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SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – I – MECHATRONICS, SENSORS & TRANSDUCERS - SPR1304

1. INTRODUCTION

1.1. MECHATRONICS

Mechatronics is a concept of *Japanese* origin and can be defined as the application of electronics and computer technology to control the motions of mechanical systems.

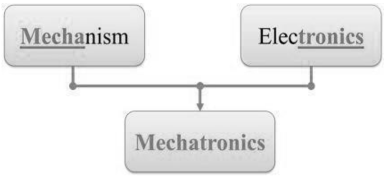


Fig 1: Origin of mechatronics

It is a multidisciplinary approach to product and manufacturing system design. 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.

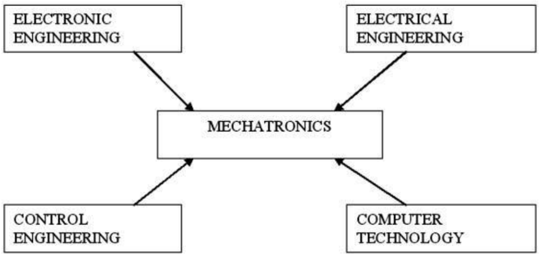


Fig 2: Mechatronics approach

1.2. SYSTEM:

A system may be defined as a black box which has an input and an output. System concerned only with the relationship between the input and output and not on the process going inside the box.

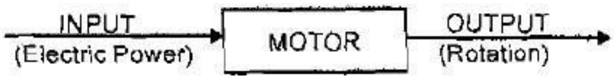


Fig 3: A system example

1.3. MECHATRONIC SYSTEM

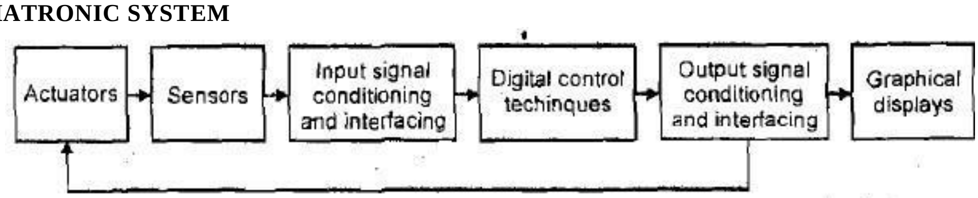


Fig 4: Elements of mechatronics

- **Actuators:** Solenoids, voice coils, D.C. motors, Stepper motors, Servomotor, hydraulics,pneumatics.
- **Sensors:** Switches, Potentiometer, Photo - electrics, Digital encoder, Strain gauge, Thermocouple, accelerometeretc.

- **Input signal conditioning and interfacing:** Discrete circuits, Amplifiers, Filters, A/D,D/D.
- **Digital control architecture:** Logic circuits, Microcontroller, SBC, PLC, Sequencing and timing, Logic and arithmetic, Control algorithm,Communication.
- **Output signal conditioning and interfacing:** D/A D/D, Amplifiers, PWM, Power transistor, Power Op -amps.
- **Graphical displays:** LEDs, Digital displays, LCD,CRT.

1.4. MEASUREMENT SYSTEM

A measurement system can be defined as a black box which is used for making measurements. It has the input as the quantity being measured and the output as a measured value of thatquantity.

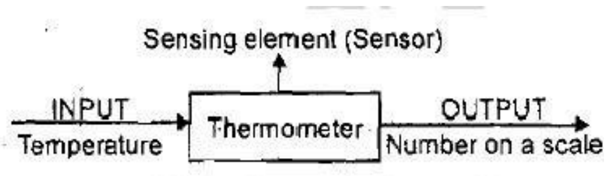


Fig 5: A measurement system

Elements of Measurement Systems:

Measurement system consists of the following three elements.

a) Sensor **b)** Signal conditioner **c)** DisplaySystem

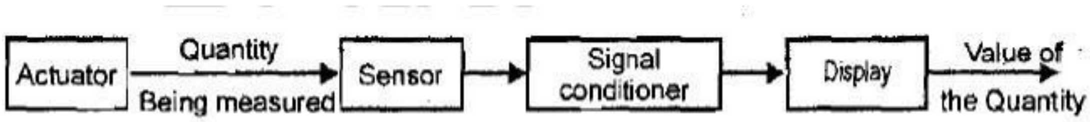


Fig 6: Elements of measurement system

- **Sensor:**

A sensor consists of transducer whose function is to convert the one form of energy into electrical form of energy. A sensor is a sensing element of measurement system that converts the input quantity being measured into an output signal which is related to the quantity.

- **SignalConditioner:**

A signal conditioner receives signal from the sensor and manipulates it into a suitable condition for display. The signal conditioner performs filtering, amplification or other signal conditioning on the sensor output.

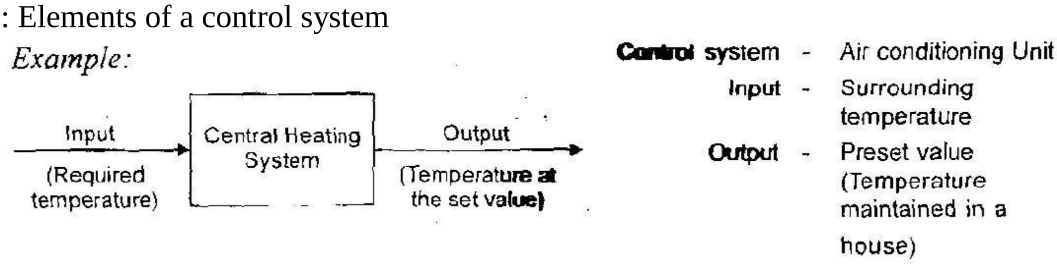
- **DisplaySystem:**

A display system displays the data (output) from the signal conditioner by analog or digital. A digital system is a temporary store such asrecorder.

1.5. CONTROL SYSTEM:

A black box which is used to control its output in a pre-set value

Fig 7: Elements of a control system



- **Open loop controlsystem:**

If there is **no feedback** device to compare the actual value with desired one. No control over its input

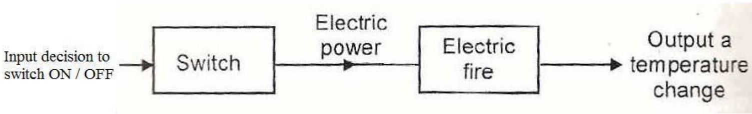


Fig 8:Open loop control system

- **Closed loop controlsystem:**

If there is **feedback** device to compare the actual value with desired one.

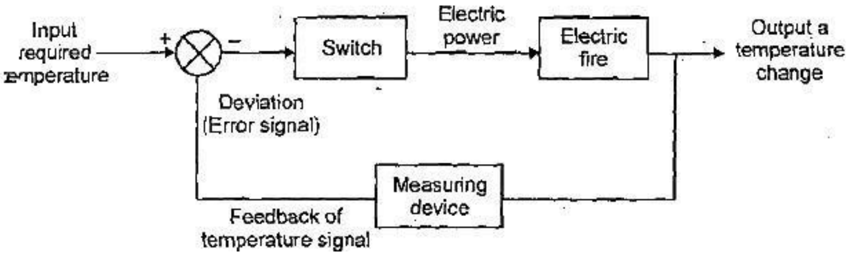


Fig 9: Closed loop control system

Elements of Closed Loop System:

The elements of closed loop control system are

- ComparisonUnit
- ControlUnit
- CorrectionUnit
- ProcessUnit
- MeasurementDevice

1.6. SYSTEM OF CONTROLLING WATER LEVEL

Controlledvariable: Water level in thetank
Referencevariable: Initial setting of the float and lever position Comparison
Element : Thelever
Error signal: Difference between the actual & initial *setting* of the lever positions
ControlUnit: The pivoted lever
CorrectionUnit: The flap opening or closing the water supply
Process: The water level in thetank
Measuringdevice: The floating ball andlever

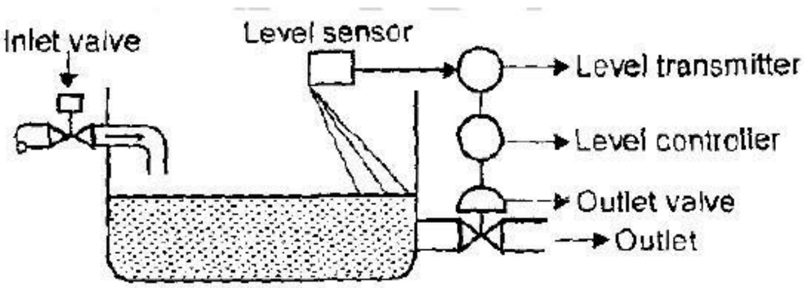


Fig 10: Water level indicator

1.7. 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-processors for controlling the wholesystem.

Measurement system comprises of sensors, transducers and signal processing devices.

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.

1. 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 preventativemeasures.
2. Reduces requirement of skilled and experiencedlabours.
3. Ultra-precision in product quality can beachieved.

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 measurandis 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 ininductance.

Transducer

It is defined as an element when subjected to some physical change experiences a related change or an element which converts a specified measured 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‟.

1.8. PERFORMANCE TERMINOLOGY

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 ofatransducerormeasurementsystem.Theseparametersarecalledassensorspecifications. Sensorspecificationsinformtheusertotheaboutdeviationsfromtheidealbehaviour of the sensors. Following are the various specifications of a sensor/transducersystem.

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 –0.2mm.

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 41µV/°C.

6. Nonlinearity

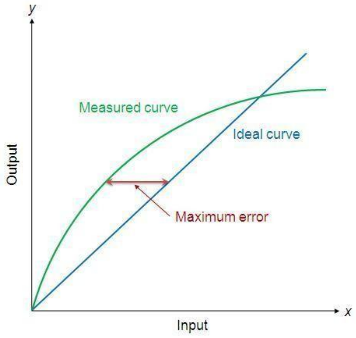


Fig 11 Non-linearity error

The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve. Figure 1 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 definedas:

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

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

7. Hysteresis

The hysteresis is an error of a sensor, which is defined as the maximum difference in output at any measurement value within the senso's specified range when approaching the point first with increasing and then with decreasing the input parameter. Figure 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.

