

Example 1: Chemical Plant Control

Chemical plant control systems are essentially a type of process control application. In an automated chemical plant, a real-time computer periodically monitors plant conditions.

Example 2: Automated Car Assembly Plant

Ex-3 Medical

Robot Used in Recovery of Displaced Radioactive Material

Ex-4 Peripheral equipments

Ex 5: Laser Printer

Ex-6. Internet and Multimedia Applications video conferencing

Elements of data acquisition

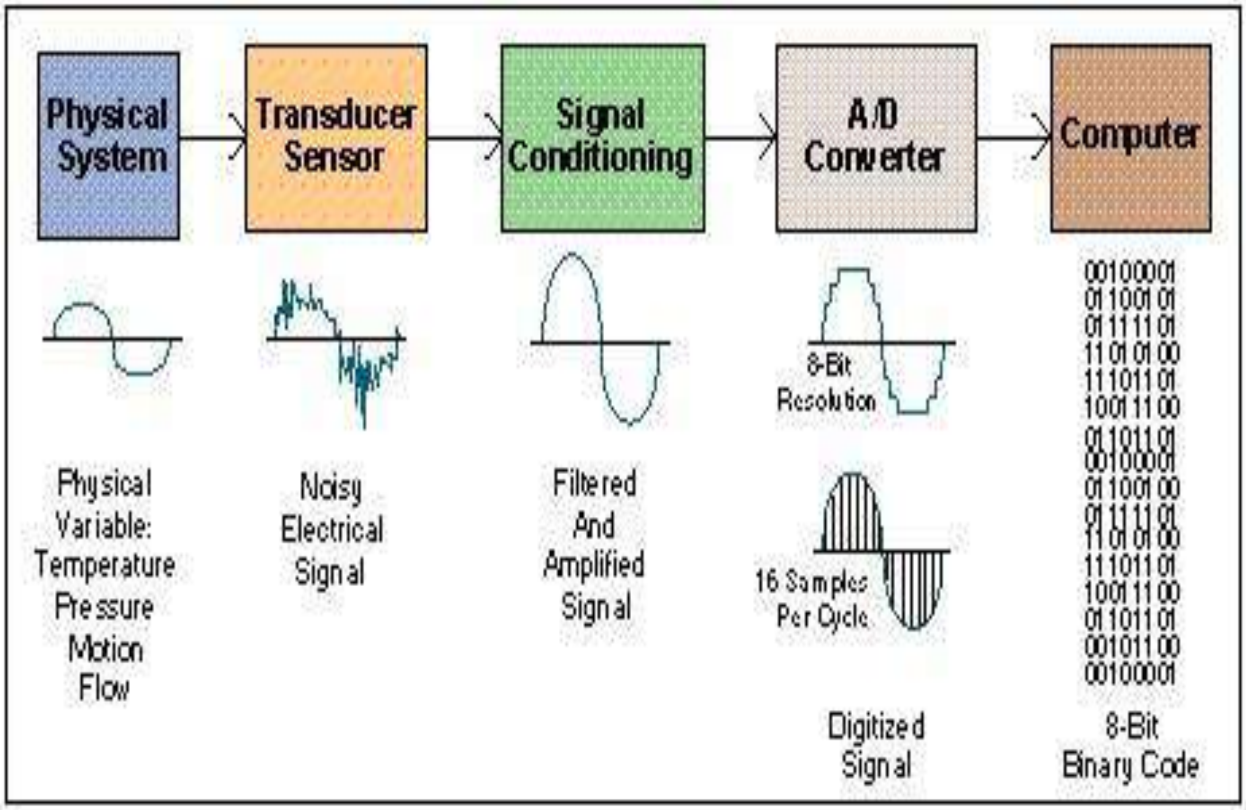
- What is Data acquisition?

Data acquisition systems are used by most engineers and scientists for laboratory research, industrial control, test and measurement to input and output data to and from a computer.

Elements

- Sensor
- Signal conditioning
- Analog input(A/D) board

- Computer
- Output interface



DAQ BLOCK DIAGRAM

<u>Sensor</u>

Measures physical variables such as temperature, strain, flow force and motion

<u>Signal conditioning:-</u>

To convert sensor outputs into signals readable by analog input board (A/D) in the PC

<u>Analog Input (A/D) board:-</u>

- Converts these signals into digital format usable by PC

<u>Computer</u>:

- A computer with appropriate software to process, analyze and lock the data to the disk. Such software may also provide a graphical display of the data.
- Output Interface:
- Provides an appropriate process control response

Module-Iv

Application of software in Mechatronics: Advance application in Mechantronics. Sensors for conditioning Monitoring, Mechatronic Control in Automated Manufacturing, Micro sensors in Mechatronics. Case studies and examples in Data Acquisition and control. Automated manufacturing etc.

Application of software in Mechatronics

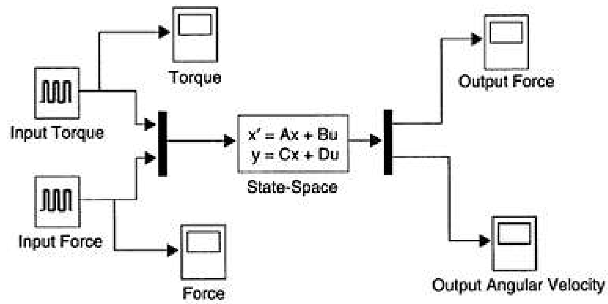
- Modelling, analysis, design, data acquisition, and control are important activities within the field of Mechatronics.
- Computer software tools and environments are available for effectively carrying out, both at the learning level and at the professional application level.
- MATLAB is an interactive computer environment with a high-level language and tools for scientific and technical computation, modelling and simulation, design, and control of dynamic systems.
- SIMULINK is a graphical environment for modelling, simulation, and analysis of dynamic systems, and is available as an extension to MATLAB.

- LabVIEW is graphical programming language and a program development environment for data acquisition, processing, display, and instrument control.
- Simulink provides a graphical environment for modeling, simulating, and analyzing linear and nonlinear dynamic systems. First a suitable block diagram model of the system is developed on the computer screen, and stored.
- The SIMULINK environment provides almost any block that is used in a typical block diagram. These include transfer functions, integrators, gains, summing junctions, inputs (i.e., source blocks), and outputs (i.e., graph blocks or scope blocks).
- Such a block may be selected and inserted into the workspace as many times as needed, by clicking and dragging using the mouse. These blocks may be connected as required, using directed lines.
- A block may be opened by clicking on it, and the parameter values and text may be inserted or modified as needed. Once the simulation block diagram is generated in this manner, it may be run and the response may be observed through an output block (graph block or scope block).
- There are two types of elements in SIMULINK: blocks and lines. Blocks are used to generate (or input), modify, combine, output, and display signals. Lines are used to transfer signals from one block to another.

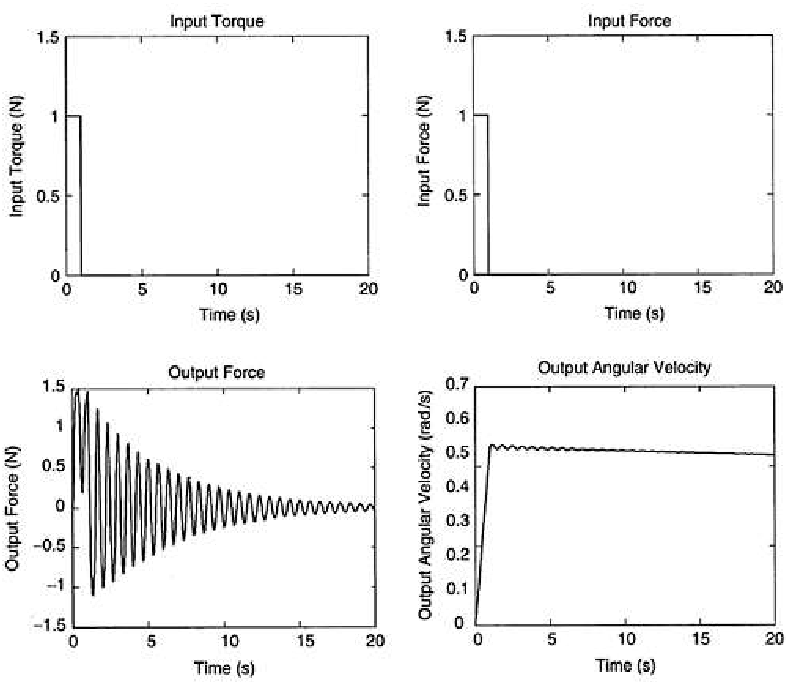
Starting Simulink

- First enter the MATLAB environment. You will see the MATLAB command prompt >>. To start SIMULINK, enter the command: simulink. Alternatively, you may click on the “Simulink” button at the top of the MATLAB command window.
- <u>Basic Elements:-</u>
- There are two types of elements in SIMULINK: blocks and lines. Blocks are used to generate (or input), modify, combine, output, and display signals. Lines are used to transfer signals from one block to another.
- <u>*Blocks:-*</u>
- The subfolders below the SIMULINK folder show the general classes of blocks available for use. They are
- • Continuous: Linear, continuous-time system elements (integrators, transfer functions, state-space models, etc.)
- A signal can be either a scalar signal (single signal) or a vector signal (several signals in parallel). The lines used to transmit scalar signals and vector signals are identical; whether it is a scalar or vector is determined by the blocks connected by the line.

a)SIMULINK model of a robotic sewing machine



(a)



(b)

(b) Simulation results.

MATLAB:

- ❖ MATLAB interactive computer environment is very useful in computational activities in Mechatronics.
- ❖ Computations involving scalars, vectors, and matrices can be carried out and the results can be graphically displayed and printed.
- ❖ MATLAB toolboxes are available for performing specific tasks in a particular area of study such as control systems, fuzzy logic, neural network, data acquisition, image processing, signal processing,

system identification, optimization, model predictive control, robust control, and statistics.

- ❖ Mathematical computations can be done by using the MATLAB command window. Simply type in the computations against the MATLAB prompt “>>” as illustrated next.

An example of a simple computation using MATLAB is given below.

```
>> x=2; y=-3;
>> z=x^2-x*y+4
z=-14
```

MATLAB Arithmetic Operations

Symbol	**Operation**
+	Addition
-	Subtraction
*	Multiplication
/	Division
^	Power

Useful Mathematical Functions in MATLAB

Function	**Description**
abs()	Absolute value/magnitude
acos()	Arc-cosine (inverse cosine)
acosh()	Arc-hyperbolic-cosine
asin()	Arc-sine
atan()	Arc-tan
cos()	Cosine
cosh()	Hyperbolic cosine
exp()	Exponential function
imag()	Imaginary part of a complex number
log()	Natural logarithm
log10()	Log to base 10 (common log)
real()	Real part of a complex number
sign()	Signum function
sin()	Sine
sqrt()	Positive square root
tan()	Tan function

Some Relational Operations

Operator	**Description**
<	Less than
<=	Less than or equal to
>	Greater than
>=	Greater than or equal to
= =	Equal to
~=	Not equal to

- ❖ Basic Logical Operations

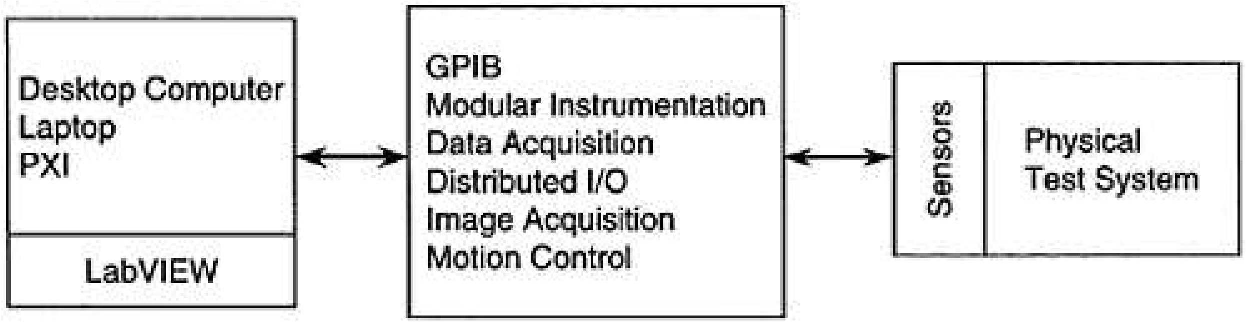
Operator	**Description**
&	AND
|	OR
~	NOT

LABVIEW

- LabVIEW or Laboratory Virtual Engineering Workbench is a product of National Instruments. It is a software development environment for data acquisition, instrument control, image acquisition, motion control, and presentation.
- LabVIEW is a complied graphical environment, which allows the user to create programs graphically through wired icons similar to creating a flowchart.

Working with LabVIEW:-

- As a software centered system, LabVIEW resides in a desktop computer, laptop or PXI as an application where it acts as a set of virtual instruments (VIs), providing the functionality of traditional hardware instruments such as oscilloscopes.
- Comparing to physical instruments with fixed functions, LabVIEW VIs are flexible and can easily be reconfigured to different applications.
- It is able to interface with various hardware devices such as GPIB, data acquisition modules, distributed I/O, image acquisition, and motion control, making it a modular solution.



ADVANCED APPLICATION OF MECHATRONICS

Application areas of mechatronics are numerous, and involve that concern mixed systems and particularly electromechanical systems.

These application may involve:

1.Modification and improvements to conventional designs by using a mechatronics approach.

2.Development and implementation of original and innovative mechatronics system.

In either category, the application will employ sensing, actuation, control, signal conditioning, component interconnection and interfacing, and communication, generally using tools of mechanical, electrical and electronic, computer and control engineering.

- Some important areas of application are indicated below.
  - Transportation
  - Manufacturing and production engineering
  - Medical and healthcare
  - Modern office environment
  - Household application
  - Computer industry
  - Civil engineering
  - Space engineering
  - Military purpose

<u>Transportation:</u>

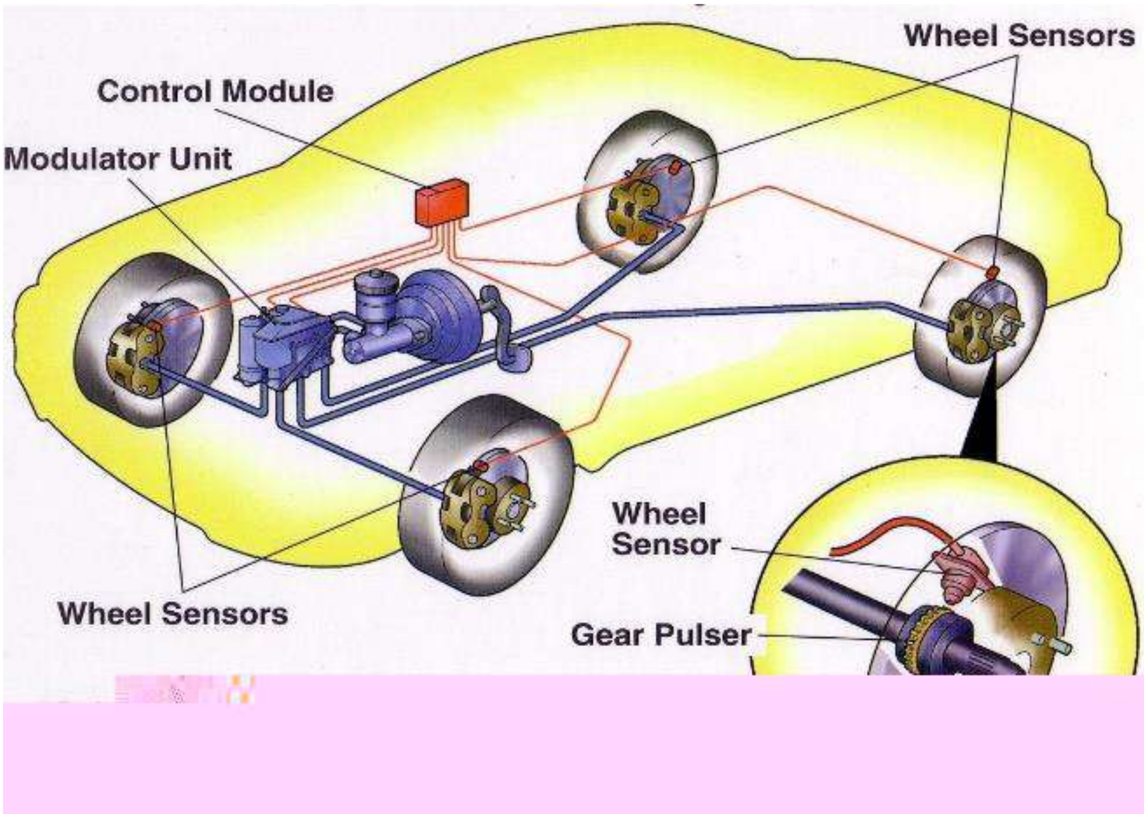
There are two field used in the mechatronics system