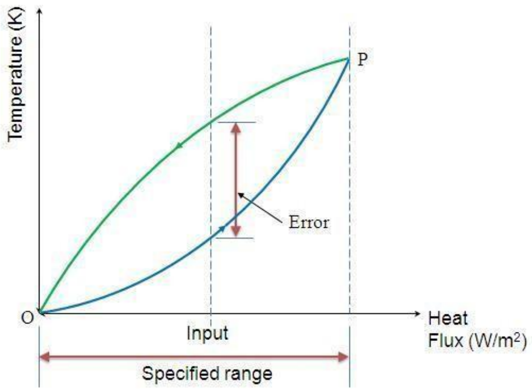


Fig 12 Hysteresis error curve

8. Resolution

Resolution is the smallest detectable incremental change of input parameter that canbe detectedintheoutput signal.Resolutioncanbe expressedeitherasaproportionofthe 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 0.2mm.

9. Stability

Stability is the ability of a sensor device to give same output when used to measure aconstantinputoveraperiodoftime.Theterm„drift"isusedtoindicatethechangeinoutput that occurs over a period of time. It is expressed as the percentage of full rangeoutput.

10. Deadband/time

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

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

12. Response time

Response time describes the speed of change in the output on a step-wise change of themeasurand.Itisalwaysspecifiedwithanindicationofinputstepandtheoutputrangefor which the response time isdefined.

1.9. 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 thermodynamicconsiderations.Thesegeneralclassificationsofsensorsarewelldescribed in the references.

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

A. Displacement, position and proximitysensors
- Potentiometer
- Strain-gaugedelement
- Capacitiveelement

- Differentialtransformers
- Eddy current proximitysensors
- Inductive proximityswitch
- Opticalencoders
- Pneumatic sensors
- Proximity switches(magnetic)
- Hall effectsensors

B. Velocity andmotion
- Incrementalencoder
- Tachogenerator
- Pyro electricsensors

C. Force
- Strain gauge loadcell

D. Fluidpressure
- Diaphragm pressuregauge
- Capsules, bellows, pressuretubes
- Piezoelectric sensors
- Tactilesensor

E. Liquidflow
- Orificeplate
- Turbinemeter

F. Liquidlevel
- Floats
- Differentialpressure

G. Temperature
- Bimetallicstrips
- Resistance temperaturedetectors
- Thermistors
- Thermo-diodes andtransistors
- Thermocouples
- Lightsensors
- Photodiodes
- Photoresistors

1.10. DISPLACEMENT AND POSITIONSENSORS

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.

1. Potentiometer Sensors

Figure shows the construction of a rotary type potentiometer sensor employed to measurethelineardisplacement.Thepotentiometercanbeoflinearorangulartype.Itworks 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 electriccontact.

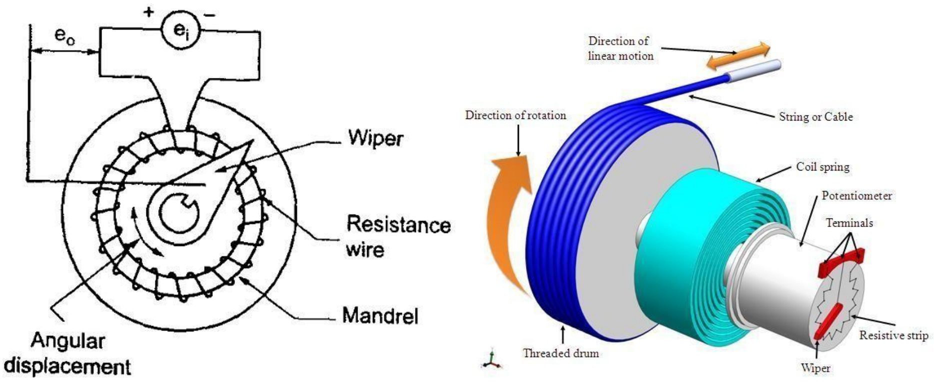


Fig13: Schematic of a potentiometer sensor for measurement of linear displacement

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

- a rotating shaft (for angulardisplacement)
- a moving rod (for lineardisplacement)
- a cable that is kept stretched duringoperation

Theresistiveelementisawirewoundtrackorconductiveplastic.Thetrackcomprises oflarge numberofcloselypackedturnsofaresistivewire.Conductiveplasticismadeupof 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 0.1μm. 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 4. The output voltage is proportional to the displacementoftheslideroverthewire.Thentheoutputparameterdisplacementiscalibrated against the output voltage*VA*.

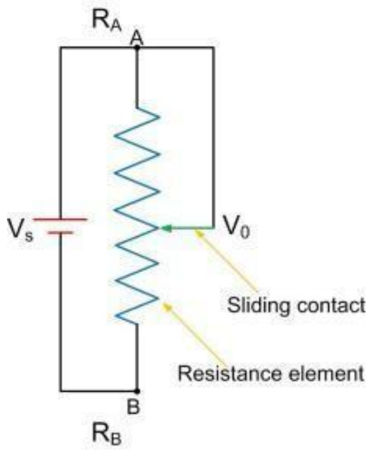


Fig14 Potentiometer: electric circuit

VA = I RA

But I = VS / (RA + RB)

Therefore VA = VS RA / (RA +RB)
As we know that R = ρ L / A, where ρ is electrical resistivity, L is length of resistor and A is area of crosssection
VA = VS LA / (LA + LB)

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 controlofinjectionmoldingmachines,woodworkingmachinery,printing,spraying,robotics, etc.

2. StrainGauges

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 cansay,

$\Delta R/R \; \alpha \; \varepsilon$;

$\Delta R/R = G \, \varepsilon$

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.

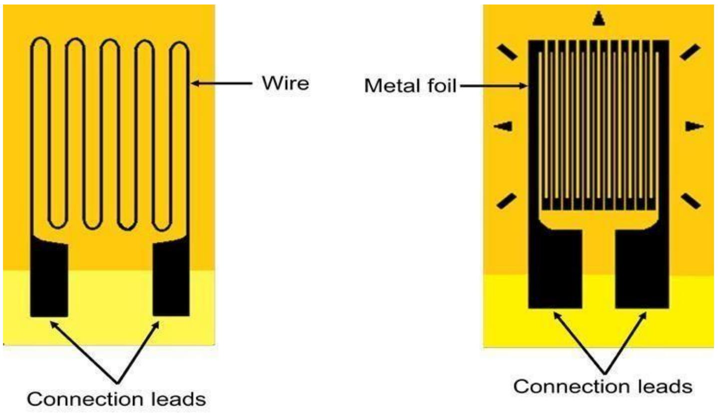


Fig15. A pattern of resistive foils

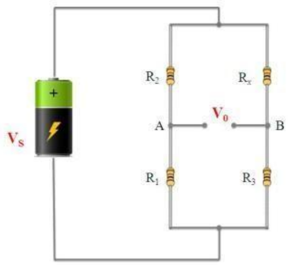


Fig16. Wheatstone's bridge

Resistance strain gauge follows the principle of change in resistance as per the equation. It comprises of a pattern of resistive foil arranged as shown in Figure 5.These foilsaremadeofConstantanalloy(copper-nickel55-45%alloy)andarebondedtoabacking material plastic (polyimide), epoxy or glass fiber reinforced epoxy. The strain gauges are secured to the workpieceby using epoxy or Cyanoacrylate cement Eastman910 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 6. 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.

3. Capacitive element basedsensor

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 separationchanges
b. Area of overlap changes due to thedisplacement.

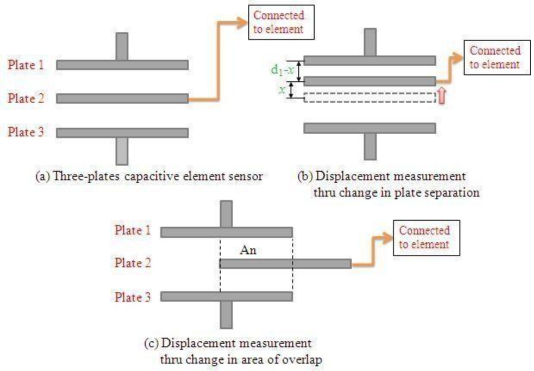


Figure 17.Shows the schematic of three-plate capacitive element sensor and displacement measurement of a mechanical element connected to the plate 2.

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

$C = \varepsilon r \varepsilon o\ A / d$

Where *εr*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 C1 and C2 are connected to a Wheatsone‟s bridge, then the resulting out-of-balance voltage would be in proportional to displacement x.

Capacitiveelementscanalso beusedasproximitysensor.Theapproachoftheobject towardsthesensorplateis used forinductionofchange inplateseparation.Thischangesthe capacitance which is used to detect theobject.

Applications of capacitive element sensors

- Feed hopper levelmonitoring
- Small vessel pumpcontrol
- Grease levelmonitoring
- Level control ofliquids
- Metrologyapplications

o to measure shape errors in the part being produced

o to analyze and optimize the rotation of spindles in various machine tools suchassurfacegrinders,lathes, millingmachines,andairbearingspindlesby measuring errors in the machine toolsthemselves

- Assembly linetesting
  - o to test assembled parts for uniformity, thickness or other designfeatures
  - o to detect the presence or absence of a certain component, such as glue etc.

4. *Linear variable differential transformer(LVDT)*

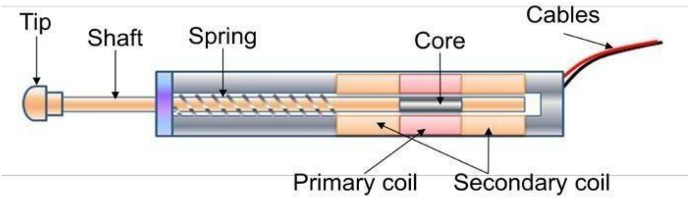


Figure 18. Construction of a LVDT sensor

Linear variable differential transformer (LVDT) is a primary transducer used for measurementoflineardisplacementwithaninputrangeofabout±2to±400mmingeneral. 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 insulatedtube.

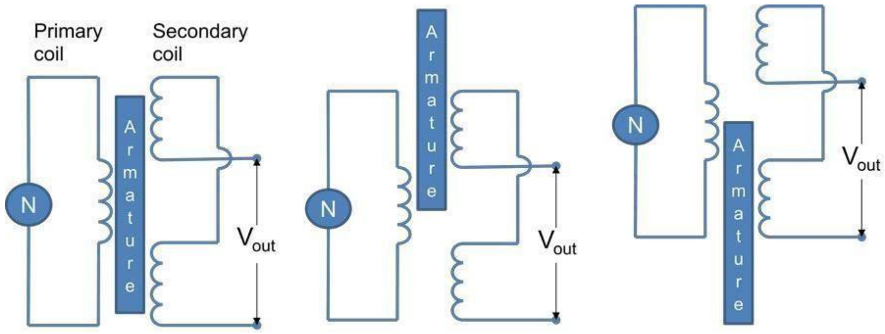


Figure 19. Working of LVDT sensor

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. IfthecoreisdisplacedfromthecentralpositionasshowninFigure9,say,moreinsecondary coil 1 than in coil 2, then more emfis 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. Withthehelpofsignalprocessingdevicessuchaslowpassfiltersanddemodulators,precise displacement can be measured by using LVDTsensors.

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 valveapplications
- To provide displacement feedback for hydrauliccylinders
- 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 detectionsystem
- To detect the number of currency bills dispensed by anATM.
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5. Eddy current proximitysensors

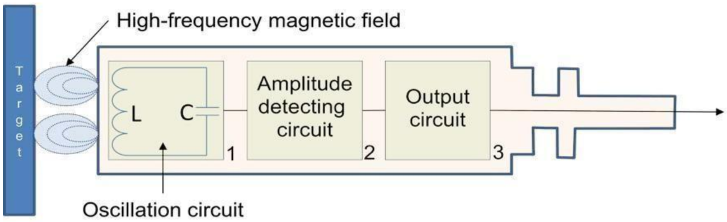

Fig 20. Schematic of Inductive Proximity Sensor

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 10 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 preciselocation
- Machine tool monitoring
- Final assembly of precision equipment such as diskdrives
- Measuring the dynamics of a continuously moving target, such as a vibrating element,
- Drive shaft monitoring
- Vibration measurements
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6. Inductive proximityswitch

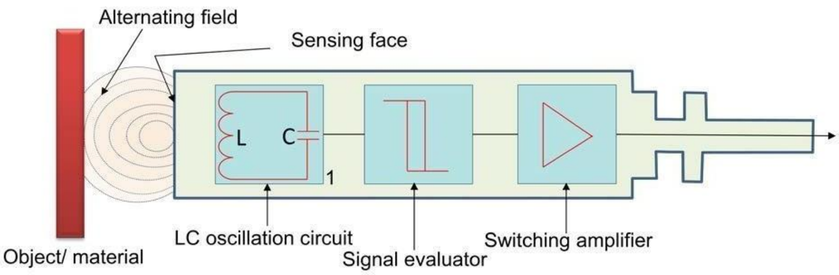


Fig 21 Schematic of Inductive Proximity Switch

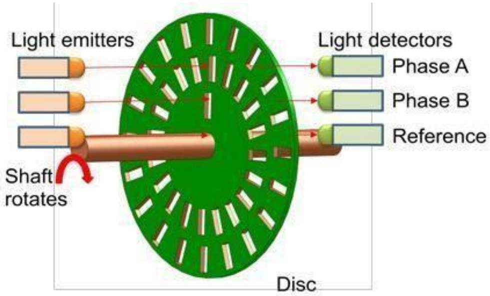
Inductive proximity switches are basically used for detection of metallic objects.

Figure shows the construction of inductive proximity switch. An inductive proximity sensor has four components; the coil, oscillator, detection circuit and output circuit. An alternating current is supplied to the coil which generates a magnetic field. When, a metal objectcomesclosertotheendofthecoil,inductanceofthecoilchanges.Thisiscontinuously monitored by a circuit which triggers a switch when a preset value of inductance change isoccurred.

Applications of inductive proximity switches

- Industrial automation: counting of products during production ortransfer.
- Security: detection of metal objects, arms, landmines.

7. Opticalencoders



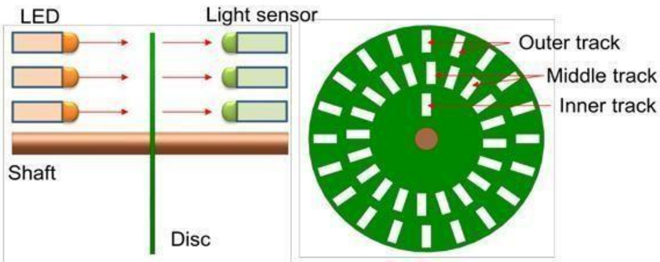


Fig 22 Construction and working of optical encoder

Optical encoders provide digital output as a result of linear / angular displacement. Thesearewidelyused intheServomotorstomeasuretherotationofshafts.Figure22shows the construction of an optical encoder. It comprises of a disc with three concentric tracks of equally spaced holes. Three light sensors are employed to detect the light passing thru the holes. These sensors produce electric pulses which give the angular displacement of the mechanical element e.g. shaft on which the Optical encoder is mounted. The inner track has just one hole which is used locate the „home‟ position of the disc. The holes on the middle track offset from the holes of the outer track by one-half of the width of the hole. This arrangement provides the direction of rotation to be determined. When the disc rotates in clockwise direction, the pulses in the outer track lead those in the inner; in counter clockwise direction they lag behind. The resolution can be determined by the number of holes on disc. With 100 holes in one revolution, the resolution wouldbe,

360^0 /100 = 3.6^0 .

8. 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 23. 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.

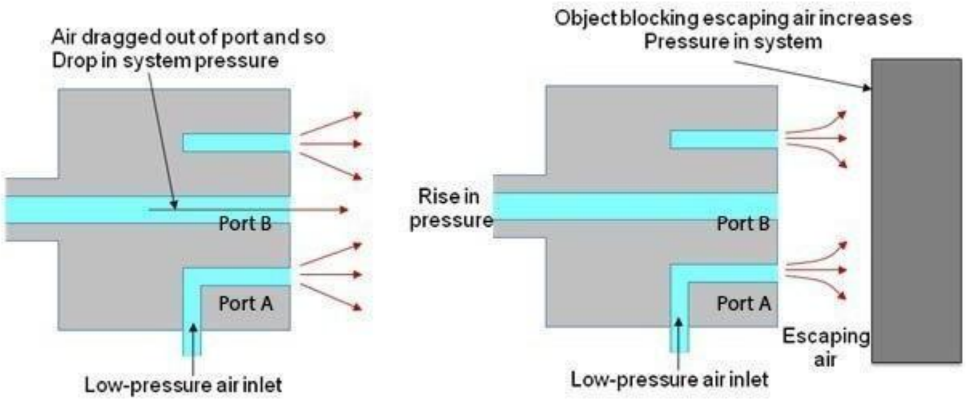


Fig23. Working of Pneumatic Sensors

1.11. PROXIMITY SWITCHES

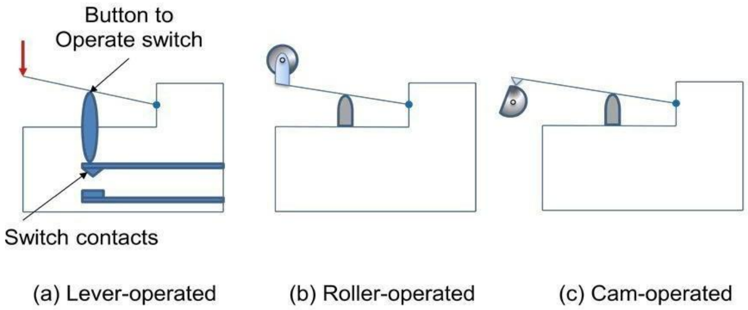


Fig24. Configurations of contact type proximity switch

Contact-type proximity switches 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 conveyorbelt.

Reed Switch

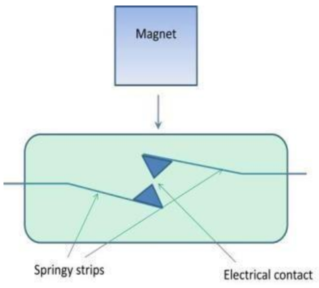


Fig 25 Reed Switch

Magnet based Reed switches are used as proximity switches. When a magnet attachedtoanobjectbroughtclosetotheswitch,themagneticreedsattracttoeachotherand close the switch contacts. A schematic is shown in Figure25.

LED based proximity sensors

Photo emitting devices such as Light emitting diodes (LEDs) and photosensitive devices such as photo diodes and photo transistors are used in combination to work as proximity sensing devices. Figure 16 shows two typical arrangements of LEDs and photo diodes to detect the objects breaking the beam and reflecting light.

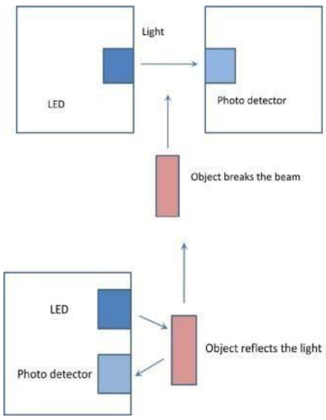


Fig 26. LED based proximity sensors

9. *Hall effectsensor*

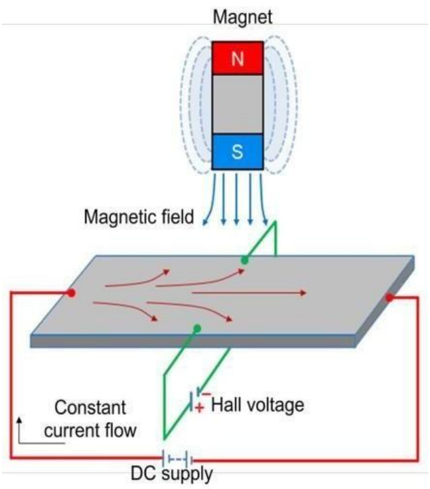


Figure 27 Principle of working of Hall effect sensor

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 generatesapotential difference which is the measure of distance of magnetic field from the disccarrying current. The typical application of Hall effect sensor is the measurement of fluid level in a container. The container comprisesofafloatwithapermanentmagnetattachedatitstop.Anelectric 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.

1.12. VELOCITY SENSOR

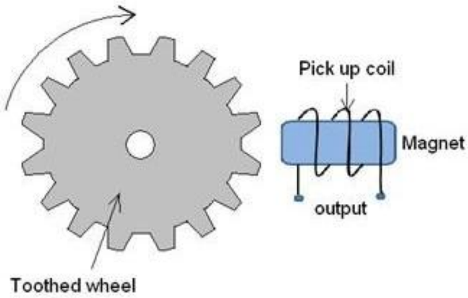


Fig 28:Tachogenerator

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. Toothed wheel is mounted on the shaft or the element of which angular motion is to be measured. Magnetic circuit comprisingofacoilwoundonaferromagneticmaterialcore.Asthewheelrotates,theairgap 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 acounter.