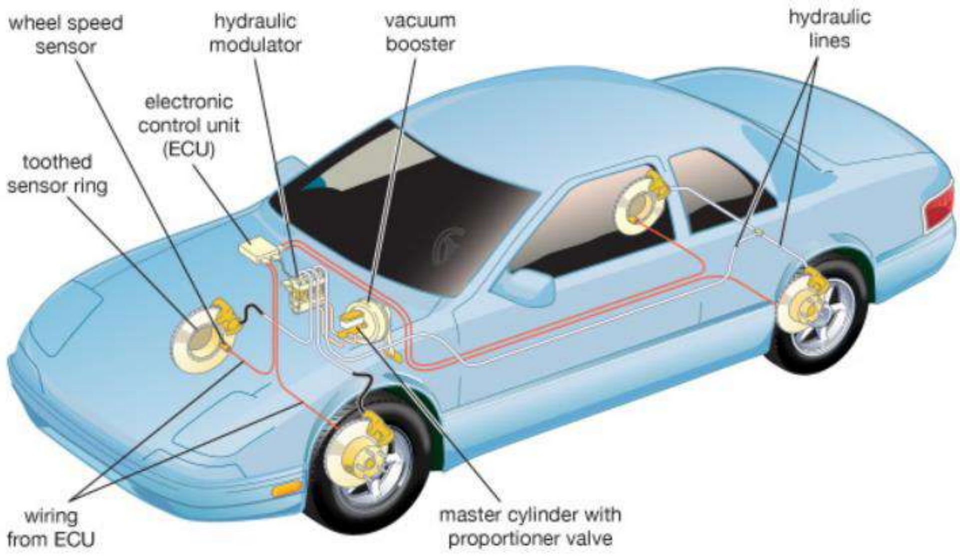
1. Ground transportation
2. Air transportation

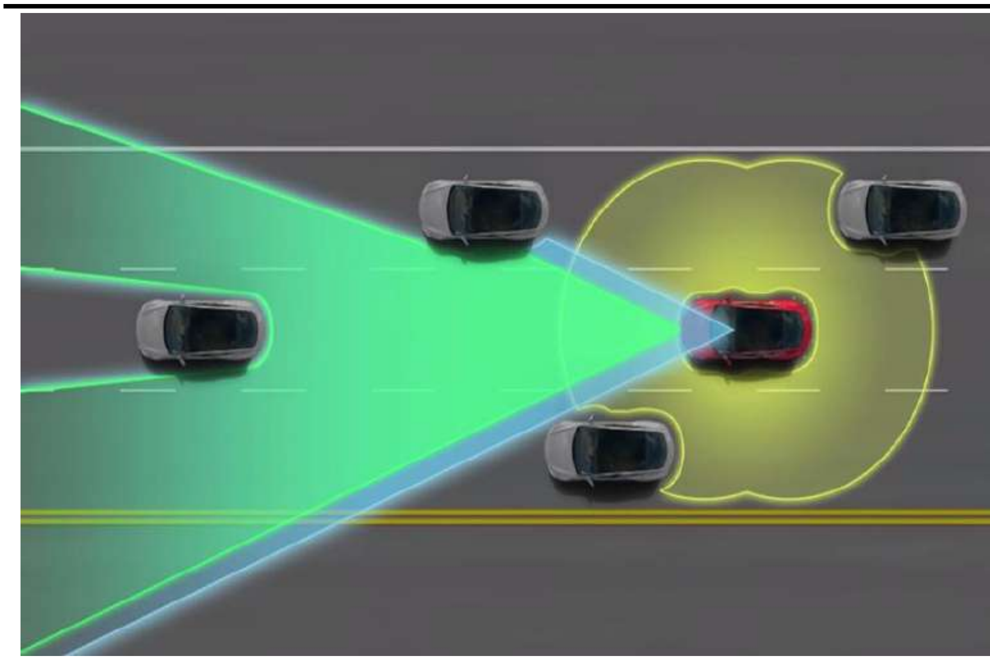
1. Ground transportation:

In ground transportation in particular automobiles, trains, and automated transit systems use mechatronics devices. They include

1. Airbag deployment systems
2 .Antilock braking systems(ABS)
3. Cruise control system
4. Active suspension system
5. Navigation
6. Control in intelligent vehicular highway systems(IVHS)


Wheel Sensors
Control Module
Modulator Unit
Wheel Sensor
Gear Pulser
Wheel Sensors





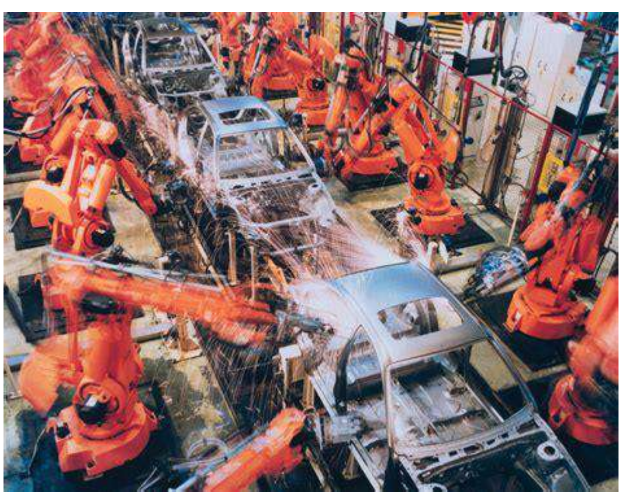
2. Air transportation:

- Modern aircraft designs with advanced materials, structures, electronics, and control benefit from the concurrent and integrated approach of mechatronics to develop improved
    - Designs of flight simulators
    - Navigation systems
    - Flight control system

- Landing gear mechanisms
- Travelers comfort aids

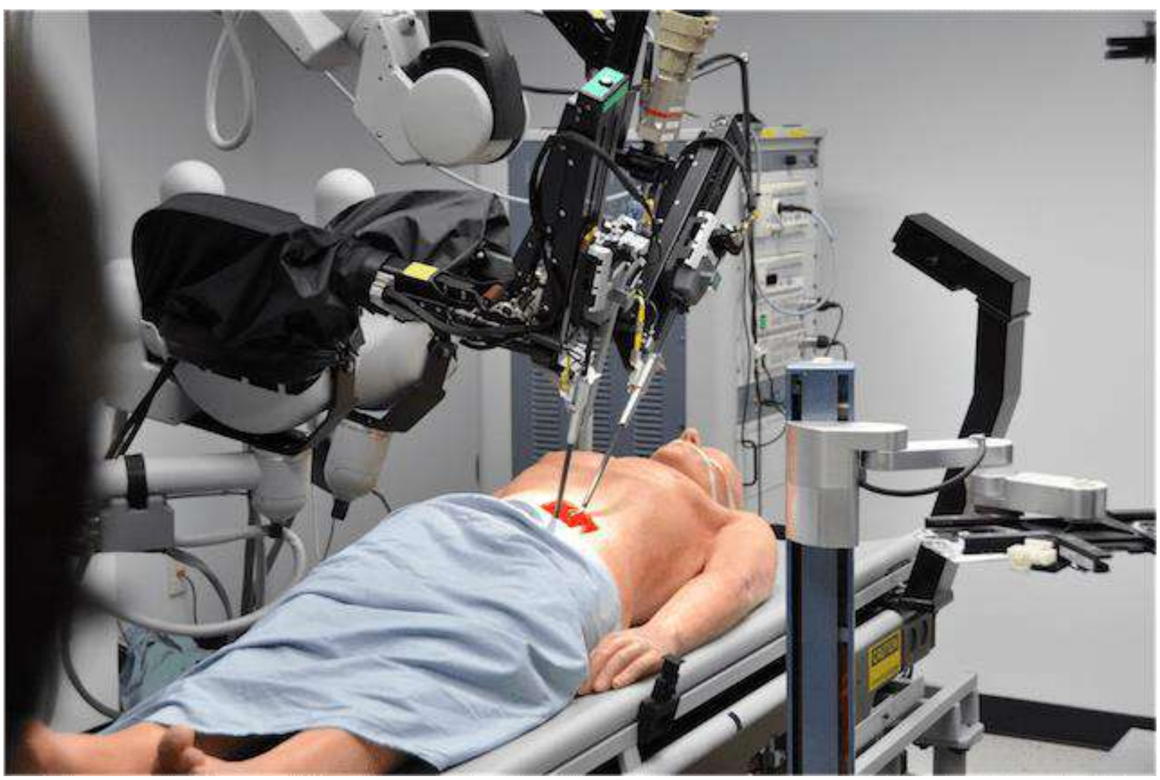
Manufacturing and production engineering:

- Manufacturing And Production Engineering is another broad field that uses mechatronics technologies and systems.
  - Factory robots (for welding, spray painting, assembly, inspection, etc.)
  - Automated guided vehicles(AGVs)
  - Modern computer-numerical control (CNC) machine tolls
  - Machining centre
  - Rapid(and virtual) prototyping systems
  - Micromachining systems



<u>Medical and healthcare;</u>

- General patient care are being developed and used.
  - Patient transit devices
- In medical and healthcare application, robotic technologies for example
  - Surgery
  - Rehabilitation(regain or improve neurocognitive function that has been lost or diminished)
  - Drug dispensing(intermediary drug)
  - Various diagnostic probes
  - Scanners
  - Beds



  - Exercise machines

<u>Modern office environment;</u>

1.Automated filing systems
2.Multi-functional copying machines(perform copying, scanning, printing, fax, etc)
3.Food dispensers
4.Multimedia presentation
5.Meeting rooms
6. Climate control system, incorporate mechatronics technology

<u>Household application;</u>

- In household application,
  - –Home security systems and robots
  - –Vacuum cleaners and robots
  - –Washers
  - –dryers
  - –Dishwashers
  - –Garage door openers
  - –Entertainment canters

Computer industry;

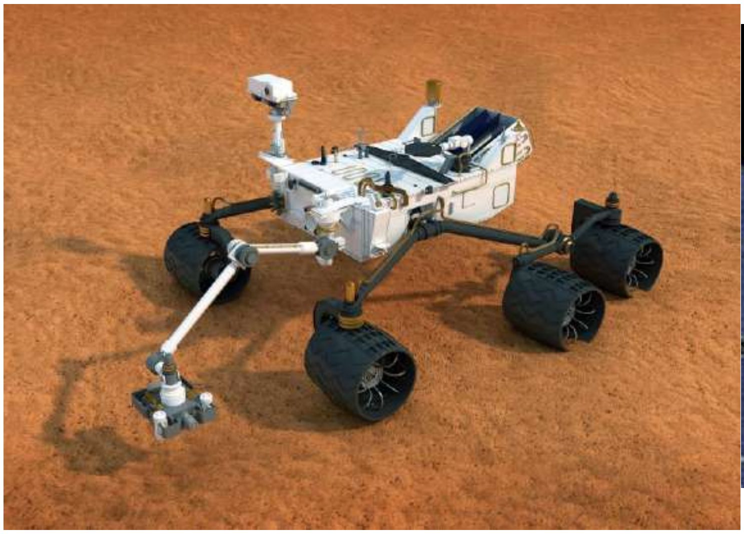
- In this computer industry
  - Hard disk drives(HDD)
  - Disk retrieval ejection devices
  - Cooling fan

Civil engineering;

- In civil engineering application
  - Cranes
  - Excavators
  - Earth removal.
  - Mixing and so on, will improve their performance by adopting a mechatronic design approach

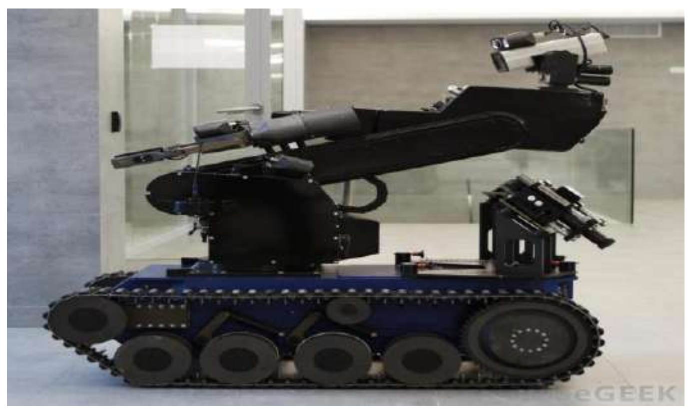
Space application;

- In space application
  - Mobile robots such as NANA’s mars exploration rover
  - Space station robots
  - Space vehicles are fundamentally mechatronics systems



Military Applications:

- In military application
    - Bomb detection robot
    - Surveillance vehicles
    - Drones



Programmable Logic Controller- Block diagram

1. Aim and Objective:

To study of the Programmable Logic Controller.

2. Prerequisites:

Electrical Machines

Power electronics

Control system

Basic C programming

3. Pre Test- MCQ type

1. Construction of BLDC is exactly similar to the _______________
   a) Conventional DC motor
   b) Induction motor
   c) Permanent magnet synchronous motor
   d) Totally different construction

ANSWER: c) Permanent magnet synchronous motor

2. Typical brushless motor doesn't have _______________
   a) Commutator
   b) Permanent magnet
   c) Electronic controller
   d) Fixed armature

ANSWER: a) Commutator

3.PWM DUTY RATIO IS-----------------

a) TON/(TON+TOFF)*100
b) ((TON+TOFF)/TON)*100
c) ((TON+TOFF)/TOFF)*100

ANSWER : TON/(TON+TOFF)*100
4.Advantages of Digital signal processing

a) Fast processing – parallel
b) Guarantee accuracy – no of bits
c) Exact reproduction or repeatability
d) All of the above

ANSWER : d) All of the above

4. Programmable Logic Controller:

4.1. Introduction:

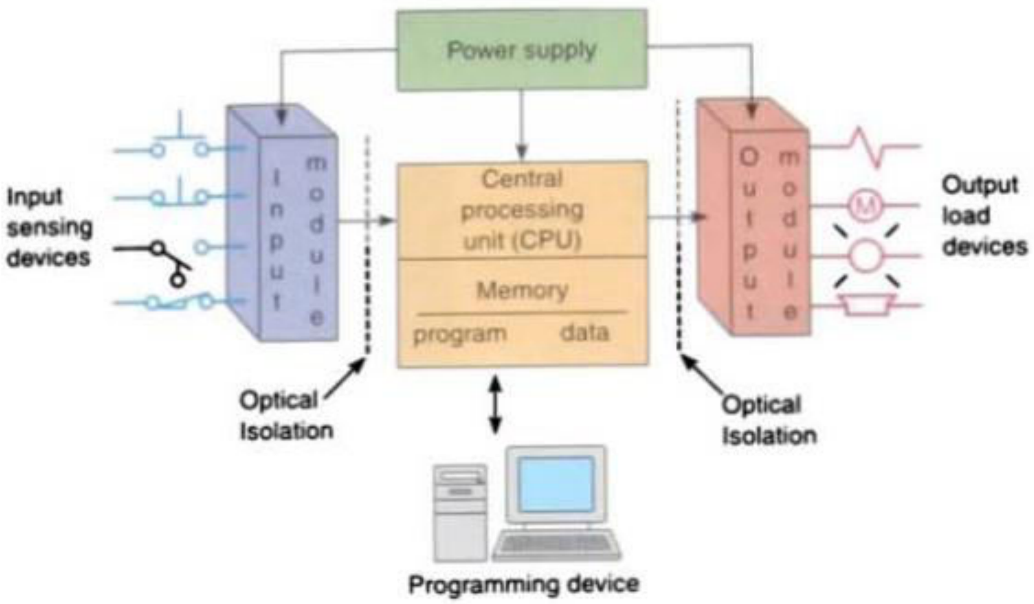
A programmable logic controller (PLC) is a specialized Programmable device which is used to control machines and processes.

It uses a programmable memory to store instructions and execute specific functions that include on/off control, timing, counting, sequencing, arithmetic, and data handling.

Advantages

- *Increased Reliability*
- *More Flexibility*
- *Lower Cost*
- *Communications Capability*
- *Faster Response Time*
- *Easier to Troubleshoot*

4.2 PLC Block diagram



Central Processing Unit

It is heart of the PLC . CPU is used to store the program, reads the status of inputs through the input module and execute the stored program and appropriate output to be activated based on the logic

CPU has two memory section one section used to store the program and other section is used to store the data

Input Module

- The I/O system forms the interface by which field devices are connected to the controller.
- The purpose of this interface is to condition the various signals received from or sent to external field devices.
- Input devices such as pushbuttons, limit switches, sensors. Selector switches. and thumbwheel switches are hardwired to terminals on the input modules.

Output Module

- Output devices such as small motors, motor starters, solenoid valves. and indicator lights are hardwired to the terminals on the output modules.

Programming device

- The programming device is used to enter the desired program into the memory of processor.
- Ladder logic programming language uses instead of words, graphic symbol...
- It is a special language written to make. it easier for people familiar with relay logic control to program

Power Supply

Leading manufacturer for PLC

- Allen Bradley
- ABB
- Siemens
- Mitsubishi PLC
- Hitachi PLC
- Delta PLC
- General Electric (GE) PLC
- Honeywell PLC

4.3Input/Output Module

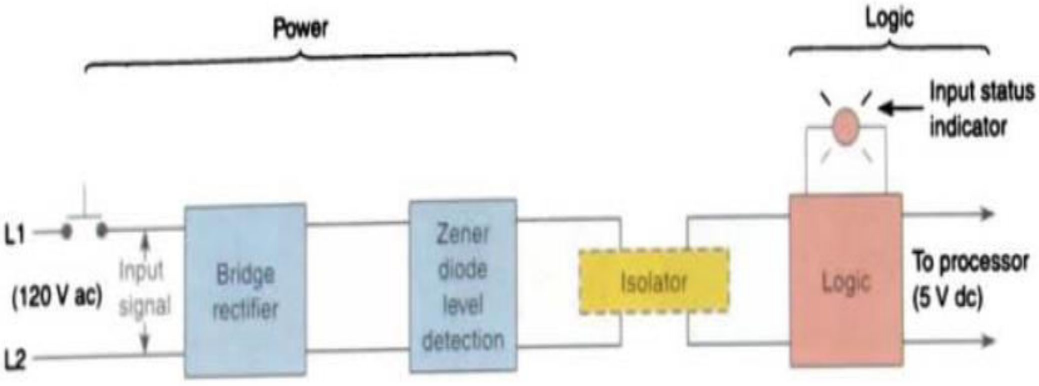
- The I/o system provides an interface between the hardwired components in the field and the CPU.

Input Module
Discrete Input Module

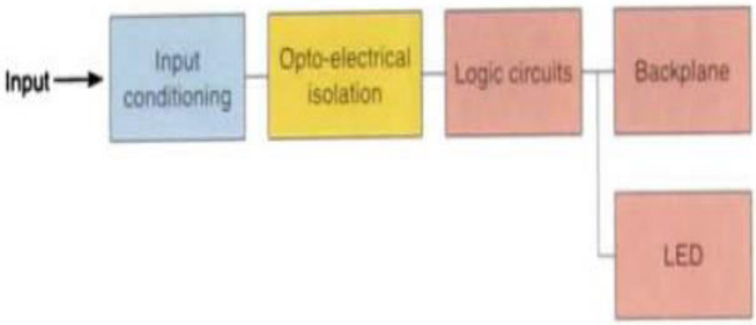
- This type of interface connects field input devices of the ON/OFF nature such as selector switches, pushbuttons and limit switches.
- Likewise, output control is limited to devices such as lights, small motors, solenoids, and motor starters that require simple ON/OFF switching.
- It is interface between the Input field device and CPU of PLC

Input modules perform four tasks in the PLC control system.

- sense when a signal is received from a sensor on the machine
- convert the input signal to the correct voltage level for the particular PLC
- isolate the PLC from fluctuations in the input signal's voltage or current
- send a Signal to the processor indicating which sensor originated the signal



Block diagrams of a discrete input module.



An input filter removes unwanted signal from the electrical interference or key bouncing issue

Opto –electrical isolating section is used to protects the any short circuit fault or high voltage surge from high voltage circuit to logic circuit which normally operated by low voltage

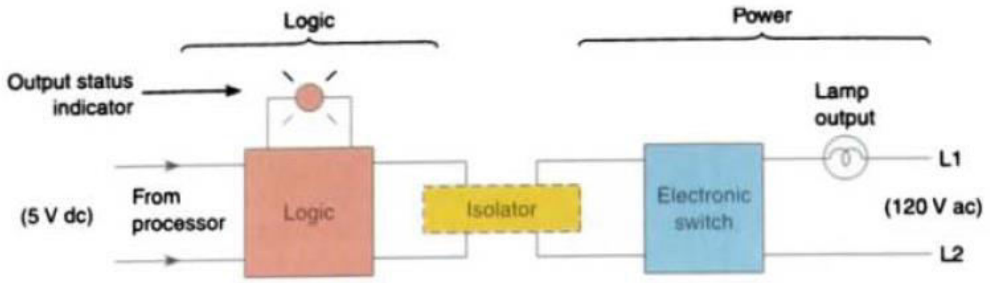
Logic section in the module is used to process the input signal based the pre designed logic and turns ON or OFF the LED

Discrete Output Module

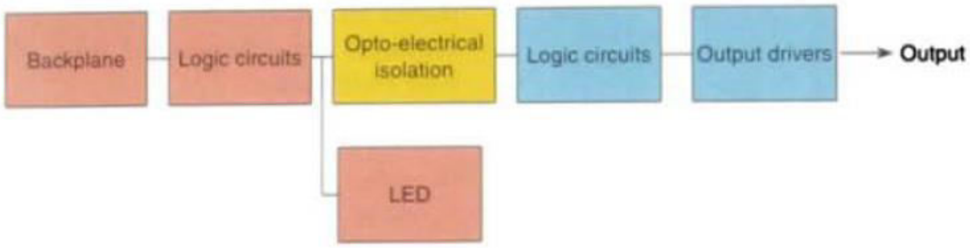
- Discrete output modules typically use the same form of opto-isolation to allow the PLC's computer circuitry to send electrical power to loads:
- it is composed of two basic sections:

  the *power section and* the *logic section , coupled by an isolation* circuit.

- The output interface can be thought of as a simple electronic switch to which power is applied to control the output device.



(a) Block diagram of a discrete output module.



- Discrete output modules are used to turn real world output devices either on or off.
- These modules can be used to control any two-state device. and they are available in ac and dc versions and in various voltage ranges and current ratings.
- Output modules can be purchased with *transistor.* triac. or relay output.
- Triac outputs can be used only for control of ac devices. whereas transistor outputs can be used only for control of dc devices. Relay outputs can be used with ac or dc devices.

Analog I/O Module

- Interface with an analog sensor or control device with CPU of PLC through ADC.
- Analog-to-Digital Converter, circuit designed to convert an analog electrical signal into a multi-bit binary word

- Voltage (0 to 10 volt, 0 to 5 volt)
- Current (0 to 20 mA, 4 to 20 mA)

Thermocouple (millivoltage)

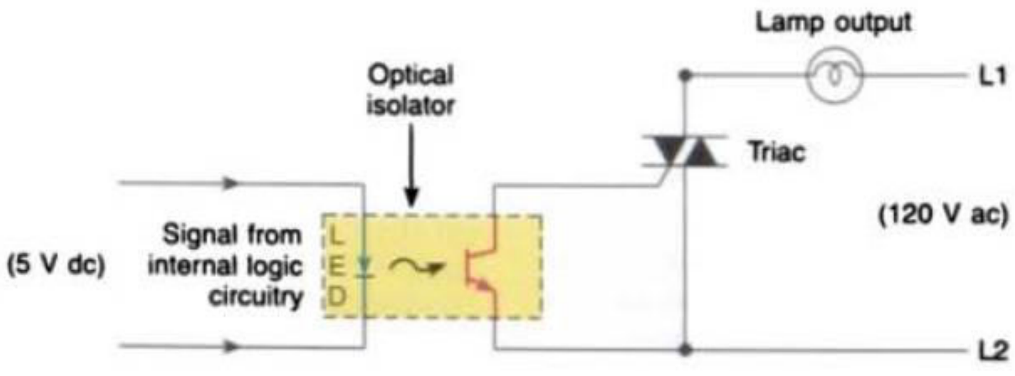
Analog input modules

- *Analog input interface modules contain the* circuitry necessary to accept analog voltage or current signals from analog field devices.
- These inputs are converted from an analog to a digital value by an *analog-lo-digital (AID)* converter circuit.
- The conversion value, which is proportional to the analog signal, is expressed as a 12-bit binary or as a 3-digit binary-coded decimal (BCD) for use by the processor.

  Analog input interface module connection to a thermocouple

- A varying dc voltage in the millivolt range. proportional tothe temperature being monitored. is produced by the thermocouple.
- This voltage is amplified and digitized by the analog input module and then sent to the processor on command from a program instruction.
- Because of the low voltage level of the input signal, a shielded cable is used in wiring the circuit to reduce unwanted electrical noise signals that can be induced in the conductors from other wiring.
- This noise can cause temporary operating errors that can lead to hazardous or unexpected machine operation

AC output Module

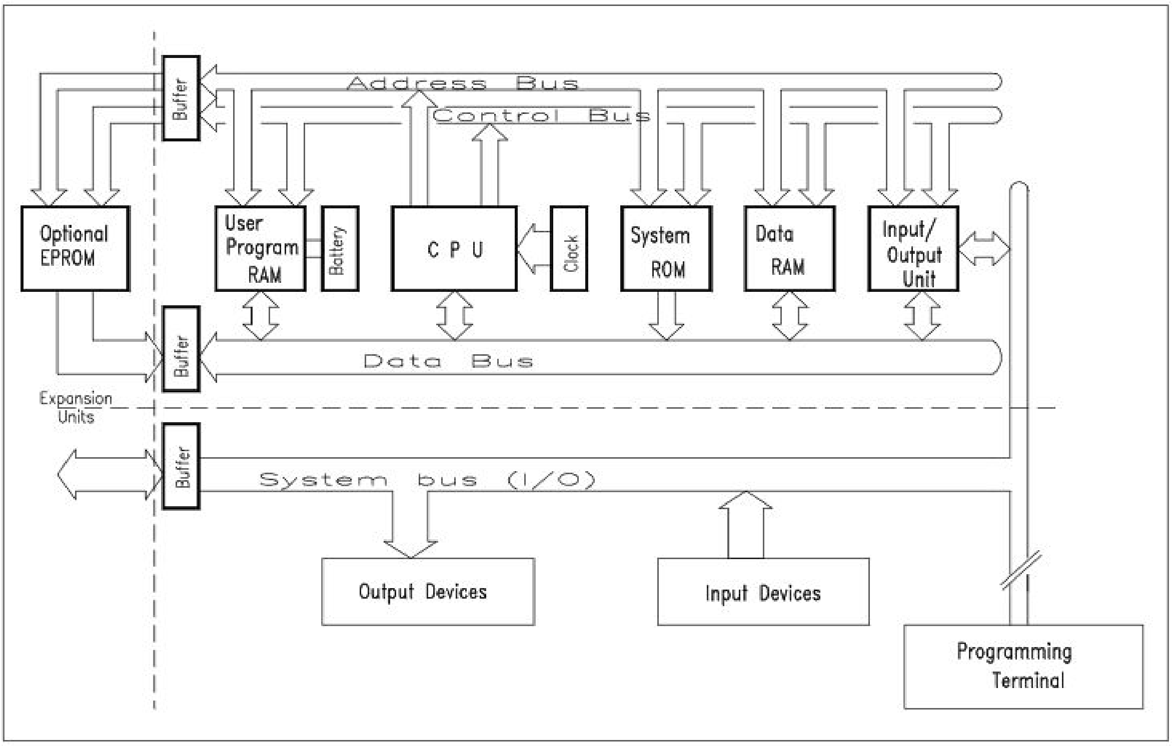


(*a*)

- When the processor calls for an output, a voltage is applied across the LED of the isolator.
- The LED then emits light, which switches the phototransistor into conduction. This in turn (5 V dc)switches the *triode DC semiconductor switch (triac) into conduction. which in turn turns* on the lamp.
- Since the triac conducts in either direction, the output to the lamp is alternating current. The triac, rather than having ON and OFF status. actually has LOW and HIGH resistance levels, respectively.
- In its OFF state (HIGH resistance), a small leakage current of a few milliamperes still flows through the triac.
- As with input circuits, the output interface is usually provided with LEDs that indicate the status of each output.

4.4.CPU Module

- The CPU contains the same type of microprocessor found in a personal computer.
- The difference is that the program used with the microprocessor is designed to facilitate industrial control rather than provide general purpose computing.
- The CPU executes the operating system, manages memory, monitors inputs, evaluates the user logic (ladder program),and turns on the appropriate outputs.
- The CPU of a PLC system may contain more than one microprocessor.
- The advantage of using multiprocessing is that control and communication tasks can be divided up. And the overall operating speed is improved.



Processor operating mode

RUN, PROG, and REM(Remote).

4.5.Power supply Module

- The power supply module is a necessary and important component of the control system.
- It is used to safely regulate and supply the voltage necessary for the PLC and other modules installed on the rack.
- The module is typically installed in the first slot of the rack.
- The output voltage of the power supply that we use is typically 24 volts DC.
- The output current varies depending on the number of the modules needed in the control system.
- For instance, this output current could be 2, 5 or 10 Ampere.

- ❑ Depending on which and how many modules are used, the output current of the power supply may need to be higher.

5.Post test MCQ

Which one of the following is not advantages of PLC

Increased Reliability

less Flexibility

Lower Cost

Easier to Troubleshoot

Which module is used for implementing the logic and controlling the communications among the modules PLC.

Power supply module

Communiation module

Processor module

Input module

The ----------------provides an interface between the hardwired components in the field and the CPU

Communication module

Power supply module

Processor module

Input and Output module

In Discrete output module, Relay outputs can be used control the

AC Devices

DC Devices

Both AC and DC devices.

None of the above

6. Conclusion

The block diagram of Programmable Logic Controller discussed and briefed about the each of the block in details

7. References

1. Gary Dunning, "Introduction Programmable Logic Controllers", CENGAGE Learning, 3rd Ed., 2006.

2. John R. Hackworth, Frederick D. Hackworth Jr., "Programmable Logic Controllers", Pearson, 2004.

3. Bolton, "Programmable Logic Controllers", Elsevier, 4th Ed., 2006.

Assignment

1. Explain the PLC block diagram in detail
2. Describe about the analog input and output module of the PLC
3. Write short about the PLC operation and PLC scan cycle.