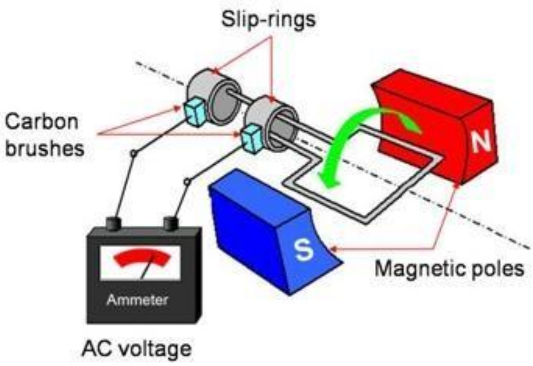


Fig 29: Tachogenerator

An alternating current (AC) generator can also be used as a techognerator. It comprises of rotor coil which rotates with the shaft. Figure shows the schematic of AC generator. The rotor rotates in the magnetic field produced by a stationary permanent magnet or electromagnet. During this process, an alternating emf is produced which is the measure of the angular velocity of the rotor. In general, these sensors exhibit nonlinearity error of about ± 0.15% and are employed for the rotationsup to about 10000rev/min.

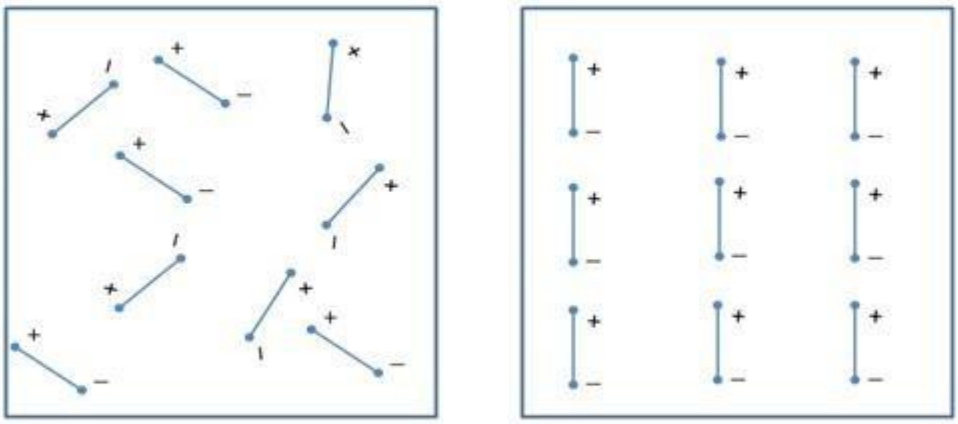


Fig 30: Pyroelectric sensors

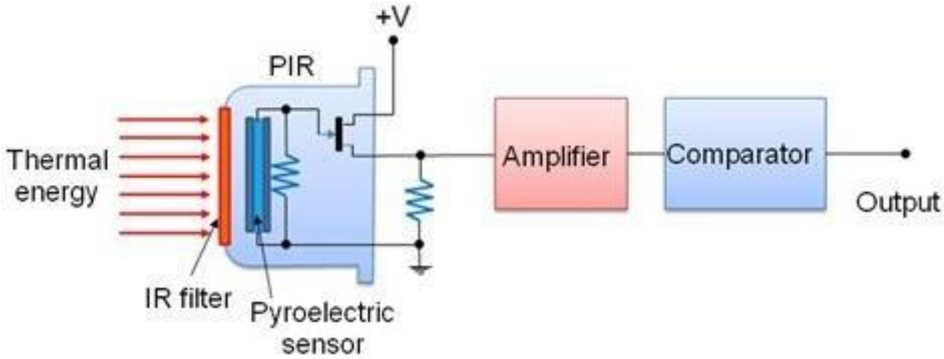


Fig 31: Pyroelectric sensor

Pyroelectric sensor comprises of a thick element of polarized material coated with thin film electrodes on opposite faces as shown in figure. 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

- Intrusiondetector
- Optothermaldetector
- Pollutiondetector
- Positionsensor
- Solar cellstudies
- Engine analysis

1.13. FORCE SENSOR

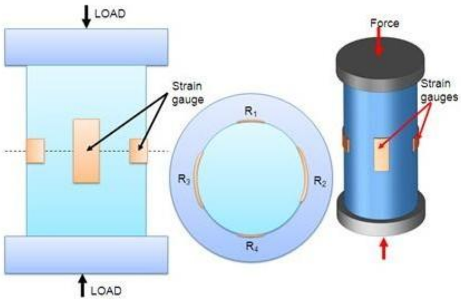


Fig 32: Strain Gauge in displacement measurement

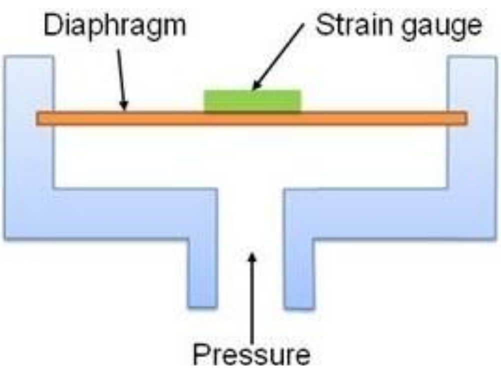


Fig 33: Strain gauge in pressure measurement

Tactile sensors

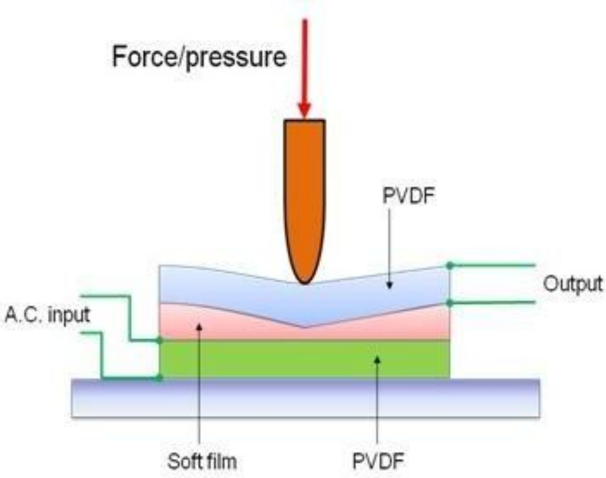


Fig 34: Tactile sensor

Piezoelectric sensor

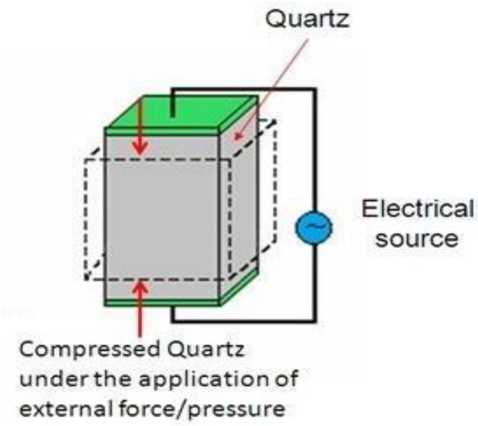


Fig 35: Liquid flow

1.14. LIQUID LEVEL

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:

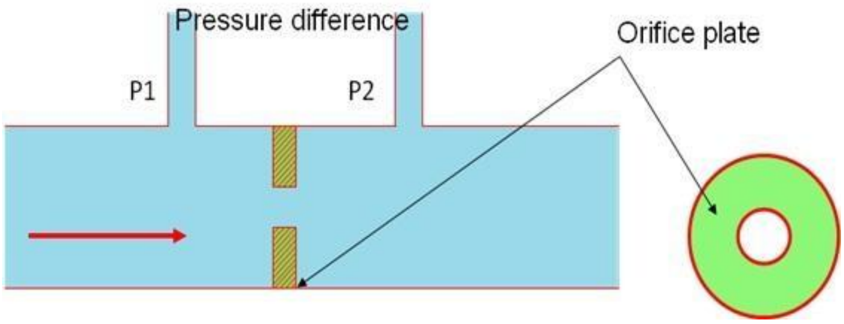


Fig 36: Orificemeter

Turbine meter

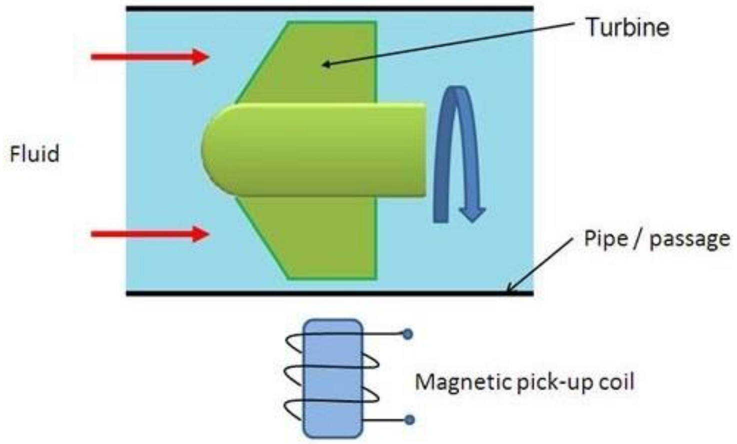


Fig 37: Turbine meter

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.

1.15. FLUID LEVEL

The level of liquid in a vessel or container can be measured,

a. directly by monitoring the position of liquidsurface
b. indirectly by measuring some variable related to theheight.

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.

1.16. TEMPERATURE SENSORS

Temperature conveys the state of a mechanical systemin 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**

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 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.