Lecture notes for Programmable Logic Controller

Subject Code :

Subject : PLC AND SCADA

Prepared by : S.RAJA, Assistant Professor, Department of EEE

UNIT-2 Basic Programming of PLC

Table of Contents **Page No.**

1. Aim and Objective

    Learn about the programming of the PLC

    Implementation of basic logic gates using ladder programming

2. Prerequisites

    Basic knowledge of logic gates

    PLC block diagram

3. Pre Test- MCQ type

1. The output of the two input NAND gate is high when

a) Only If the both inputs are high
b) Only If the both inputs are low
c) Only If the one input is high other one is low
d) If at least one of the input is low

2. A XOR gate has inputs A and B and output Y. Then the output equation is

a) Y = AB
b) Y = AB + A’ B
c) Y = A’ B + A B’
d) Y = AB + A’ B’

3. A solenoid is an example of an ---------------output device.

a) True
b) False
c)None of the above

4.Which module is used for implementing the logic and controlling the communications among the modules PLC.

a)Power supply module

b) Communication module

c) Processor module

d) Input module

5. Which one of the following is an input device?

a) Motor

b) Light
c) Valve
d) Sensor

4. Basic programming of PLC

The 5 most popular types of PLC Programming Languages are:

- **Ladder Diagram (LD)**
- **Sequential Function Charts (SFC)**
- **Function Block Diagram (FBD)**
- **Structured Text (ST)**

Instruction List (IL)

4.1 Ladder Diagram (LD)

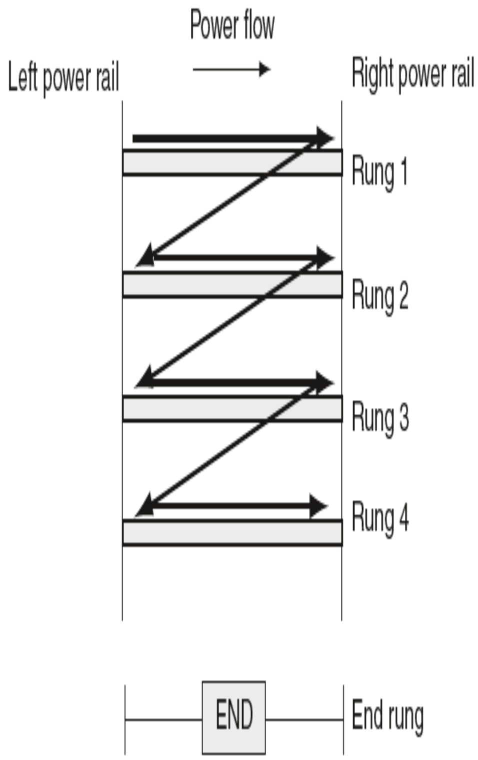
- Ladder logic is the simplest form of PLC programming.
- It is also known as "relay logic". The relay contacts used in relay controlled systems are represented using ladder logic.
- Functional Block Diagram (FBD) is a simple and graphical method to program multiple functions in PLC

Advantages of the Ladder Diagram (LD)

- It is easily programmed and has an easily understood programming language.
- It has flexibility in programming and reprogramming.
- Troubleshooting is easier and faster

Rules to draw the ladder logic diagram

- The ladder diagram consists of two vertical lines representing the power rails.
- Circuits are connected as horizontal lines, i.e., the rungs of the ladder, between these two verticals.



1. The vertical lines of the diagram represent the power rails between which circuits are connected. The power flow is taken to be from the left-hand vertical across a rung.

2. Each rung on the ladder defines one operation in the control process.

3. A ladder diagram is read from left to right and from top to bottom, showing the scanning motion employed by the PLC.

The top rung is read from left to right. Then the second rung down is read from left to right and so on.

4. Each rung must start with an input or inputs and must end with at least one output. The term input is used for a control action, such as closing the contacts of a switch, used as an input to the PLC. The term output is used for a device connected to the output of a PLC, e.g., a motor.

5. Electrical devices are shown in their normal condition. Thus a switch, which is normally open until some object closes it, is shown as open on the ladder diagram. A switch that is normally closed is shown closed.

6. A particular device can appear in more than one rung of a ladder. For example, we might have a relay that switches on one or more devices. The same letters and/or numbers are used to label the device in each situation.

7. The inputs and outputs are all identified by their addresses, the notation used depending on the PLC manufacturer. This is the address of the input or output in the memory of the PLC.

8.The instructions used are the relay equivalent of normally open (NO) and normally closed (NC) contacts and coils.

9.Contact symbolism is a simple way of expressing the control logic in terms of symbols that are used on relay control schematics.

10.A rung is the contact symbolism required to control an output. Some PLCs allow a rung to have multiple outputs.

11.A complete ladder logic program thus consists of several rungs. each of which controls an output.

12.Because the PLC uses ladder logic diagrams. the conversion from any existing relay logic to programmed logic is simple.

13. Each rung is a combination of input conditions (symbols) connected from left to right, with the symbol that represents the output at the far right.

14.The symbols that represent the inputs are connected in series, parallel. or some combination of the two to obtain the desired logic.

15.Because the PLC uses ladder logic diagrams. the conversion from any existing relay logic to programmed logic is simple.

16. Each rung is a combination of input conditions (symbols) connected from left to right, with the symbol that represents the output at the far right.

17.The symbols that represent the inputs are connected in series, parallel. or some combination of the two to obtain the desired logic.

RUNG

- A type of line diagram that uses the input and output symbols used by **PLC** ladder logic.
- Line diagrams are converted to programming diagrams before being entered into a **PLC**

4.2 PLC Instructions

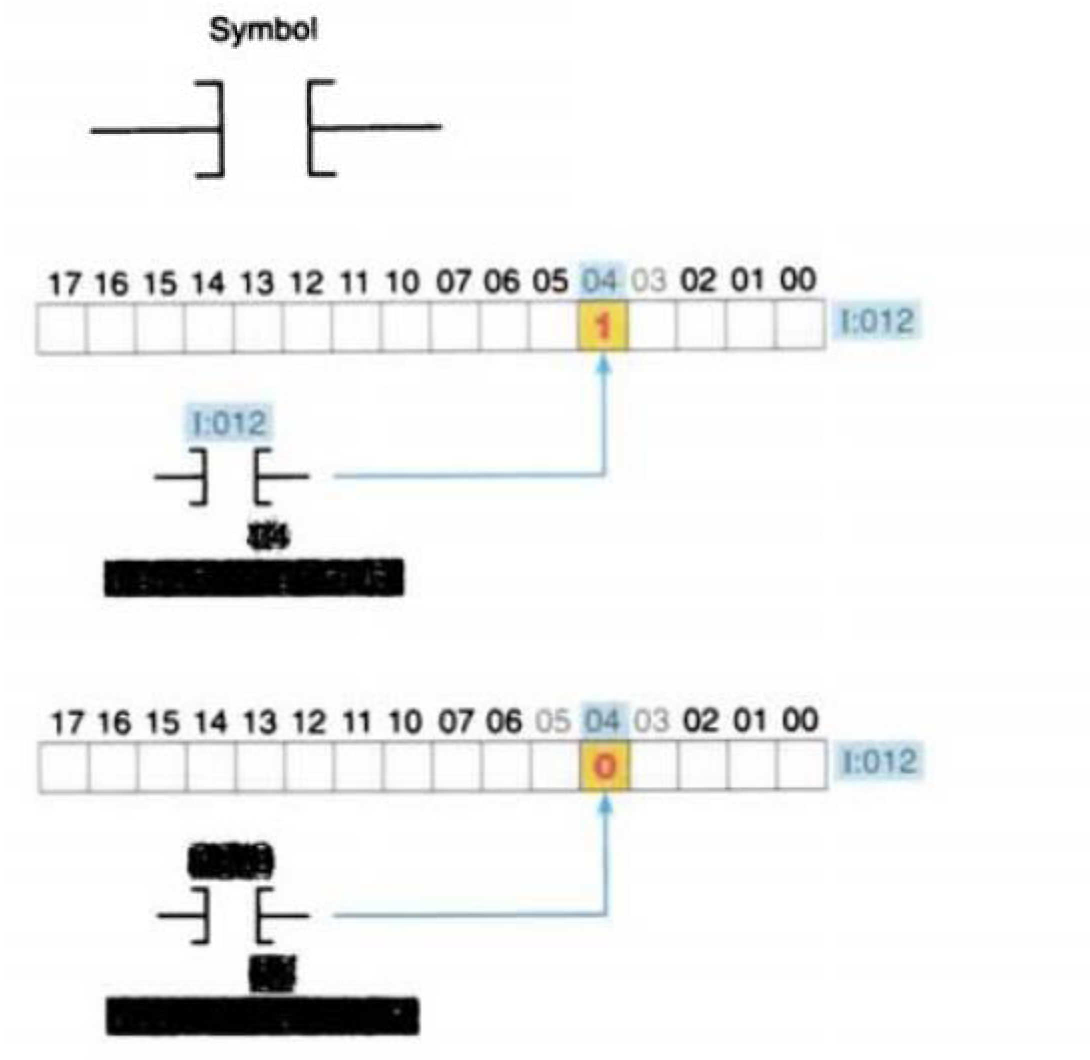
RELAY-TYPE INSTRUCTIONS

- The ladder diagram language is basically a *symbolic set of instructions used to create the con*troller program.
- The three fundamental symbols that are used to translate relay control logic to contact symbolic logic are EXAMINE IF CLOSED,EXAMINE IF OPEN, and OUTPUT ENERGIZE

Normally open

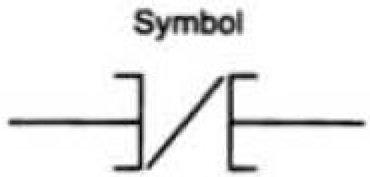
- Analogous to the normally open relay contact. For this instruction.
- we ask the processor to EXAMINE IF (the contact is) CLOSED.
- The status bit will be either1(ON) or 0 (OFF)
- The status bit is examined for an ON condition.
- If the status bit is I (ON). Then the instruction is TRUE.

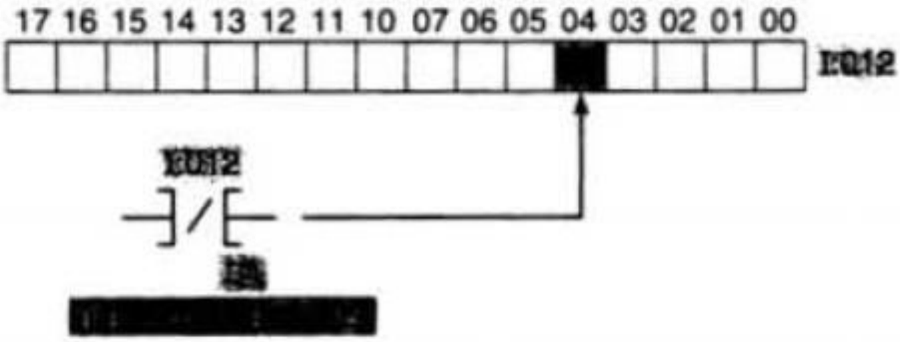
- If the status bit is 0 (OFF). Then the instruction is FALSE.

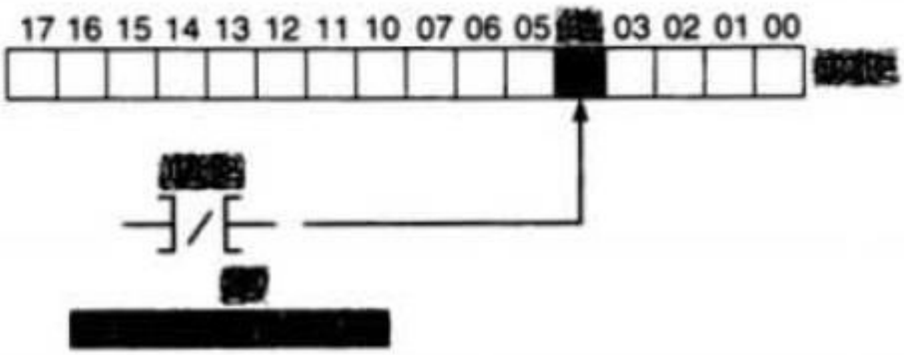


Normally closed

- instruction, we ask the processor to EXAMINE IF (the contact is) OPEN.
- The status bit will be either 1 (ON) or 0 (OFF).
- The status bit is examined for an OFF condition.
- If the status bit is 0 (OFF), then the instruction is TRUE.
- It the status bit is 1 (ON), then the Instruction is FALSE.



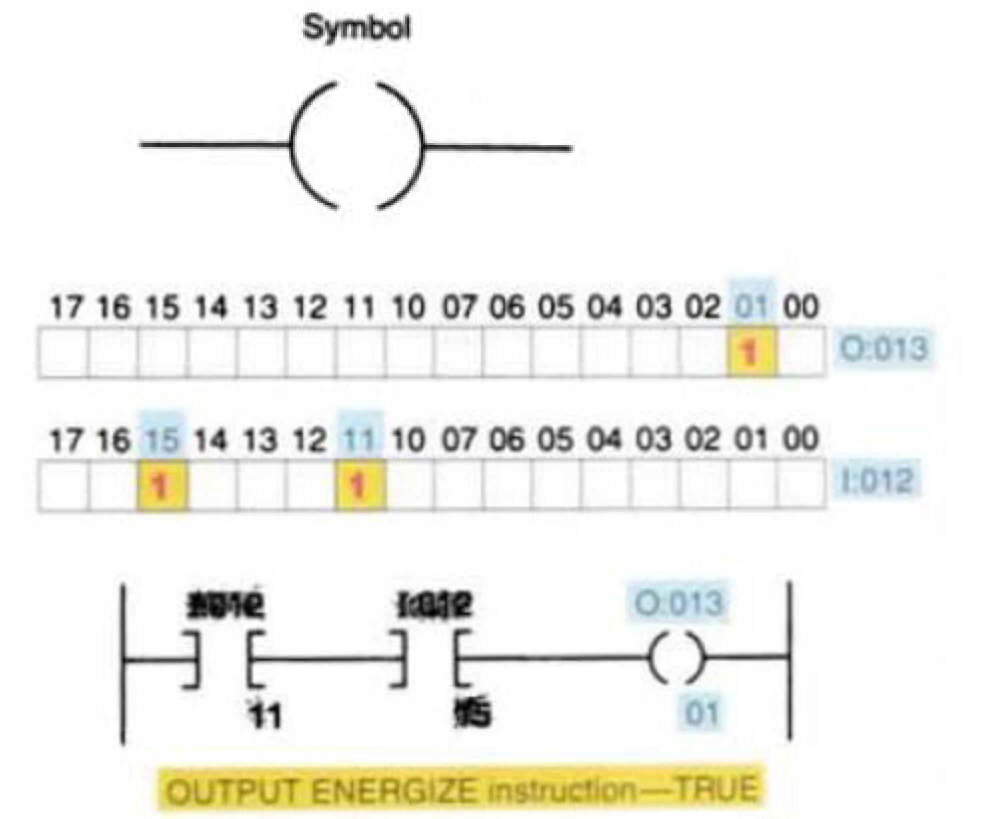




Relay coil (OTE)

- The processor (makes it is Instruction true (analogous to energizing a coil) when there is a path 01 true XIC and XIO instructions in the rung.
- If any left to right path of input conditions is TRUE. the output is energized (turned ON).
- The status bit 01 the addressed OUTPUT Energize instruction is set to 1 (ON) when the rung is TRUE.

- The status bit 01 the addressed OUTPUT Energize instruction is reset 10 0 (OFF) when the rung is FALSE.



Branching instructions

- Branch instructions are used to create parallel paths of input condition instructions.
- This allows more than one combination of input conditions (OR logic) to establish logic continuity in a rung.
- The rung will be true if either instruction A or *B is TRUE.*

Types

1. **Parallel input Branching**

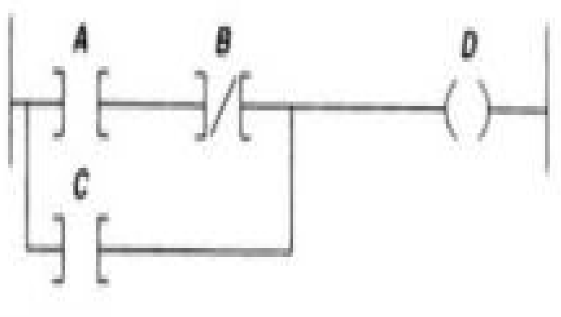
2. Parallel input Branching with Output branching

3. Parallel output branching with input

4. Nested branching

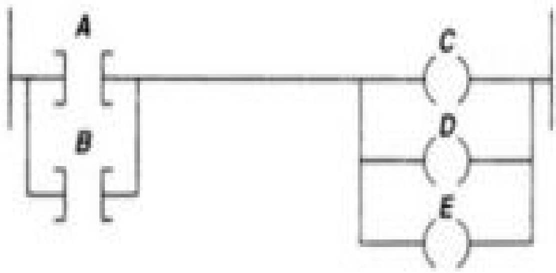
Parallel input Branching

- Input branching by formation of parallel branches can be used in your application program to allow more than one combination of input conditions,
- If at least one of these parallel branches forms a true logic path, the rung logic is enabled.
- If none of the parallel branches forms a true logic path. rung logic is not enabled and the output instruction logic will not be TRUE.
- In the example shown, either A and *B or C pro*vides a true logical path.



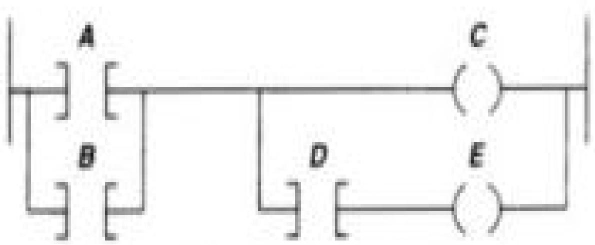
Parallel input Branching with Output branching

- branches can be established at both input and output portions of a rung. With output branching.
- you can Program parallel outputs on a rung to allow a true logic path to control multiple outputs.
- When there is a true logic path. all parallel outputs become TRUE.
- either A or *B* provides a true logical path to all three output instructions: C, D, and *E.*



Parallel output branching with input

- Additional input logic instructions (conditions) can be programmed in the output branches to enhance condition contra) of the outputs.
- When there is a true logic path, including extra input conditions on an output branch. That branch becomes TRUE.
- either *A and D or Band D provide a* true logic path to *E.*



Nested

- Input and output branches can be *nested to* avoid redundant instructions and to speed up processor scan time.
- Input and output branches can be *nested to* avoid redundant instructions and to speed up processor scan time.

4.3. Implementation of logic gates using ladder

AND Logic

It is a basic gate. Whenever the all the input condition must true then output becomes true

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

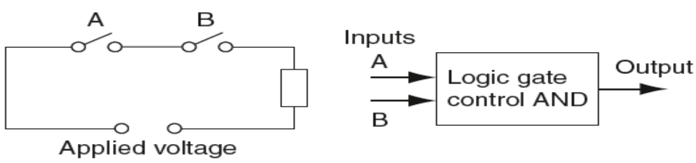


Figure (a)Truth table of the AND logic (b) block diagram of AND logic

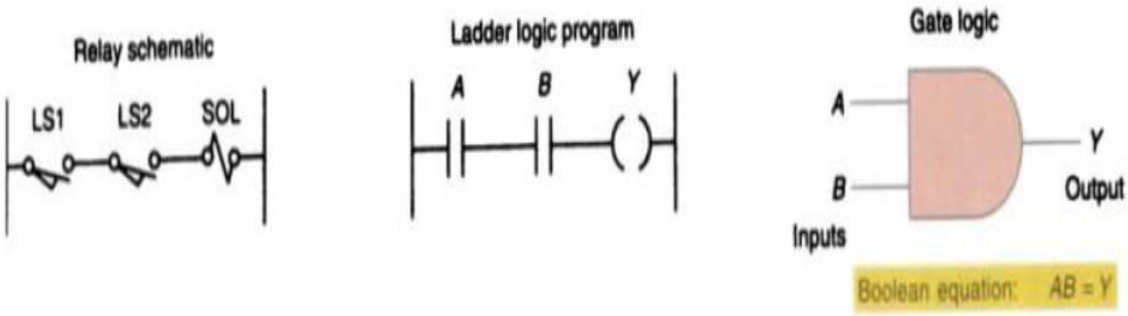
Logic equation

$$Y = A \cdot B$$

or

$$Y = AB$$

Ladder Logic diagram for AND Logic



OR LOGIC

It is basic gate. Whenever any one of the input conditions is true the output becomes true

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

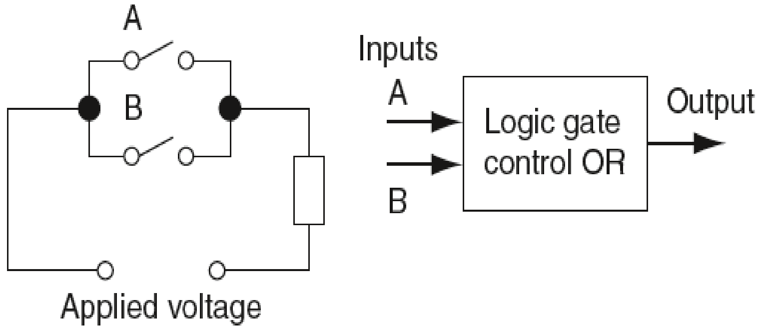
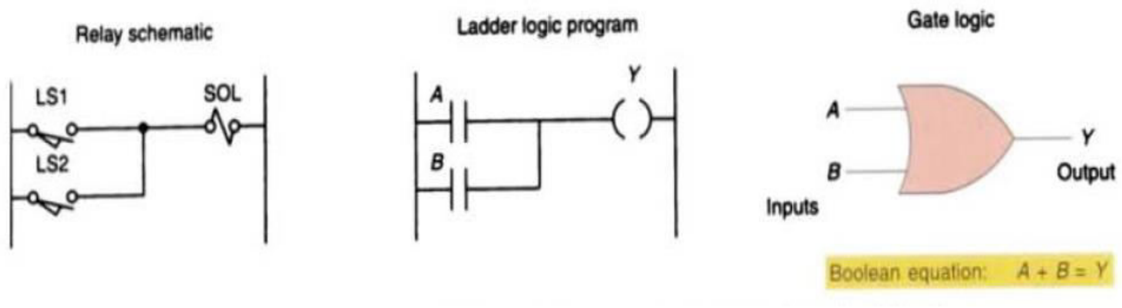


Figure (a)Truth table of the OR logic (b) block diagram of OR logic

Logic equation

$$Y = A+B$$

Ladder logic diagram of the OR logic



- Two limit switches connected in parallel and used to control a solenoid valve.

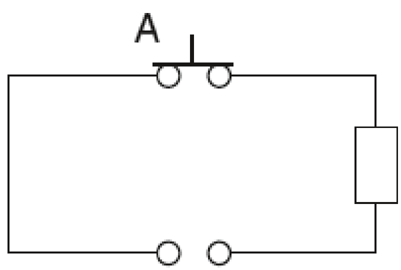
NOT logic

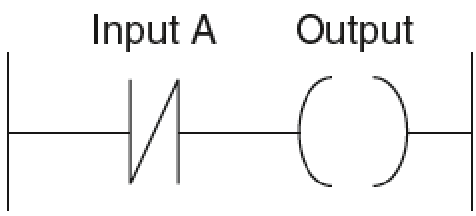
It is one of the basic logic gate output always the complement of input

Truth Table of NOT logic

Input A	Output
0	1
1	0

Ladder logic diagram of NOT logic





NAND LOGIC

It is an universal gate. Whenever the all the input must true condition the output becomes false or

If any one of the inputs is false condtion then output becomes true.

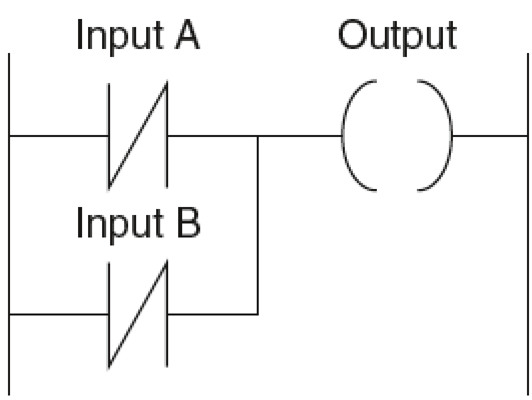
Truth Table of the NAND Logic

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

Logic Equation of the NAND Logic

$$Y = \overline{AB}$$

Ladder Logic diagram for NAND logic



NOR Logic

It is an universal gate. Whenever all the input conditions are false then output becomes true

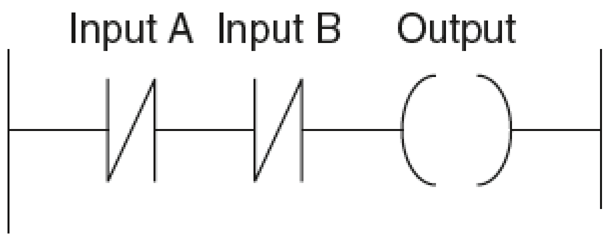
TRUTH TABLE of the NOR logic

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

LOGIC equation

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

Ladder logic diagram for NOR logic



Exclusive OR

- The output of this circuit is ON only when pushbutton A or *B is pressed, but not both.*

<u>**Case 1**</u>When A= 0 and B= 0:

Let us analyze main rung. When I1 = 0, the normally open instruction is false and, normally closed instruction is true, but since normally open instruction is false, there is no logical continuity and output cannot be energized. Similar analysis can be done in parallel rung, normally closed instruction will be true and normally open instruction will be false and output is not energized.

Case 2 When A= 0 and B = 1:

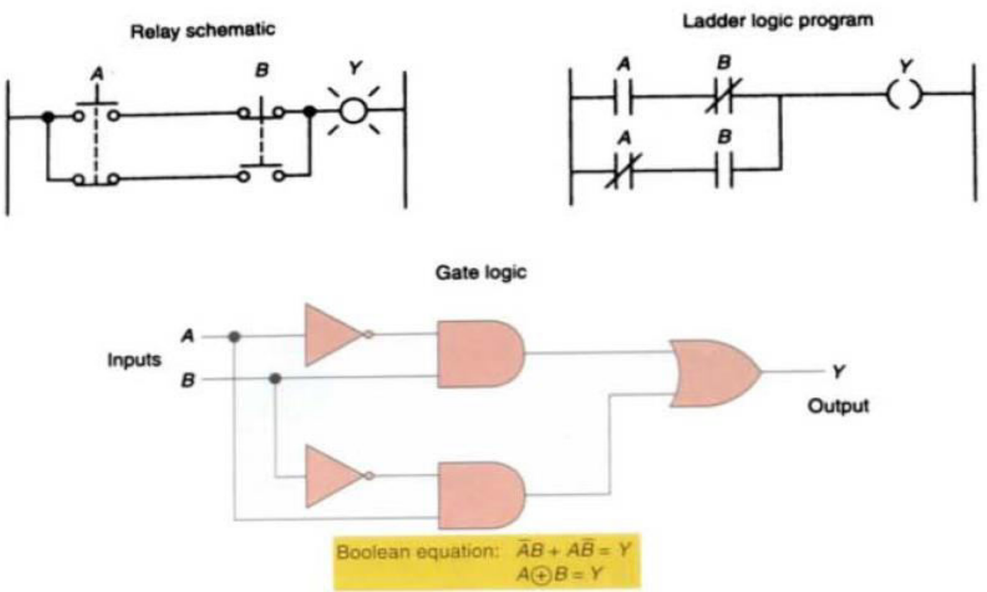
In main rung, normally open instruction will be false and, normally closed instruction will be true, but since there is no logical continuity this rung logic cannot energize the output. But, in parallel rung, normally closed instruction will be true, as well as normally open instruction will also be true, hence there is logical continuity, and output is energized.

Case 3 When I1 = 1 and I2 = 0:

This case is similar to case 2, only the role of inputs are interchanged i.e. here main rung is true and energizes the output and parallel rung is false.

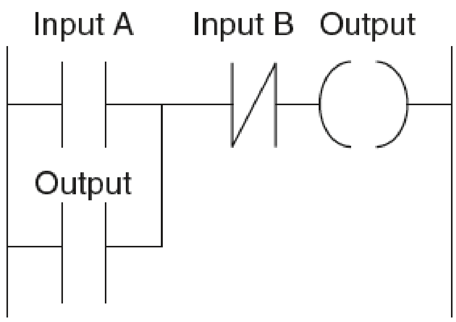
Case 4

- When both inputs are true, the main ladder rung as well as the parallel ladder rung goes false. In main rung, normally open instruction is true but normally closed instruction is false. Hence, there is no logical continuity. In parallel ladder rung, normally closed instruction is false and normally open instruction is true, and here also there is no logical continuity. Hence, the output is not energized.



Latch circuit

- There are often situations where it is necessary to hold an output energized, even when the input ceases.
- A simple example of such a situation is a motor, which is started by pressing a push button switch.
- Though the switch contacts do not remain closed, the motor is required to continue running until a stop push button switch is pressed.
- The term latch circuit is used for the circuit used to carry out such an operation.
- It is a self-maintaining circuit in that, after being energized, it maintains that state until another input is received.



4.4.Simple Programs

- A lighting control system is to be developed. The system will be controlled by four switches, SWITCH1, SWITCH2, SWITCH3, and SWITCH4.

  These switches will control the lighting in a room based on the following criteria:

  1. Any of three of the switches SWITCH1, SWITCH2, and SWITCH3, if turned ON can turn the lighting on, but all three switches must be OFF before the lighting will turn OFF.

  2. The fourth switch SWITCH4 is a Master Control Switch. If this switch is in the ON position, the lights will be OFF and none of the other three switches have any control.

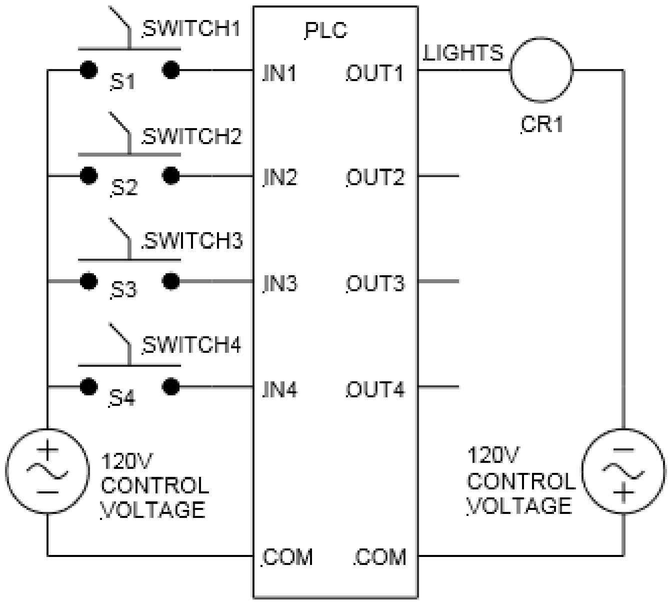
Design the wiring diagram for the controller connections, assign the inputs and outputs and develop the ladder diagram which will accomplish the task.

Number of PLC Inputs Required

- INPUT IN1 = SWITCH1
- INPUT IN2 = SWITCH2
- INPUT IN3 = SWITCH3
- INPUT IN4 = SWITCH4 (Master Control Switch)

Number of PLC Outputs Required

- OUTPUT OUT1 = Lights control relay coil CR1

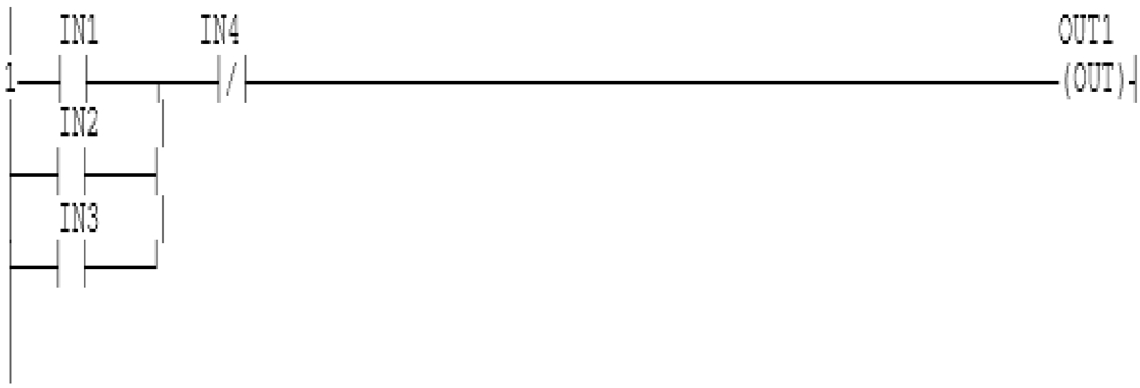


- Any of three of the switches SWITCH1, SWITCH2, and SWITCH3, if turned ON can turn the lighting on

- The fourth switch SWITCH4 is a Master Control Switch. If this switch is in the ON position, the lights will be OFF

Boolean logic

CR1=(IN1 OR IN2 OR IN3) AND IN4



5. POST MCQ

1. Function Block Diagram (FBD) is a type of____________.

   a) PLC Language

UNIT – IV

INTRODUCTION AND CONCEPTS OF NC/ CNC MACHINE

SPRX1008 – PRODUCTION TECHNOLOGY - II

Numerical Control

Computer **N**umeric **C**ontrol (C**NC**) is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium (computer command module, usually located on the device) as opposed to controlled manually by hand wheels or levers, or mechanically automated by cams alone. Most NC today is **computer (or computerized) numerical control** (**CNC**), in which computers play an integral part of the control.