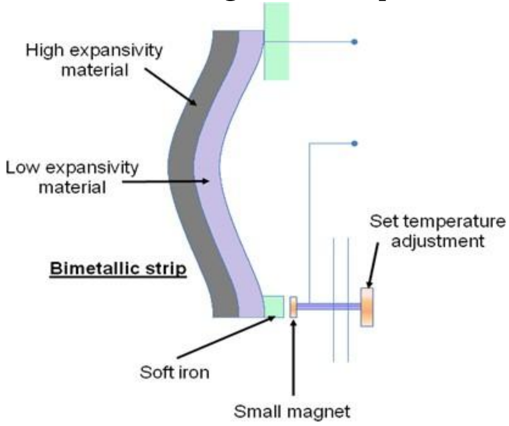


Fig 38: Bimetallic strip

2. Resistance temperature detectors(RTDs)

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

$$R_t = R_0(1 + \alpha T)$$

Where $R_t$is the resistance at temperature T (°C) and R_0 is the temperature at 0°C 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

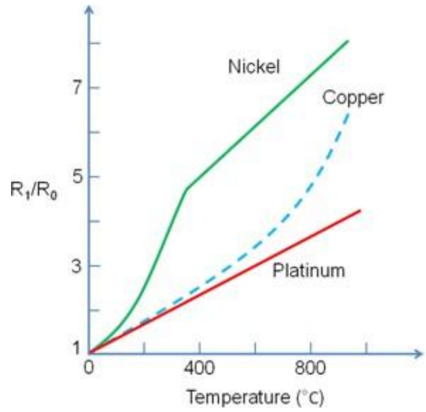


Fig 39: RTD Charateristics by elements

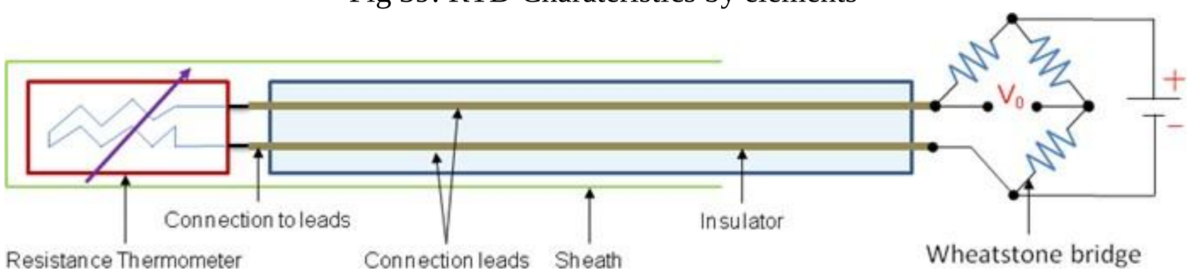


Fig 40: RTD Construction

Figure 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 refrigerationservicing
- FoodProcessing
- Stoves andgrills
- Textileproduction
- Plasticsprocessing
- Petrochemicalprocessing
- Microelectronics
- Air, gas and liquid temperature measurement in pipes andtanks
- Exhaust gas temperaturemeasurement

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) ordopedpolycrystalline 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 41 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.

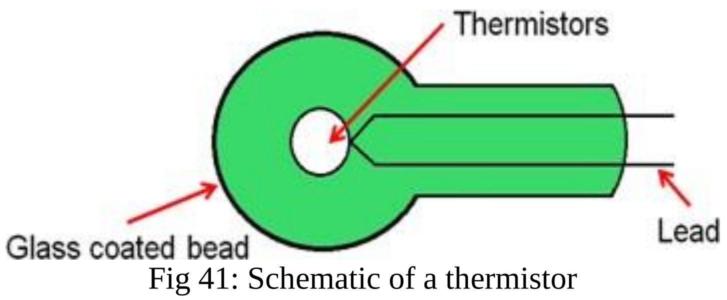


Fig 41: Schematic of a thermistor

Applications of Thermistors

- To monitor the coolant temperature and/or oil temperature inside theengine
- To monitor the temperature of anincubator
- Thermistors are used in modern digitalthermostats
- To monitor the temperature of battery packs whilecharging
- To monitor temperature of hot ends of 3Dprinters
- 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.

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 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, $\Delta V_{AB} = \alpha \Delta T$

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

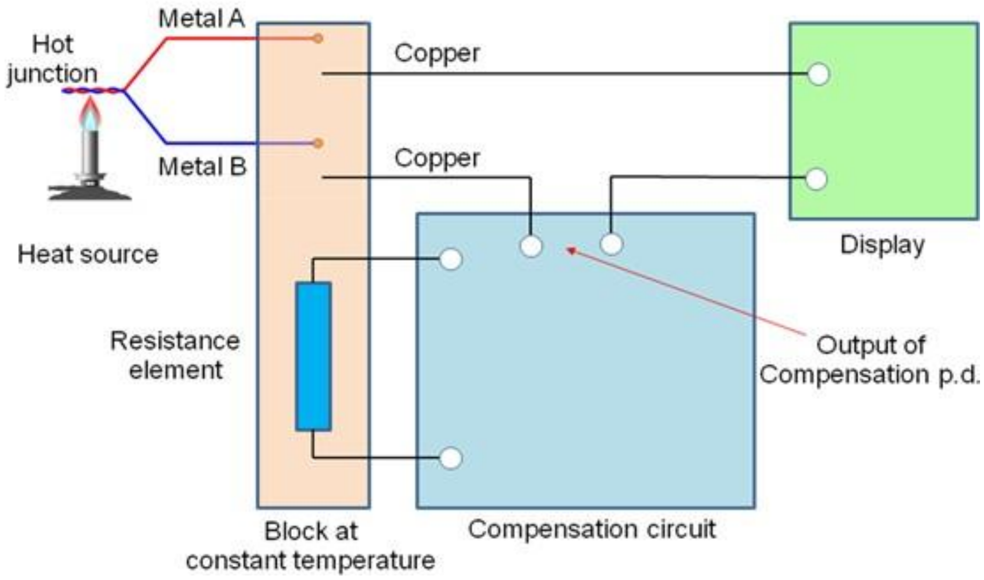


Fig 42: Schematic of thermocouple circuit

- 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 combinationsand application temperatureranges.

Applications of Thermocouples

- To monitor temperatures and chemistry throughout the steel makingprocess
- Testing temperatures associated with process plants e.g. chemical productionand petroleumrefineries
- Testing of heating appliancesafety
- Temperature profiling in ovens, furnaces andkilns
- Temperature measurement of gas turbine and engineexhausts
- Monitoring of temperatures throughout the production and smelting process inthe steel, iron and aluminumindustry

1.17. LIGHT SENSORS

A light sensor is a device that is used to detect light. There are different types of light sensorssuch 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 CdSphotoresistor varies inversely to the amount oflight incident upon it.Photoresistor follows the principle of p hotoconductivity which results from the generation of mobile carriers when photons are absorbed by the semiconductor material.

Figure 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.

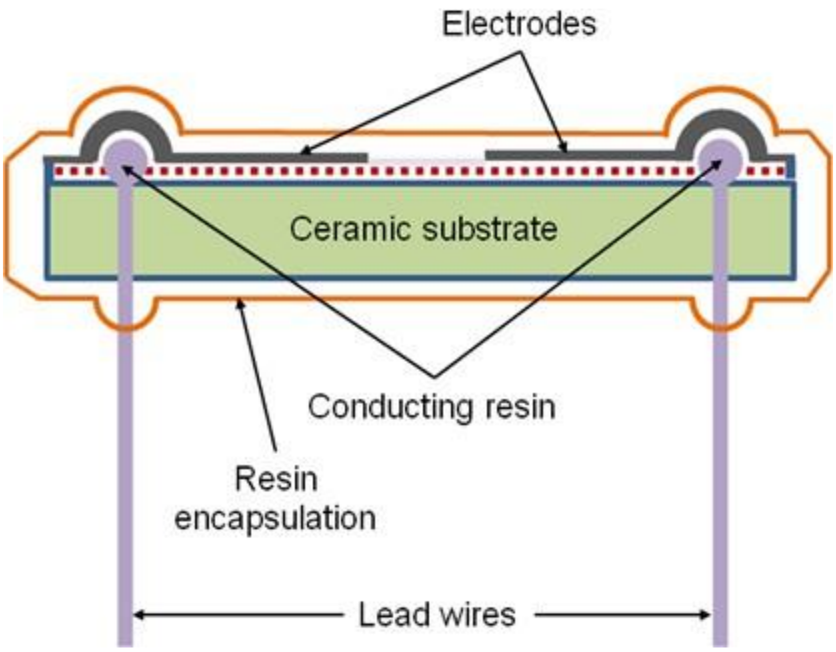


Fig 43: Construction of a photo resistor

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 ascreen
- Barcode scanners used in retailer locations work using light sensortechnology
- 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 isdetected.
- Auto Flash forcamera
- Industrial processcontrol

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 a opening or optical fiber connection to allow light to reach the sensitive part of the device.

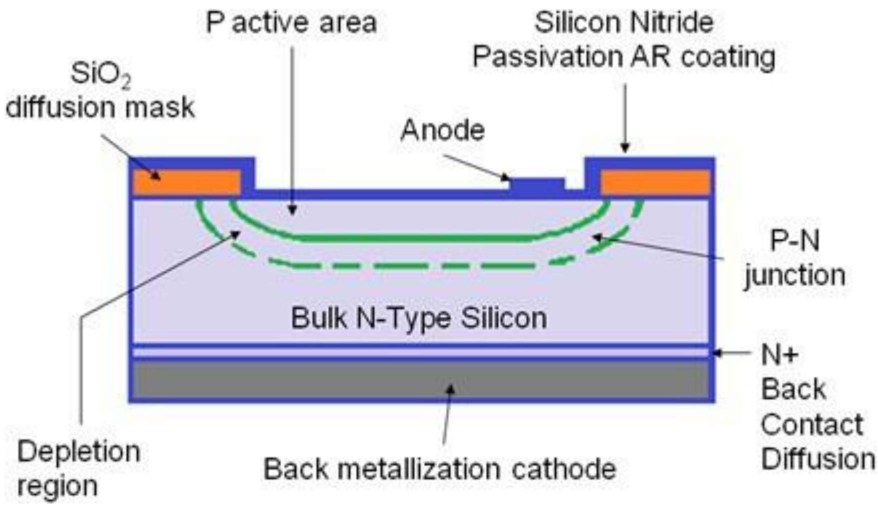


Fig 44: Photodiode

Figure 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 CodeScanners
- LightPens
- BrightnessControls
- Encoders
- PositionSensors
- SurveyingInstruments
- Copiers - Density of Toner.

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UNIT – 2 - SIGNAL CONDITIONING - SPR1304

2. SIGNALCONDITIONING

2.1. INTRODUCTION

The output signal from sensor of a measurement system has to be processed in a suitable form for next stage of operation.

Example:

Too small amplified
Interference removed
Non- linear Linearisation
Analog Digital
Digital Analog
Resistance change Current change
Voltage change Suitable current change

The above changes are referred as signal conditioning

Output from thermocouple is small voltage (few millivolts) – a signal conditioning module is used to convert into suitable size current signal

Interfacing with Microprocessor

- Input & output devices are connected to a microprocessor system through ports.
- Interface is used to make connections between devices a& a port.
- Input from sensors, switches, & keyboards and output to displays & actuators.
- Simplest interface is a piece of wire.
- Interface consists of signal conditioning & protection (prevent from damage)

1. Protection to prevent damage to next element (microprocessor) – high current or voltage. Current limiting resistors, fuses to break when there is high current.
2. Getting the signal into the right type of signal.
   Converting signal into d.c voltage or current.
   (Resistance change of strain gauge converted to voltage change, done by Wheatstone bridge)
3. Getting the level of the signal right. (Thermocouple signal – few millivolts, fed into an analog to digital converter, input for a microprocessor, to be made larger i.e volts rather than millivolts, operational amplifier used).
4. Eliminating or reducing noise. (Filters used to eliminate mains noise from signal).
5. Signal manipulation: making it a linear function of some variable. Flowmeter, signals will be nonlinear – signal conditioner used to next elementto make it linear.