In modern CNC systems, end-to-end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine by use of a post processor, and then loaded into the CNC machines for production. Since any particular component might require the use of a number of different tools – drills, saws, etc. – modern machines often combine multiple tools into a single "cell". In other installations, a number of different machines are used with an external controller and human or robotic operators that move the component from machine to machine. In either case, the series of steps needed to produce any part is highly automated and produces a part that closely matches the original CAD design.

Definition

Computer Numerical Control (CNC) is one in which the functions and motions of a machine tool are controlled by means of a prepared program containing coded alphanumeric data. CNC can control the motions of the work piece or tool, the input parameters such as feed, depth of cut, speed, and the functions such as turning spindle on/off, turning coolant on/off.

Applications

The applications of CNC include both for machine tool as well as non-machine tool areas. In the machine tool category, CNC is widely used for lathe, drill press, milling machine, grinding unit, laser, sheet-metal press working machine, tube bending machine etc. Highly automated machine tools such as turning centre and machining centre which change the cutting tools automatically under CNC control have been developed. In the non-machine tool category, CNC applications include welding machines (arc and resistance), coordinate measuring machine, electronic assembly, tape laying and filament winding machines for composites etc.

Advantages and Limitations

The benefits of CNC are (1) high accuracy in manufacturing, (2) short production time, (3) greater manufacturing flexibility, (4) simpler fixturing, (5) contour machining (2 to 5 -axis machining), (6) reduced human error. The drawbacks include high cost, maintenance, and the requirement of skilled part programmer.

ELEMENTS OF A CNC

A CNC system consists of three basic components (Figure 2) : Part Program 1 . Part program 2 . Machine Control Unit (MCU) 3 . Machine tool (lathe, drill press, milling machine etc) The part program is a detailed set of commands to be followed by the machine tool. Each command specifies a position in the Cartesian coordinate system (x,y,z) or motion (workpiece travel or cutting tool travel), machining parameters and on/off function. Part programmers should be well versed with machine tools, machining processes, effects of process variables, and limitations of CNC controls. The part program is written manually or by using computerassisted language such as APT (Automated Programming Tool).

Machine Control Unit

The machine control unit (MCU) is a microcomputer that stores the program and executes the commands into actions by the machine tool. The MCU consists of two main units: the data processing unit (DPU) and the control loops unit (CLU). The DPU software includes control system software, calculation algorithms, translation software that converts the part program into a usable format for the MCU, interpolation algorithm to achieve smooth motion of the cutter, editing of part program (in case of errors and changes). The DPU processes the data from the part program and provides it to the CLU which operates the drives attached to the machine leadscrews and receives feedback signals on the actual position and velocity of each one of the axes. A driver (dc motor) and a feedback device are attached to the leadscrew. The CLU consists of the circuits for position and velocity control loops, deceleration and backlash take up, function controls such as spindle on/off.

Machine Tool

The machine tool could be one of the following: lathe, milling machine, laser, plasma, Coordinate measuring machine etc. Figure 3 shows that a right-hand coordinate system is used to describe the motions of a machine tool . There are three linear axes (x,y,z), three rotational axes (i,j,k), and other axes such as tilt (9) are possible. For example, a 5-axis machine implies any combination of x,y,z, i,j,k,and 6.

PRINCIPLES OF CNC

Basic Length Unit (BLU)

Each BLU unit corresponds to the position resolution of the axis of motion. For example, 1 BLU = 0.0001" means that the axis will move 0.0001" for every one electrical pulse received by the motor. The BLU is also referred to as Bit (binary digit).

Pulse = BLU = Bit

Point-to-Point Systems

Point-to-point systems are those that move the tool or the workpiece from one point to another and then the tool performs the required task. Upon completion, the tool (or workpiece) moves to the next position and the cycle is repeated (Figure 4). The simplest example for this type of system is a drilling machine where the workpiece moves.

In this system, the feed rate and the path of the cutting tool (or workpiece) have no significance on the machining process. The accuracy of positioning depends on the system's resolution in terms of BLU (basic length unit) which is generally between 0.001" and 0.0001".

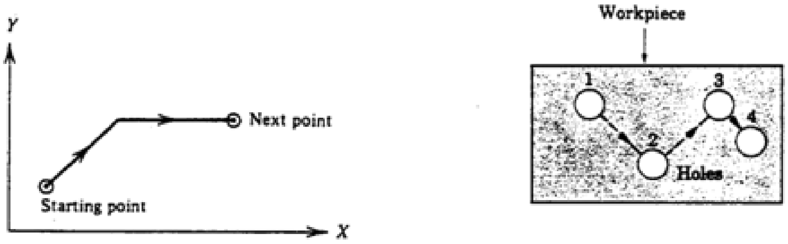


Figure 4. Cutter path between holes in a point-to-point system

Example 1

The XY table of a drilling machine has to be moved from the point (1,1) to the point (6,3). Each axis can move at a velocity of 0.5"/sec, and the BLU is 0.0001", find the travel time and resolution.

Travel time in X-axis is (6-1)/0.5 = 10 sec, in Y-axis is (3-1)/0.5= 4 sec.
Travel time = 10 sec
Resolution = BLU = 0.0001

Continuous Path Systems (Straight cut and Contouring systems)

These systems provide continuous path such that the tool can perform while the axes are moving, enabling the system to generate angular surfaces, two-dimensional curves, or three-dimensional contours. Example is a milling machine where such tasks are accomplished (Figure 5). Each axis might move continuously at a different velocity. Velocity error is significant in affecting the positions of the cutter (Figure 5). It is much more important in circular contour cutting where one axis follows sine function while the other follows cosine function. Figure 6 illustrates point-to-point and continuous path for various machines.

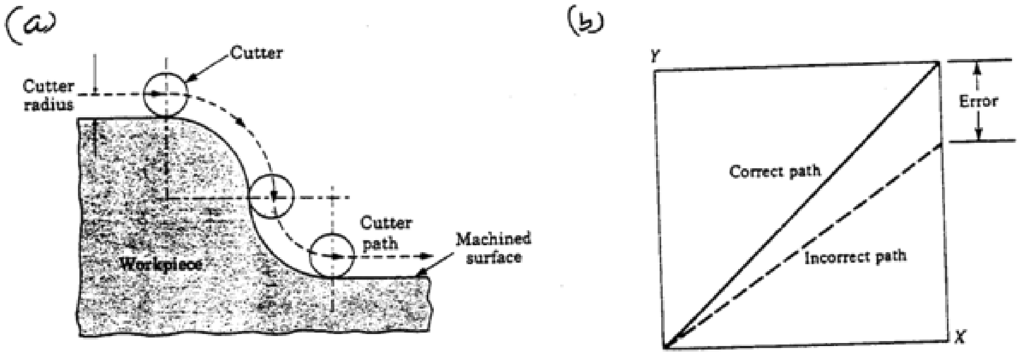


Figure 5. (a) Continuous path cutting and (b) Position error caused by the velocity error

Example 2

A CNC milling machine has to cut a slot located between the points (0,0) and (4,3) on the XY-plane where the dimensions are in inches. If the speed along the slot is to be 0.1 in/sec, find the cutting time and axial velocities.

Distance traveled along the slot $= (16+9)^{1/2} = 5"$

Cutting time = 5/0.1 = 50 sec

$V_x = xV/(x^2+y^2)^{1/2} = 4(0.1)/5 = 0.08$ in/sec
$V_y = yV/(x^2+y^2)^{1/2} = 3(0.1)/5 = 0.06$ in/sec

If the velocity is Y-axis is off by 10%, what would be the new position ?

New velocity in y is 0.9 x 0.06 = 0.054 in/sec

In 50 sec, the y- will move a distance [50(0.054)] = 2.7 in.

Incremental and Absolute systems

CNC systems are further divided into incremental and absolute systems (Figure 8). In incremental mode, the distance is measured from one point to the next. For example, if you want to drill five holes at different locations, the x-position commands are x + 500, + 200, + 600, - 300, -700, -300. An absolute system is one in which all the moving commands are referred from a reference point (zero point or origin). For the above case, the x-position commands are x 500,700, 1300, 1000, 300, 0. (Figure 8). Both systems are incorporated in most CNC systems. For an inexperienced operator, it is wise to use incremental mode.

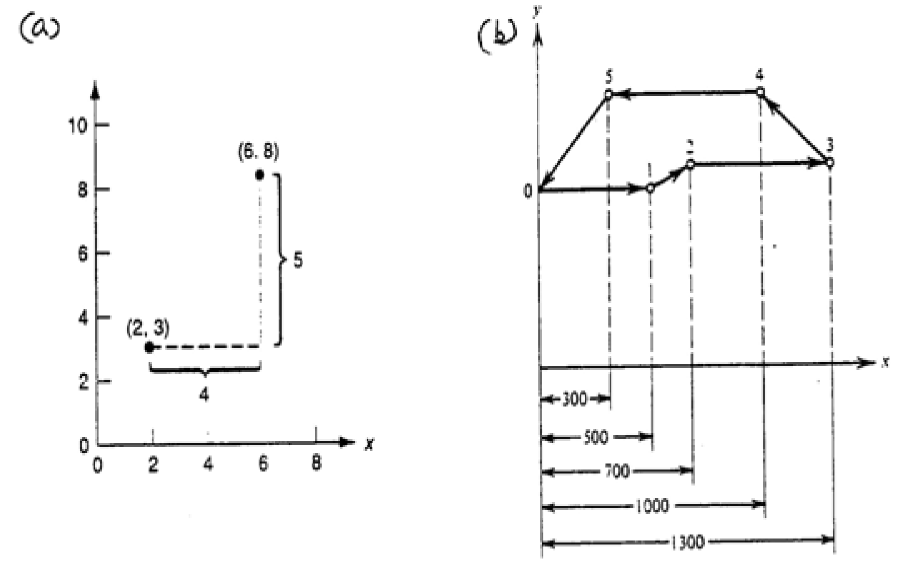


Figure 8. (a) Absolute versus incremental; In absolute positioning, the move is specified by x = 6, y = 8; in incremental, the move is specified by x=4, y=5 for the tool to be moved from (2,3) to (6,8)

(b) Drilling 5-holes at different locations

The absolute system has two significant advantages over the incremental system:

1. *Interruptions caused by, for example, tool breakage (or tool change, or checking the parts), would not affect the position at the interruption.*

If a tool is to be replaced at some stage, the operator manually moves the table, exchanges the tool, and has to return the table to the beginning of the segment in which the interruption has occurred. In the absolute mode, the tool is automatically returned to the position. In incremental mode, it is almost impossible to bring it precisely to that location unless you repeat the part program

2. *Easy change of dimensional data*

The incremental mode has two advantages over the absolute mode.

1. *Inspection of the program is easier because the sum of position commands for each axis must be zero.* A nonzero sum indicates an error . Such an inspection is impossible with the absolute system.

2. *Mirror image programming (for example, symmetrical geometry of the parts) is simple by changing the signs of the position commands.*

Open Loop Control Systems

The open-loop control means that there is no feedback and uses stepping motors for driving the leadscrew. A stepping motor is a device whose output shaft rotates through a fixed angle in response to an input pulse (Figure 9). The accuracy of the system depends on the motor's ability to step through the exact number. The frequency of the stepping motor depends on the load torque. The higher the load torque, lower would be the frequency. Excessive load torque may occur in motors due to the cutting forces in machine tools. Hence this system is more suitable for cases where the tool force does not exist (Example: laser cutting).

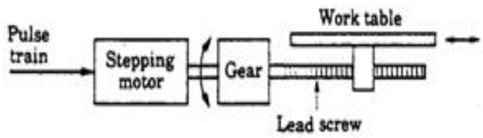


Figure 9. Open loop control system

The stepping motor is driven by a series of electrical pulses generated by the MCU. Each pulse causes the motor to rotate a fraction of one revolution. The fraction is expressed in terms of the step angle, α, given by

$$\alpha = 360/N, \text{ degrees where } N = \text{number of pulses required for one revolution}$$

If the motor receives "n" number of pulses then the total angle,

$$A = n\,(360/N), \text{ degrees}$$

In terms of the number of revolutions, it would be (n/N)

If there is a 1:1 gear ratio between the motor and the leadscrew, then the leadscrew has (n/N) revolutions. If the pitch of leadscrew is p (in/rev), then the distance traveled axially, say x,

$$x = p(n/N)$$

can be used to achieve a specified x-increment in a point-to-point system.

The pulse frequency, f, in pulses/sec determines the travel speed of the tool or the workpiece.

$60\ f = N\ (RPM)$ where N = number of pulses per revolution,
RPM = RPM of the lead screw

The travel speed, V, is then given by $V = p\ (RPM)$ where p pitch in in/rev

Example 3

A stepping motor has N = 150, p = 0.2"/rev; If n = 2250 pulses, what is the distance traveled in x-direction ? What should be the pulse frequency for a travel speed of 16 in./min ?

$$x = (0.2)\ (2250)/150 = 3''$$

$16 = 0.2\ (RPM)$, from which, RPM = 80

$f = (150)\ (80)/60 = 200$ Hz

Example 4

A stepping motor of 200 steps per revolution is mounted on the leadscrew of a drilling machine. If the pitch is 0.1 in/rev.,

a. What is the BLU ?
b. If the motor receives a pulse frequency of 2000 Hz, what is the speed of the table ?

a. BLU = 0.1/200 = 0.0005"

b. Table speed = (p) (RPM) = (0.1) (60) (2000)/200 = 60 in/min

Closed-loop Control Systems

Closed -loop NC systems are appropriate when there is a force resisting the movement of the tool/workpiece. Milling and turning are typical examples. In these systems (Figure 10) the DC servomotors and feedback devices are used to ensure that the desired position is achieved. The feedback sensor used is an optical encoder shown in Figure 11. The encoder consists of a light source, a photodetector, and a disk containing a series of slots. The encoder is connected to the leadscrew. As the screw turns, the slots cause the light to be seen by the photodetector as a series of flashs which are converted into an equivalent series of electrical pulses which are then used to characterize the position and the speed. The equations remain essentially the same as open-loop except that the angle between the slots in the disk is the step angle, α.

Both the input to the control loop and the feedback signals are a sequence of pulses, each pulse representing a BLU unit. The two sequences are correlated by a comparator and gives a signal, by means of a digital-to-analog converter, (a signal representing the position error), to operate the drive motor (DC servomotor).

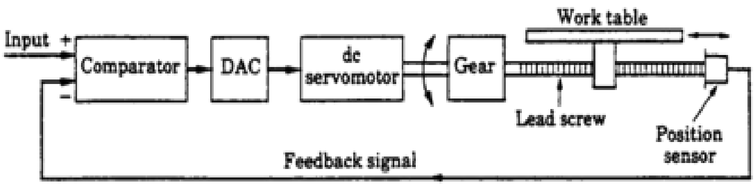


Figure 10. Closed loop control system

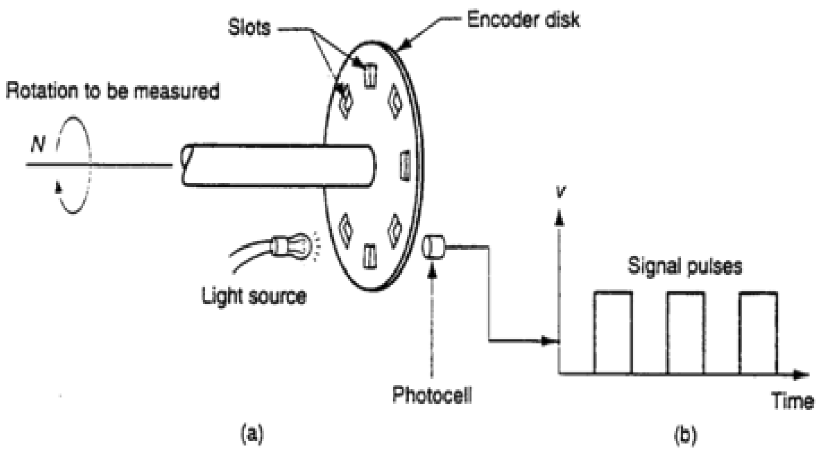


Figure 11. Optical Encoder (a) Device (b) Series of pulses emitted

Coordinate systems:

The machine tool is positioned by describing sets of coordinates. In the case of the VMC (Vertical Machining Centre) shown on the left, the coordinate will be described by 3 Axes.

A basic lathe operates by describing positions using 2 axes.

The coordinate system is laid out by identifying the Z axis first. The Z axis is always in line with the main rotating spindle. On the VMC this holds the cutting tool and is vertical; on the lathe this holds the work piece, it is horizontal and in line with the bed.

The X axis is used next and then the Y axis. The Axes for the VMC are shown in the image, the lathe uses just the Z and X axes.

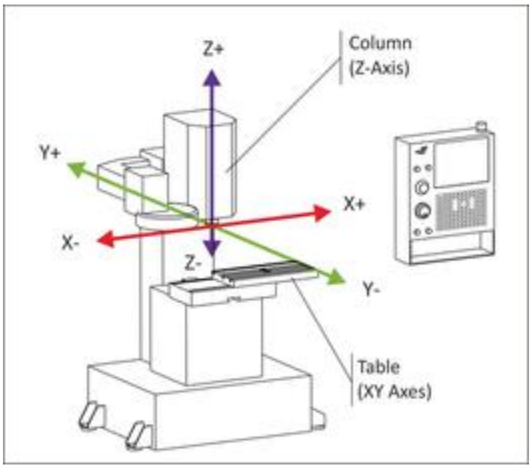
The coordinate system used in most cases of CNC machining is a rectangular system, the technical name for this being the Cartesian coordinate system. When writing coordinates it is standard practise to write them in the order of X, Y, and Z.

When CNC programming the coordinate system must reference from a fixed point; this is called the origin or more commonly in manufacturing, the datum. The datum is the position where X, Y, and Z all equal zero. This is usually a point on the component and this position is usually decided by the manufacturing engineer or CNC programmer.

The coordinate system is almost always an absolute coordinate system. Absolute meaning all coordinates are measured from the datum. Other coordinate system are found in CNC manufacturing; it is not unusual to find Incremental (Relative) coordinates used on many machines and it is possible to use Polar coordinates on most machines.

Incremental coordinates do not refer back to the original datum, the position of the datum moves with the programmed coordinate. The machine moves towards a programmed position; when it gets to that position the position becomes X0Y0Z0 (the new datum). the next position is described from this new datum.

Polar coordinates can be used in Abs and Inc modes but the coordinate system is not rectangular; the Polar coordinate system is based on a rotating angle and length of radius. Basic programming - such as the programming used during the 16wk college course uses Cartesian coordinates using absolute positioning.



CARTESIAN COORDINATE

A **Cartesian coordinate system** is a coordinate system that specifies each point uniquely in a plane by a pair of numerical **coordinates**, which are the signed distances to the point from two fixed perpendicular directed lines, measured in the same unit of length. Each reference line is called a *coordinate axis* or just *axis* of the system, and the point where they meet is its *origin*, usually at ordered pair (0, 0). The coordinates can also be defined as the positions of the perpendicular projections of the point onto the two axes, expressed as signed distances from the origin.

One can use the same principle to specify the position of any point in three-dimensional space by three Cartesian coordinates, its signed distances to three mutually perpendicular planes (or, equivalently, by its perpendicular projection onto three mutually perpendicular lines). In general, *n* Cartesian coordinates (an element of real *n*-space) specify the point in an *n*-dimensional Euclidean space for any dimension *n*. These coordinates are equal, up to sign, to distances from the point to *n* mutually perpendicular hyper planes.

POLAR COORDINATE

In mathematics, the **polar coordinate system** is a two-dimensional coordinate system in which each point on a plane is determined by a distance from a reference point and an angle from a reference direction.

The reference point (analogous to the origin of a Cartesian system) is called the *pole*, and the ray from the pole in the reference direction is the *polar axis*. The distance from the pole is called the *radial coordinate* or *radius*, and the angle is called the *angular coordinate*, *polar angle*

AUTOMATIC TOOL CHANGER (ATC)

An **Automatic tool changer** or **ATC** is used in computerized numerical control (CNC) machine tools to improve the production and tool carrying capacity of the machine. ATC changes the tool very quickly, reducing the non-productive time. Generally, it is used to improve the capacity of the machine to work with a numbers of tools. It is also used to change worn out or broken tools. It is one more step towards complete automation.

Simple CNC machines work with a single tool. Turrets can work with a large number of tools. But if even more tools are required, then ATC is provided. The tools are stored on a magazine. It allows the machine to work with a large number of tools without an operator. The main parts of an automatic tool changer are the base, the gripper arm, the tool holder, the support arm and tool magazines. Although the ATC increases the reliability, speed and accuracy, it creates more challenges compared to manual tool change, for example the tooling used must be easy to centre, be easy for the changer to grab and there should be a simple way to provide the tool's self-disengagement. Tools used in ATC are secured in toolholders specially designed for this purpose.

After receiving the tool change command, the tool to be changed will assume a fixed position known as the "tool change position". The ATC arm comes to this position and picks up the tool. The arm swivels between machine turret and magazine. It will have one gripper on each of the two sides. Each gripper can rotate 90°, to deliver tools to the front face of the turret. One will pick up the old tool from turret and the other will pick up the new tool from the magazine. It then rotates to 180° and places the tools into their due position.

The use of automatic changers increases the productive time and reduces the unproductive time to a large extent. It provides the storage of the tools which are returned automatically to the machine tool after carrying out the required operations, increases the flexibility of the machine tool. makes it easier to change heavy and large tools, and permits the automatic renewal of cutting edges.

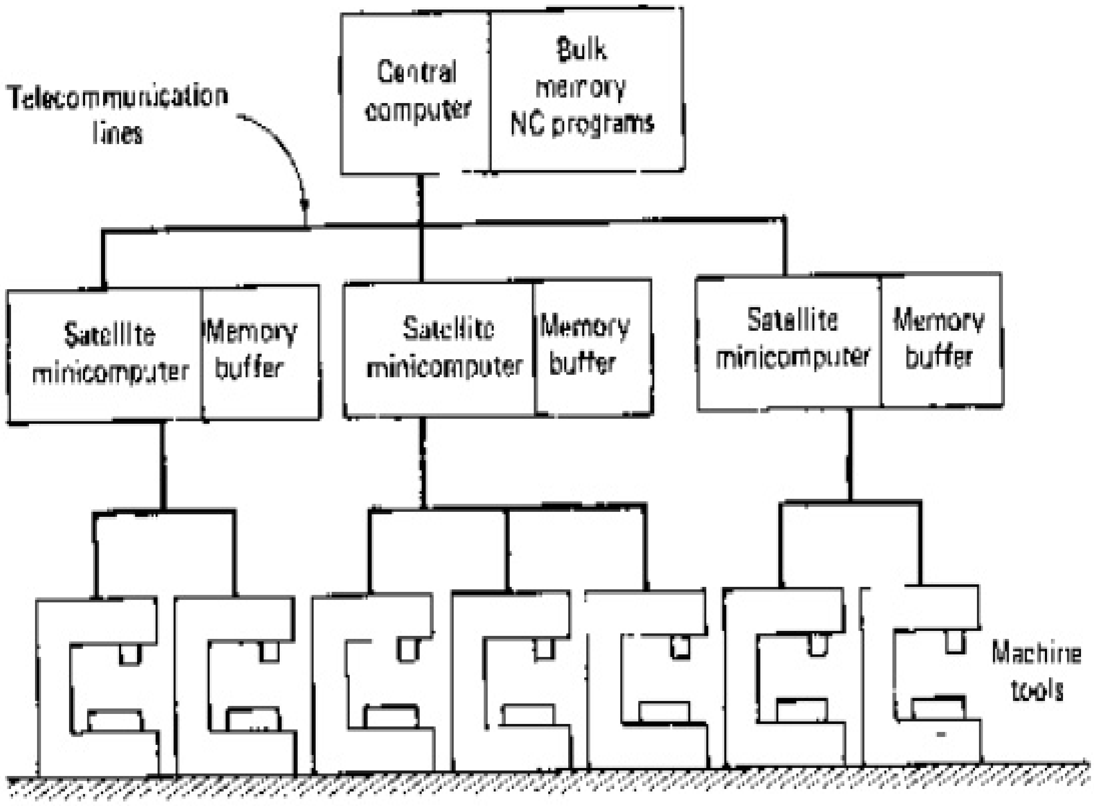
DIRECT NUMERICAL CONTROL

Direct numerical control (**DNC**), also known as **distributed numerical control** (also **DNC**), is a common manufacturing term for networking CNC machine tools. On some CNC machine controllers, the available memory is too small to contain the machining program (for example machining complex surfaces), so in this case the program is stored in a separate computer and sent *directly* to the machine, one block at a time. If the computer is connected to a number of machines it can *distribute* programs to different machines as required. Usually, the manufacturer of the control provides suitable DNC software. However, if this provision is not possible, some software companies provide DNC applications that fulfill the purpose. DNC networking or DNC communication is always required when CAM programs are to run on some CNC machine control.

Wireless DNC is also used in place of hard-wired versions. Controls of this type are very widely used in industries with significant sheet metal fabrication, such as the automotive, appliance, and aerospace industries.

One of the issues involved in machine monitoring is whether or not it can be accomplished automatically in a practical way. In the 1980s monitoring was typically done by having a menu on the DNC terminal where the operator had to manually indicate what was being done by selecting from a menu, which has obvious drawbacks. There have been advances in passive monitoring systems where the machine condition can be determined by hardware attached in such a way as not to interfere with machine operations (and potentially void warranties). Many modern controls allow external applications to query their status using a special protocol. MT Connect is one prominent attempt to augment the existing world of proprietary systems with some open-source, industry-standard protocols and XML schemas and an ecosystem of massively multiplayer app development and mashups (analogous to that with smart phones) so that these long-sought higher levels of manufacturing business intelligence and workflow automation can be realized.

A challenge when interfacing into machine tools is that in some cases special protocols are used. Two well-known examples are Mazatrol and Heidenhain. Many DNC systems offer support for these protocols. Another protocol is DNC2 or LSV2 which is found on Fanuc controls. DNC2 allows advanced interchange of data with the control, such as tooling offsets, tool life information and machine status as well as automated transfer without operator intervention.



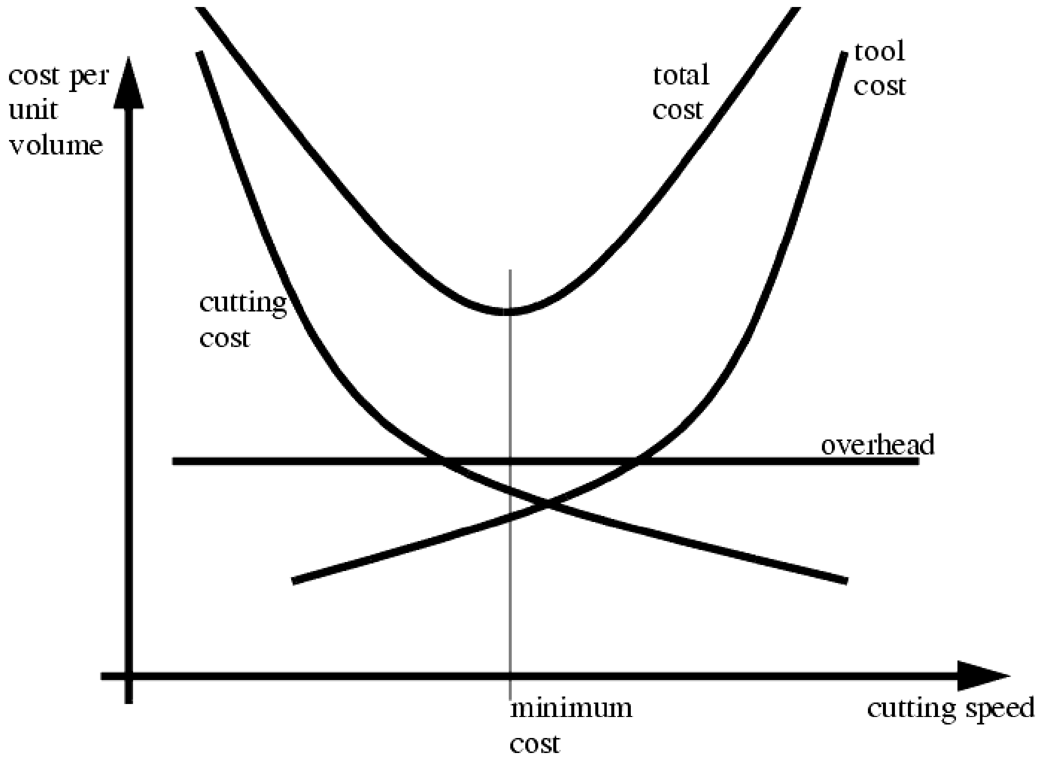
DIRECT NUMERICAL CONTROL

ECONOMICS OF CNC MACHINES

It is normal for a company to embark on a feasibility study prior to the purchase of any capital equipment such as a CNC machine tool. This study fulfils many functions, such as determining the capacity and power required together with its configuration - horizontal/vertical spindle for a machining centre, or flat, or slant bed for a turning centre. Many other features must also be detailed in the study, encompassing such factors, in the age of 5-axis machining, as the number of axes required and whether the machine tool should be loaded manually, by robot, or using pallets. An exhaustive list is drawn up of all the relevant points to be noted and others that at first glance seem rather esoteric, but will affect the ability of the company to manufacture its products. It has been shown time and again that many mistakes have been made in the past when companies rush into the purchase of new equipment without considering all of the problems, not only of the machine tool itself, but of the manning and training requirements together with its effect on the rest of the machine shops productive capability. Often the fact that an advanced, highly

productive machine is now present in the shop could affect the harmonious flow of production, causing bottlenecks later, when the purpose of purchasing the machine was to overcome those problems at an earlier production stage. Aerospace machine tools have even been purchased in the past without due regard for the components they must manufacture, or without correct assessment of future work.

This latter point is not often considered, as many companies are all too concerned with today's production problems rather than those of the future. Taking this theme a little further, in a volatile market a feasibility study should perceive not only the short and medium term productivity goals, but also the long term ones, as it is often the long term trends of productive capability which are the most important if a company is tc amortise their costs. When highly sophisticated plant such as an FMS is required, it can be several years from its original conception before this is a reality on the shop floor, and a company's production demands may have changed considerably in the meantime. If, for any reason, the wrong machine has been purchased, or more likely, something has been overlooked during the feasibility study, then the "knock-on effect" of this poor judgement is that it will have cost the company dearly and, at the very least, any future study will be looked on by the upper management with disdain and scepticism.



COST ANALYSIS

UNIT-I

INTRODUCTION

The field of robotics has its origins in science fiction. The term robot was derived from the English translation of a fantasy play written in Czechoslovakia around 1920. It took another 40 years before the modern technology of industrial robotics began. Today Robots are highly automated mechanical manipulators controlled by computers. We survey some of the science fiction stories about robots, and we trace the historical development of robotics technology. Let us begin our chapter by defining the term robotics and establishing its place in relation to other types of industrial automation.

Robotics: -

Robotics is an applied engineering science that has been referred to as a combination of machine tool technology and computer science. It includes machine design, production theory, micro electronics, computer programming & artificial intelligence.

OR

"Robotics" is defined as the science of designing and building Robots which are suitable for real life application in automated manufacturing and other non-manufacturing environments.