BASIC ELEMENTS IN SIGNAL CONDITIONING

- Operational amplifier
- Inverting amplifier
- Non-inverting amplifier
- Summer
- Difference amplifier
- Instrumentations amplifier
- Integrator
- Differentiator
- Comparator
- Sample and hold Circuit

2.2.OPERATIONAL AMPLIFIER

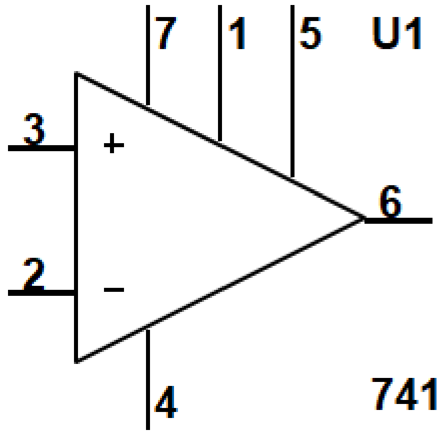

Fig 1: Op-amp

It is the basics of many signal conditioning modules.

High gain d.c. amplifier, gain being order of 100000 or more, supplied as an integrated circuit on a silicon chip.

Consists of 2 inputs, Inverting input (-) & Non-inverting input (+).

Output depends on the connections made to these inputs.

Few other inputs are, negative voltage supply, a positive voltage supply & two inputs termed offset null (enable to made corrections for non-ideal behaviour of the amplifier).

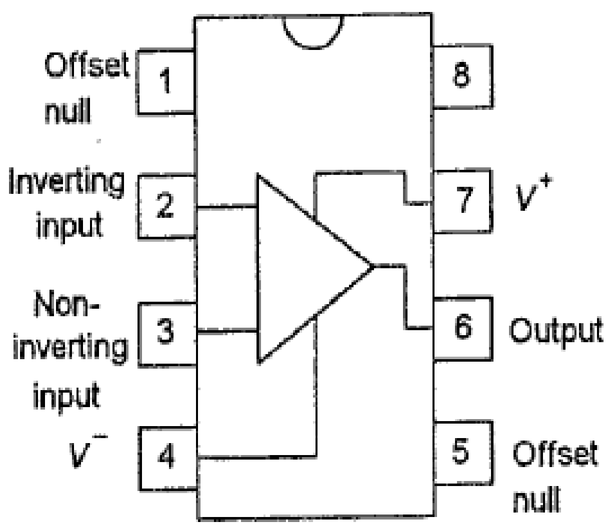

Fig 2: Pin configuration of Op-amp

INVERTING AMPLIFIER

Connections made to the amplifier when used as an inverting amplifier.Input is taken to inverting input throughresistor R1 with Non-inverting input,connected to ground.Afeedback path provided from output through R2 to the inverting input.OA – 100000 & change in o/p is $\pm$ 10VThis is virtually Zero & so X is at virtually earth potential (virtual earth) Potential difference across (V_{in} – V_X), $V_{in}= I_1R_1$. ⟶1 For ideal OA with infinite gainOP has high impedance b/w I/P terminals.

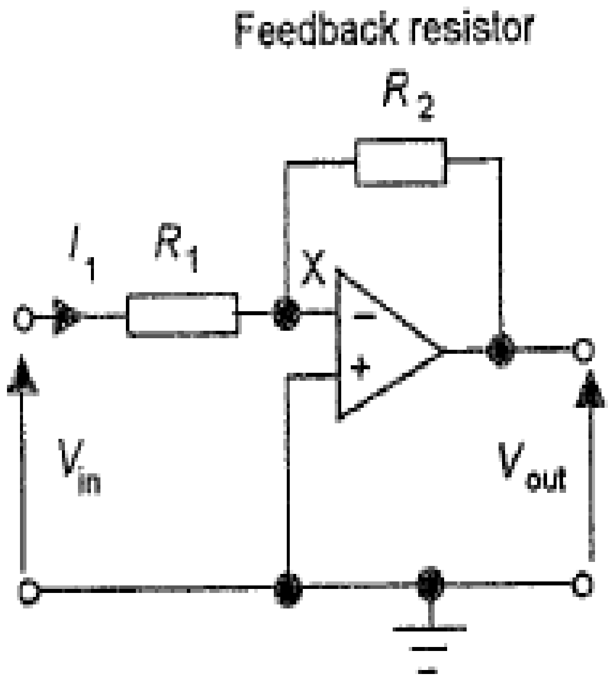

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Fig 3: Inverting op-amp circuit

Virtually no current flows through X, considering I/P impedance as infinite for Ideal OA & hence no current through X.Potential difference across R2 ($V_X - V_{out}$), is Current I1 through R1 must be through R2…-$V_{out} = I_1R_2$ ⟶ 2. Since Vx is 0Potential difference across R2 is –Vout. Dividing 2 by 1Voltage gain of circuit=$V_{out}/ V_{in} = R_2/R_1$
Voltage gain is determined by relative values of R_2& R_1Negative sign indicates O/P is inverted (180° out of phase) w.r.t I/p

NON-INVERTING AMPLIFIER

OA connected as Non- Inverting amplifier.O/P considered to be taken from across a potential divider circuit consisting R_1 in serieswith R_2. Vx is then fraction of $R_1/ (R_1 + R_2)$ of the O/P

$$V_X = \frac{R_1}{R_1 + R_2} V_{out}$$

. Virtually no current through OA between 2 Inputs, So virtually no potential difference b/w them.Thus with Ideal OA, Vx = V_{out}. Voltage gain of circuit =

$$\frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

Used when the feedback loop is ashort circuit R2 = 0Vol gain is 1The I/P to circuit is into a large resistance

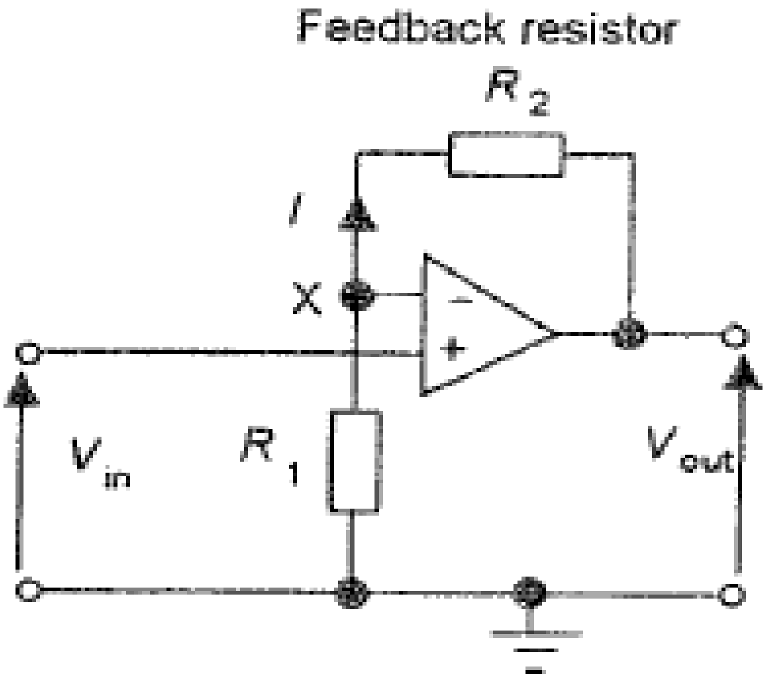


Fig 4: Non-inverting op-amp circuit

SUMMING AMPLIFIER

In inverting amplifier, X is a virtual earth.Sum of the currents entering X must equal that leaving

$I = I_A + I_B + I_C$

it.

$I_A = \frac{VA}{RA}$, $I_B = \frac{VB}{RB}$, $I_C = \frac{VC}{RC}$

Same current I passing through the feedback resistor.Potential difference across $R_2 = (V_X – V_{out})$

Since $V_X = 0$, $– V_{out}$& $I = – V_{out} / R_2$

$$-\frac{V_{out}}{R_2} = \frac{V_A}{R_A} + \frac{V_B}{R_B} + \frac{V_C}{R_C}$$

The O/P is thus the scaled sum of the I/P

$$V_{out} = -\left(\frac{R_2}{R_A}V_A + \frac{R_2}{R_B}V_B + \frac{R_2}{R_C}V_C\right)$$

If **RA** = **RB** = **RC**= **R1** , Then

$$V_{out} = -\frac{R_1}{R_2}(V_A + V_B + V_C)$$

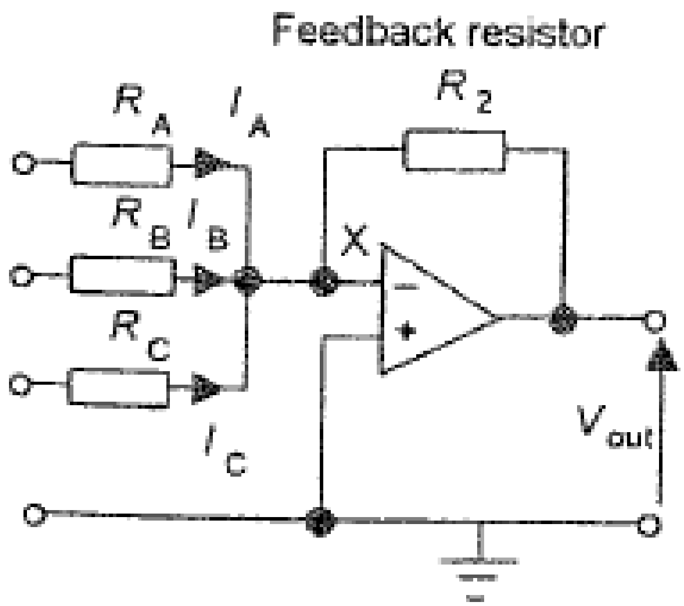


Fig 5: Summing circuit

INTEGRATING AMPLIFIER

An inverting amplifier circuit with feedback through capacitor is considered. Current is the movement of charge q $I_A = C_{v,\ v\ =}$ Voltage across it, then the current through the capacitor $i = dq/dt = C\ dv/dt$. Potential difference across C is $(V_X - V_{out})$, as $V_X = 0$, virtual earth, $- V_{out}$, current through capacitor is $-C\ dv_{out}/dt$.

But its current through resistance R. $\frac{v_{in}}{R} = -C\frac{dv_{out}}{dt}$

Rearranging $dv_{out} = -\left(\frac{1}{RC}\right) v_{in}\, dt$

$$v_{out}(t_2) - v_{out}(t_1) = -\frac{1}{RC}\int_{t_1}^{t_2} v_{in}\, dt$$

Integrating both sides,

O/P voltage at time t_2 O/P voltage at timet$_1$

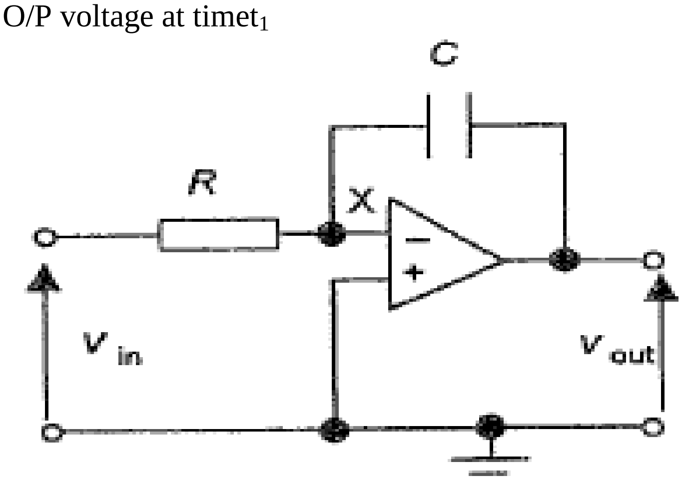


Fig 6: Integrator circuit

DIFFERENTIAL AMPLIFIER
Amplifies the difference between 2 I/P.There is no current through the high Resistance in the OA betweentwo I/P. Terminals, no potential drop, both I/p X will be at same potential.V_2 is across

R_1& R_2 in series. Potential V_X at X $$\frac{V_X}{V_2} = \frac{R_2}{R_1 + R_2}$$

The current through the feedback resistance must be equal to that from V_1 through R_1

$$\frac{V_1 - V_X}{R_1} = \frac{V_X - V_{out}}{R_2}$$

Rearranging $$\frac{V_{out}}{R_2} = V_X\left(\frac{1}{R_2} + \frac{1}{R_1}\right) - \frac{V_1}{R_1}$$

By substituting V_X $$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

O/P is a measure of difference b/w 2 I/P voltages

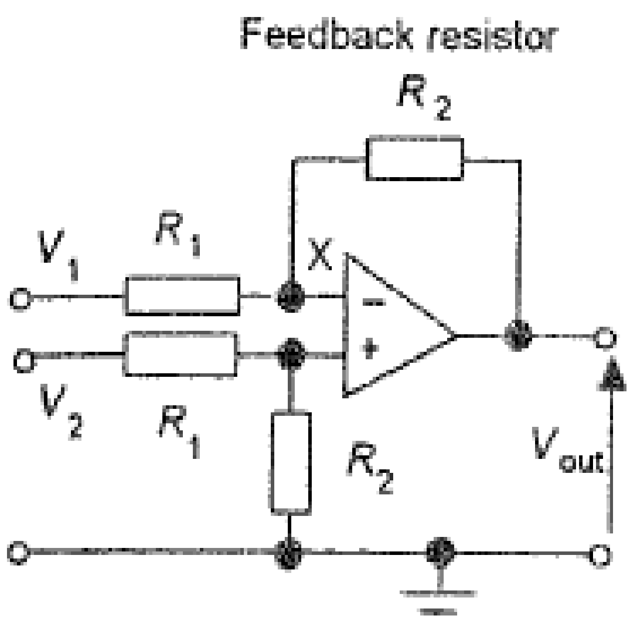


Fig 7: Differentiator ciruit

LOGRATHMIC AMPLIFIER
Some sensors have O/P, non-linear.O/P from thermocouple is not a perfectlyLinear function of the temp difference between its junction.A signal conditioner – linearise O/P, Done by OA circuit

having non-linearityRelationship b/w its I/P & O/P, I/P is Non-linear & O/P is Linear.Logarithmic amplifier – example of such sensorFeedback loop contains a diode (transistor with a grounded base), has Non-linearity characteristics.

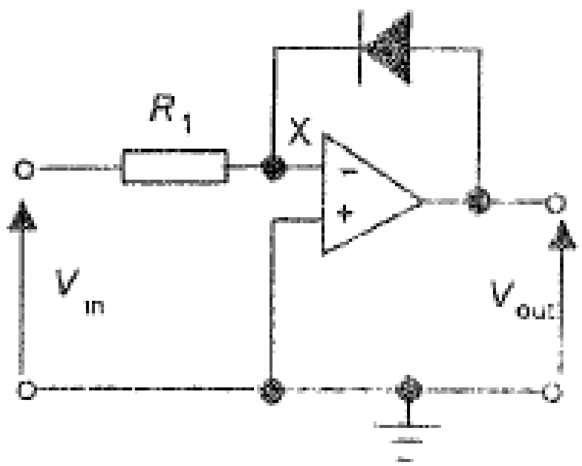


Fig 8: Logarithmic circuit

Represented by V = C in I, C – ConstantCurrent through feedback loop is same as the current through I/P resistance.Potential difference across diode is – V_{out}

$$V_{out} = -C \ln (V_{in}/R) = K \ln V_{in}$$

K – Propotionality constant. If the I/P V_{in} =is provided by a sensor with an I/P t,

$$V_{in} = A \ e^{at},$$

A & a – constants

$$V_{out} = K \ln V_{in} = K \ln (A \ e^{at}) = K \ln A + Kat$$

The result is a linear relationship betweenV_{out}& t.

COMPARATOR

A comparator indicates which of 2 voltages isthe larger.An OA is used with no feedback or other components can be used as comparator.One of the Voltage is applied to I/P & other toNon-Inverting I/P.When 2 I/P are equal there is no O/P.When non-inverting I/P is greater than invertingI/P by more than a small fraction of a volt, O/P Jumps to positive saturation voltage of +10V When Inverting I/P is greater than Non-InvertingI/P, O/P jumps to a steady negative saturation Voltage of -10V.Used to determine when a voltage exceeds a certain level,The O/P being used to perhaps initiate some action

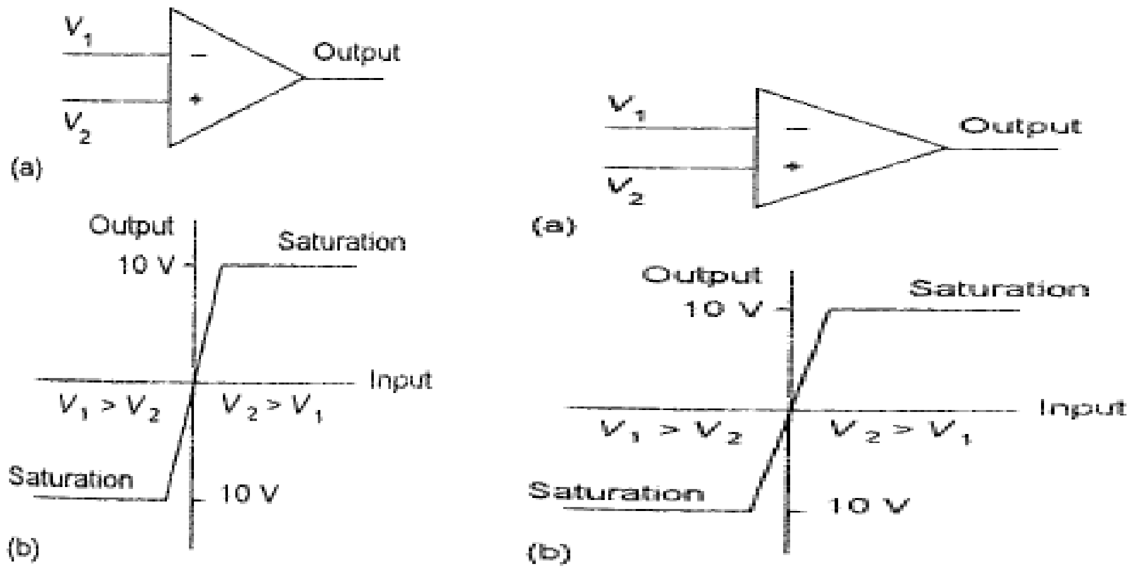


Fig 9: Relationship b/w O/P voltage & difference b/w I/P voltage

DIGITAL SIGNALS

- O/P from most sensors tends to be in analogue form
- When a microprocessor is used as part of measurement or control system, the analogue o/p from sensor has to converted to digital form, before used as an i/p to microprocessor.
- Most actuators operates with analogue form before it can be used as an i/p by the actuator.

ANALOG TO DIGITAL CONVERSION

- Involves converting analogue signals into binary words.
- Clock supplies regular time signal pulses to the ADC

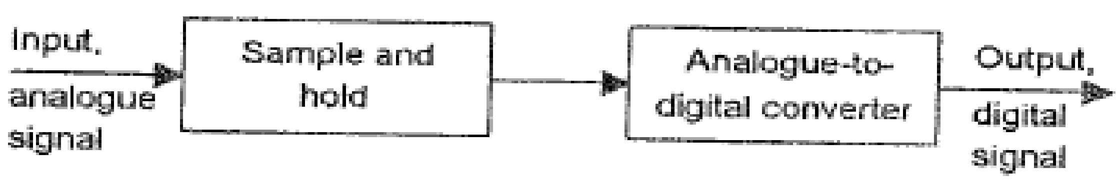
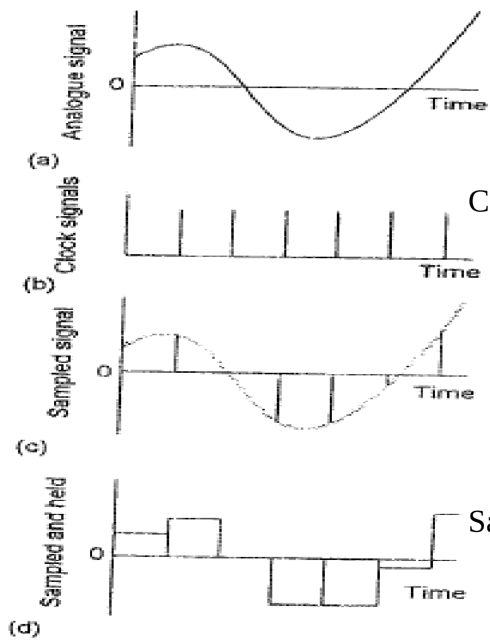


Fig 10:

Clock supplies regular time signal pulses to the ADC
Every time it receives a pulse & it samples the analogue signal
Result of sampling is a series of narrow pulses (C)