Industrial robot: -

The official definition of an industrial robot is provided by the robotics industries association (RIA). Industrial robot is defined as an automatic, freely programmed, servo-controlled, multi-purpose manipulator to handle various operations of an industry with variable programmed motions.

Automation and robotics:-

Automation and robotics are two closely related technologies. In an industrial context, we can dean automation as a technology that is concerned with the use of mechanical, electronic, and computer-based systems in the operation and control of production Examples of this technology include transfer lines. Mechanized assembly machines, feedback control systems (applied to industrial processes), numerically controlled machine tools, and robots. Accordingly, robotics is a form of industrial automation.

Ex:- Robotics, CAD/CAM, FMS, CIMS

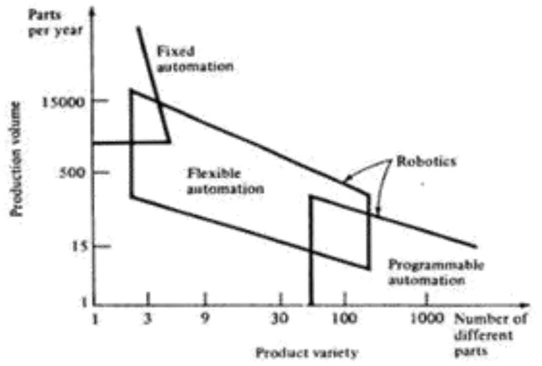
Types of Automation:-

Automation is categorized into three types. They are,

1)Fixed Automation

2) Programmable Automation

3) Flexible Automation.



Relationship of fixed automation, programmable automation, and flexible au omation as a tuncuon of production volume and product variety.

<u>(1) Fixed Automation:-</u>

It is the automation in which the sequence of processing or assembly operations to be carried out is fixed by the equipment configuration. In fixed automation, the sequence of operations (which are simple) are integrated in a piece of equipment. Therefore, it is difficult to automate changes in the design of the product. It is used where high volume of production is required Production rate of fixed automation is high. In this automation, no new products are processed for a given sequence of assembly operations.

<u>Features:-</u>

i) High volume of production rates,

ii) Relatively inflexible in product variety (no new products are

produced). <u>Ex:-</u> Automobile industries … etc.

<u>(2) Programmable Automation:-</u>

It is the automation in which the equipment is designed to accommodate various product configurations in order to change the sequence of operations or assembly operations by means of control program. Different types of programs can be loaded into the equipment to produce products with new configurations (i.e., new products). It is employed for batch production of low and medium volumes. For each new batch of different configured product, a new control program corresponding to the new product is loaded into the equipment. This automation is relatively economic for small batches of the product.

<u>Features:-</u>
i) High investment in general purpose,
ii) Lower production rates than fixed automation,
iii) Flexibility & Changes in products configuration,
iv) More suitable for batch production.
<u>Ex:-</u> Industrial robot, NC machines tools… etc.

<u>(3) Flexible Automation:-</u>

A computer integrated manufacturing system which is an extension of programmable automation is referred as flexible automation. It is developed to minimize the time loss between the changeover of the batch production from one product to another while reloading. The program to produce new products and changing the physical setup i.e., it produces different products with no loss of time. This automation is more flexible in interconnecting work stations with material handling and storage system.

Features:-

i) High investment for a custom engineering system.

ii) Medium Production rates

iii) Flexibility to deal with product design variation,

iv) Continuous production of variable mixtures of products. Ex:- Flexible manufacturing systems (FMS)

Advantages:-

1.High Production rates

2.Lead time decreases

3.Storing capacity decreases

4.Human errors are eliminated.

5.Labour cost is decreases.

Disadvantages:-

1.Initial cost of raw material is very high,

2.Maintenance cost is high,

3.Required high skilled Labour.

4.Indirect cost for research development & programming increases.

Reasons for implementation of automated systems in manufacture industries:-

The reasons for the implementation of automated systems in manufacturing industries are as follows,

(i) To Increase the Productivity Rate of Labour
(ii) To Decrease the Cost of Labour
(iii) To Minimize the Effect of Shortage of Labour
(iv) To Obtain High Quality of Products
(v) A Non-automation nigh Cost is Avoided
(vi) To Decrease the Manufacturing Lead Time
(vii) To upgrade the Safety of Workers.

Need for using robotics in industries:-

Industrial robot plays a significant role in automated manufacturing to perform different kinds of applications.

1. Robots can be built a performance capability superior to those of human beings. In terms of strength, size, speed, accuracy…etc.

2. Robots are better than humans to perform simple and repetitive tasks with better quality and consistence's.
3. Robots do not have the limitations and negative attributes of human works .such as fatigue, need for rest, and diversion of attention…..etc.
4. Robots are used in industries to save the time compared to human beings.
5. Robots are in value poor working conditions
6. Improved working conditions and reduced risks.

CAD/CAM & Robotics:-

CAD/CAM is a term which means computer aided design and computer aided manufacturing. It is the technology concerned with the use of digital computers to perform certain functions in design & production.

CAD:- CAD can be defined as the use of computer systems to assist in the creation modification, analysis OR optimization of design.

Cam:- CAM can be defined as the use of computer system to plan, manage & control the operation of a manufacturing plant, through either direct or in direct computer interface with the plant's production resources.

Specifications of robotics:-

1.Axil of motion

2.Work stations

3.Speed

4. Acceleration

5.Pay load capacity

6.Accuracy

7.Repeatability etc…

Overview of Robotics:-

"Robotics" is defined as the science of designing and building Robots which are suitable for real life application in automated manufacturing and other non-manufacturing environments. It has the following objectives,

1.To increase productivity

2.Reduce production life

3.Minimize labour requirement

4. Enhanced quality of the products

5.Minimize loss of man hours, on account of accidents.

6.Make reliable and high speed production.

The robots are classified as,
Programmable/Reprogrammable purpose

robots

*Tele-operated, Man controlled robots

*Intelligent robots.

Robots are used in manufacturing and assembly units

such as,

1. Spot or arc welding
2. Parts assembly
3. Paint spraying
4. Material, handling
5. Loading and unloading

The feature and capabilities of the robots are as follows,

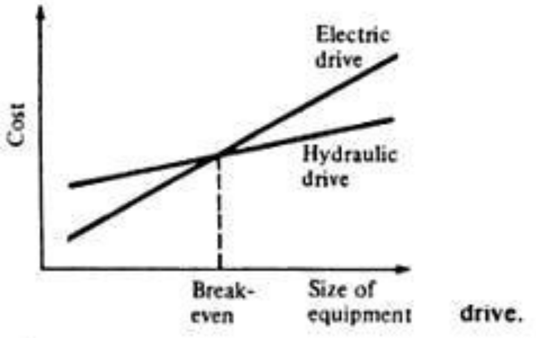
1. Intelligence
2. Sensor capabilities
3. Telepresence
4. Mechanical design
5. Mobility and navigation
6. Universal gripper
7. System integration and networking.

Types of drive systems:-

1.Hydraulic drive

2.Electric drive

3.Pneumatic drive



1. Hydraulic drive:-

Hydraulic drive and electric drive arc the two main types of drives used on more sophisticated robots.

Hydraulic drive is generally associated with larger robots, such as the Unimate 2000 series. The usual advantages of the hydraulic drive system are that it provides the robot with greater speed and strength. The disadvantages of the hydraulic drive system are that it typically adds to the floor space required by the robot, and that a hydraulic system is inclined to leak on which is a nuisance.

This type of system can also be called as non-air powered cylinders. In this system, oil is used as a working fluid instead of compressed air. Hydraulic system need pump to generate the required pressure and flow rate. These systems are quite complex, costly and require maintenance.

2. Electric drive:-

Electric drive systems do not generally provide as much speed or power as hydraulic systems. However, the accuracy and repeatability of electric drive robots are usually better. Consequently, electric robots tend to be smaller. Require less floor space, and their applications tend toward more precise work such as assembly.

In this System, power is developed by an electric current. It required little maintenance and the operation is noise less.

3. Pneumatic drive:-

Pneumatic drive is generally reserved for smaller robots that possess fewer degrees of freedom (two- to four-joint motions).

In this system, air is used as a working fluid, hence it is also called air-powered cylinders. Air is compressed in the cylinder with the aid of pump the compressed air is used to generate the power with required amount of pressure and flow rates.

Applications of robots:-

Present Applications of Robots:-

(i) Material transfer applications

(ii) Machine loading and unloading

(iii) Processing operations like,

(a) Spot welding

(b) Continuous arc welding

(c) Spray coating

(d) Drilling, routing, machining operations

(e) Grinding, polishing debarring wire brushing

(g) Laser drilling and cutting etc.

(iv) Assembly tasks, assembly cell designs, parts mating.
(v) Inspection, automation.

Future Applications of Robots:-

The profile of the future robot based on the research activities will include the following,

(i) Intelligence

(ii) Sensor capabilities

(iii) Telepresence

(iv) Mechanical design

(v) Mobility and navigation (walking machines)

(vi) Universal gripper

(vii) Systems and integration and networking

(viii) FMS (Flexible Manufacturing Systems)

(Ix) Hazardous and inaccessible non-manufacturing environments

(x) Underground coal mining

(xi) Fire fighting operations

(xii) Robots in space

(xiii) Security guards

(xiv) Garbage collection and waste disposal operations

(xv) Household robots

(xvi) Medical care and hospital duties etc.

Classification of Robots (or) Classification by co-ordinate system and control system:-

Co-ordinate systems:-

Industrial robots are available in a wide variety of sizes, shapes, and physical configurations. The vast majority of today's commercially available robots possess one of the basic configurations:

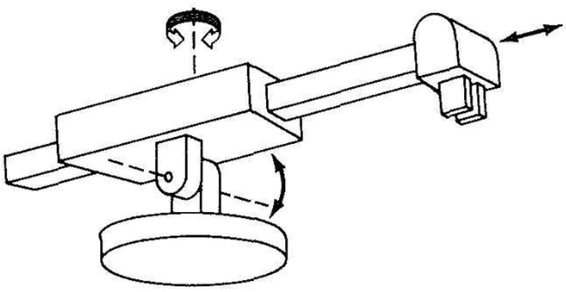
I. Polar configuration

2. Cylindrical configuration

3. Cartesian coordinate configurable

4. Jointed-arm configuration

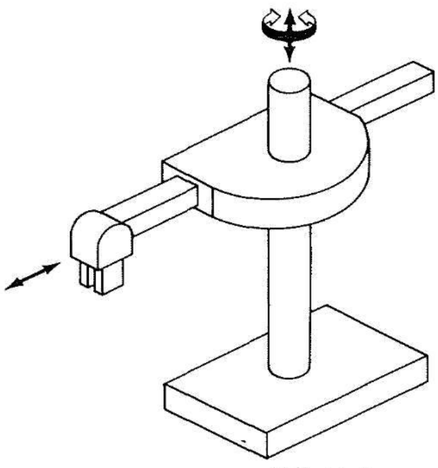
1. Polar configuration:-



Spherical

The polar configuration is pictured in part (a) of Fig. It uses a telescoping arm that can be raised or lowered about a horizontal pivot The pivot is mounted on a mta6ng base These various joints provide the robot with the capability to move its arm within a spherical space, and hence the name "spherical coordinate" robot is sometimes applied to this type. A number of commercial robots possess the polar configuration.

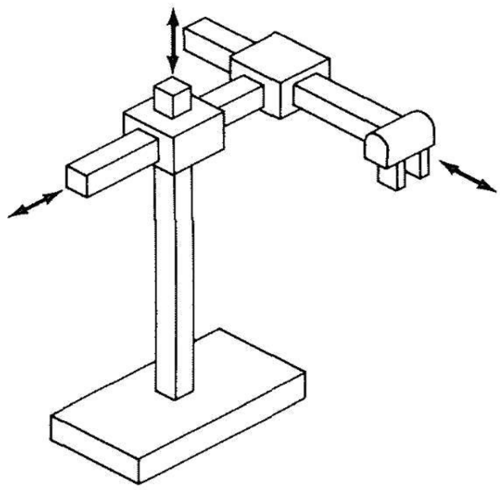
2. Cylindrical configuration:-



Cylindrical

The cylindrical configurable, as shown in fig, uses a vertical column and a slide that can be moved up or down along the column. The robot arm is attached to the slide so that it cm he moved radially with respect to the column. By routing the column, the robot is capable of achieving a work space that approximation a cylinder.

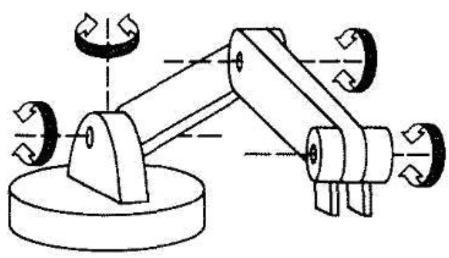
3. Cartesian coordinate configurable:-



Cartesian or *xyz*

The cartesian coordinate robot, illustrated in part Cc) of Fig, uses three perpendicular slides to construct the x, y, and z axes. Other names are sometimes applied W this configuration, including xyz robot and rectilinear robot, By moving the three slides relative to one another, the robot is capable of operating within a rectangular work envelope.

4. Jointed-arm configuration:-



Revolute

The jointed-arm robot is pictured in Fig. Its configuration is similar to that of the human arm. It consists of two straight components. Corresponding to the human forearm and upper arm, mounted on a vertical pedestal. These components are connected by two rotary joints corresponding to the shoulder and elbow.

Control systems:-

With respect to robotics, the motion control system used to control the movement of the end-effector or tool.

1. Limited sequence robots (Non-servo)
2. Playback robots with point to point (servo)
3. Play back robots with continuous path control,
4. Intelligent robots.

Limited sequence robots (Non-servo):-

Limited sequence robots do not give servo controlled to inclined relative positions of the joints; instead they are controlled by setting limit switches & are mechanical stops. There is generally no feedback associated with a limited sequence robot to indicate that the desired position, has been achieved generally thin type of robots involves simple motion as pick & place operations.

Point to point motion:-

These type robots are capable of controlling velocity acceleration & path of motion, from the beginning to the end of the path. It uses complex control programs, PLC's (programmable logic controller's) computers to control the motion.

The point to point control motion robots are capable of performing motion cycle that consists of a series of desired point location. The robot is tough & recorded, unit.

Continuous path motion:-

In this robots are capable of performing motion cycle in which the path followed by the robot in controlled. The robot move through a series of closely space point which describe the desired path.

Ex:- Spray painting, arc welding & complicate assembly operations.

Intelligent robots:-

This type of robots not only programmable motion cycle but also interact with its environment in a way that years intelligent. It taken make logical decisions based on sensor data receive from the operation.

There robots are usually programmed using an English like symbolic language not like a computer programming language.

Precision of movement (or) parameters of robot:-

The preceding discussion of response speed and stability is concerned with the dynamic performance of the robot. Another measure of performance is precision of the robot's movement. We will define precision as a function of three features:

1. Spatial resolution
2. Accuracy
3. Repeatability

These terms will be defined with the following assumptions.

1) The definitions will apply at the robot’s wrist end with no hand attached to the wrist.
2) The terms apply to the worst case conditions, the conditions under which the robot's precision will be at its wont. This generally means that the robot’s arm is fully extended in the case of a jointed arm or polar configurable.
3) Third, our definitions will he developed in the context of a point-to-point robot.

1. Spatial resolution:-

The spatial resolution of a robot is the smallest increment of movement into which the robot can divide its work volume. Spatial resolution depends on two factors: the system's control resolution and the robot's mechanical inaccuracies. It is easiest to conceptualize these factors in terms of a robot with 1 degree of freedom.

2. Accuracy:-

Accuracy refers to a robot's ability to position its wrist end at a desired target point within the work volume. The accuracy of a robot can be denned in terms of spatial resolution because the ability to achieve a given target point depends on how closely the robot can define the control increments for each of its joint motions.

3. Repeatability:-

Repeatability is concerned with the robot's ability to position its wrist or an end effector attached to its wrist at a point in space is known as repeatability. Repeatability and accuracy refer to two different aspects of the robot’s precision. Accuracy relates to the robot's capacity to be programmed to achieve a given target point. The actual programmed point will probably be different from the target point due to limitations of control resolution Repeatability refers to the robot’s ability to return to the programmed point when commanded to do so.