Clock, supplies time signals, sampling occurs

Sampled, series of pulses

Sampled & held, used to hold each sampled value until next pulse occurs

Fig11: Types of signals at various stages

2.3. DIGITAL TO ANALOUE CONVERSION

I/p to ADC is a binary words. o/p is an analogue signal, represents weighted sum of the non-zero bits (words). An i/p of 0010 to give an analogue o/p, which is twice that given by an i/p 000. Each additional bit increases o/p voltage by 1V

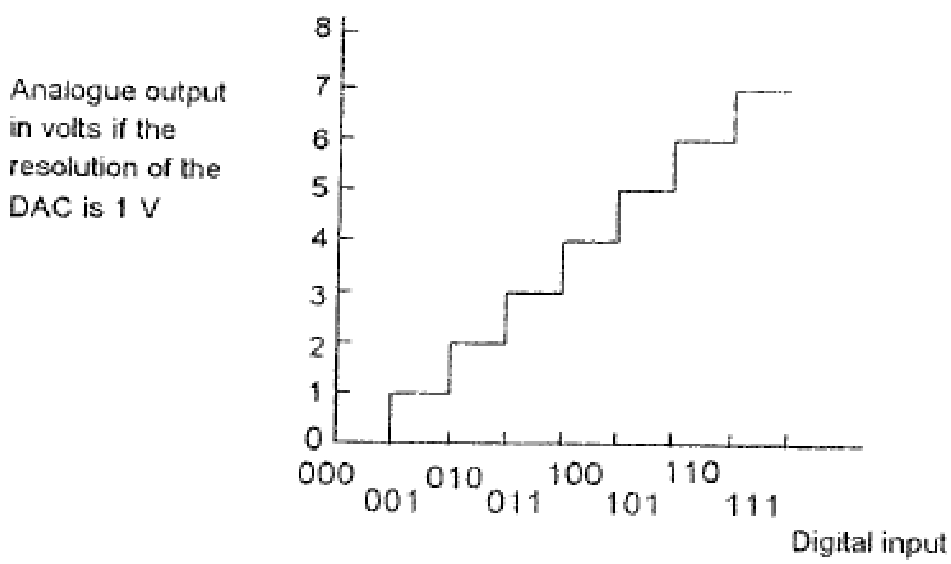


Fig 12: DAC Converter

Uses a summing up amplifier.Reference voltage is connected to resistor by means of electronic switches(binary 1)Value of i/p resistances depend on which bit in the word responding to.

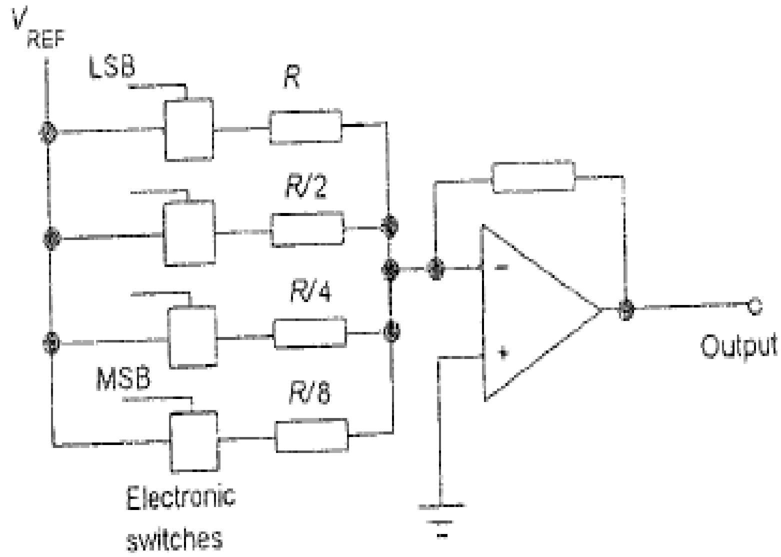


Fig 13: DAC circuit

2.4. DIGITAL CIRCUITS

In the large-scale-digital systems, a single line is required to carry on two or more digital signals – and, of course! At a time, one signal can be placed on the one line. But, what is required is a device that will allow us to select; and, the signal we wish to place on a common line, such a circuit is referred to as multiplexer.

The function of a multiplexer is to select the input of any ‘n’ input lines and feed that to one output line. The function of a de-multiplexer is to inverse the function of the multiplexer and the shortcut forms of the multiplexer. The de-multiplexers are mux and demux. Some multiplexers perform both multiplexing and de-multiplexing operations. The main function of the multiplexer is that it combines input signals, allows data compression, and shares a single transmission channel.

MULTIPLEXER

Multiplexer is a device that has multiple inputs and a single line output. The select lines determine which input is connected to the output, and also to increase the amount of data that can be sent over a network within certain time. It is also called a data selector.

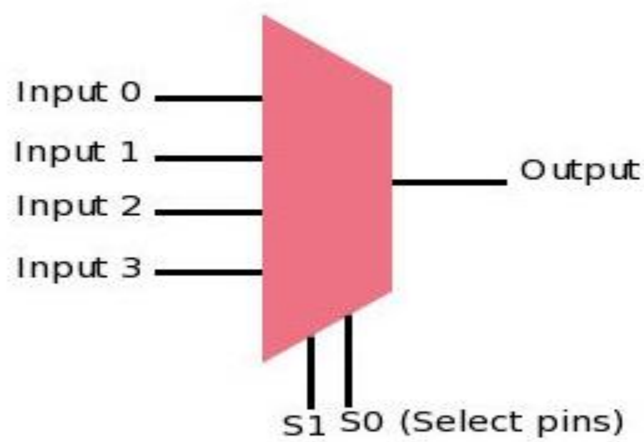


Fig 15: Multiplexer

The single pole multi-position switch is a simple example of non-electronic circuit of multiplexer, and it is widely used in many electronic circuits.. The multiplexer is used to perform high-speed switching and is constructed by electronic components.
Multiplexers are capable of handling both analoganddigital applications.. In analog applications, multiplexers are made up of of relays and transistor switches, whereas in digital applications, the multiplexers are built from standard logic gates. When the multiplexer is used for digital applications, it is called a digital multiplexer.

MULTIPLEXER TYPES

- 2-1 multiplexer (1select line)
- 4-1 multiplexer (2 select lines)
- 8-1 multiplexer(3 select lines)
- 16-1 multiplexer (4 select lines)

Microprocessor-

- First generation of processor: 4-bitMicroprocessor

The first microprocessor was introduced in 1971 by Intel Corp. It was named Intel 4004 as it was a 4 bit processor. It was a processor on a single chip. It could perform simple arithmetic and logic operations such as addition, subtraction, Boolean AND & Boolean OR. It had a control unit capable of performing control functions like fetching an instruction from memory, decoding it, and generating control pulses to execute it. It was able to operate on 4 bits of data at a time. This first microprocessor was quite a success in industry. Soon other microprocessors were also introduced. Intel introduced the enhanced version of 4004, the 4040. Some other 4 bit processors are International's PPS4 and Toshiba's T3472.

- Second generation of processor: 8-bitMicroprocessor

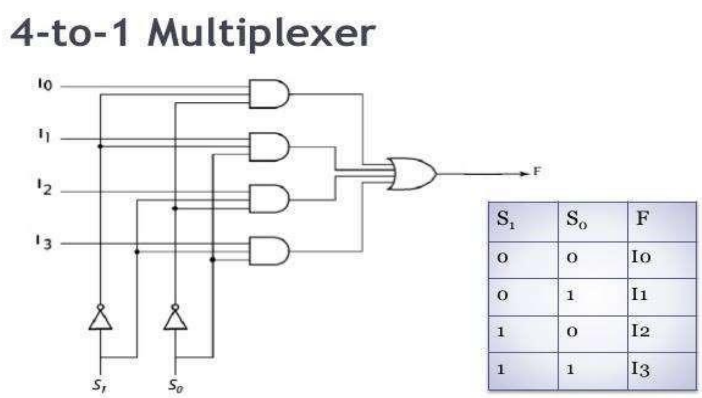


Fig 16: 4-to-1 multiplexer

Applications of Multiplexers

Multiplexers are used in various applications wherein multiple-data need to be transmitted by using single line.

- **Communication System**

A communication system has both a communication network and a transmission system. By using a multiplexer, the efficiency of the communication system can be increased by allowing the transmission of data, such as audio and video data from different channels through single lines or cables.

- **Computer Memory**

Multiplexers are used in computer memory to maintain a huge amount of memory in the computers, and also to reduce the number of copper lines required to connect the memory to other parts of the computer.

- **Telephone Network**

In telephone networks, multiple audio signals are integrated on a single line of transmission with the help of a multiplexer.

- **Transmission from the Computer System of a Satellite**

Multiplexer is used to transmit the data signals from the computer system of a spacecraft or a satellite to the ground system by using a GSM satellite.

De-multiplexer

De-multiplexer is also a device with one input and multiple output lines. It is used to send a signal to one of the many devices. The main difference between a multiplexer and a de-multiplexer is that a multiplexer takes two or more signals and encodes them on a wire, whereas a de-multiplexer does reverse to what the multiplexer does.

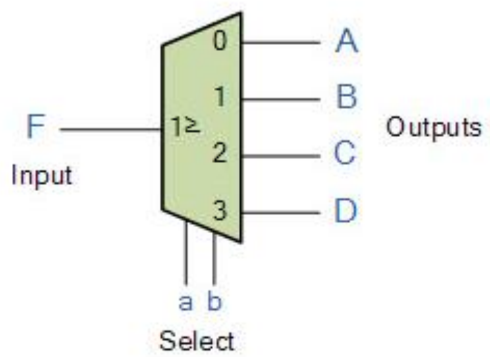


Fig 17: De-multiplexer

Types of De multiplexer

De-multiplexers are classified into four types

- 1-2 demultiplexer (1 select line)
- 1-4 demultiplexer (2 select lines)
- 1-8 demultiplexer (3 select lines)
- 1-16 demultiplexer (4 select lines)

1-8 De-multiplexers

The demultiplexer is also called as data distributors as it requires one input, 3 selected lines and 8 outputs. De-multiplexer takes one single input data line, and then switches it to any one of the output line. 1-to-8 demultiplexer circuit diagram is shown below; it uses 8 AND gates for achieving the operation. The input bit is considered as data D and it is transmitted to the output lines. This depends on the control input value of the AB. When AB = 01, the upper second gate F1 is enabled, while the remaining AND gates are disabled, and the data bit is transmitted to the output giving F1= data. If D is low, the F1 is low, and if D is high, the F1 is high. So the value of the F1 depends on the value of D, and the remaining outputs are in low state.

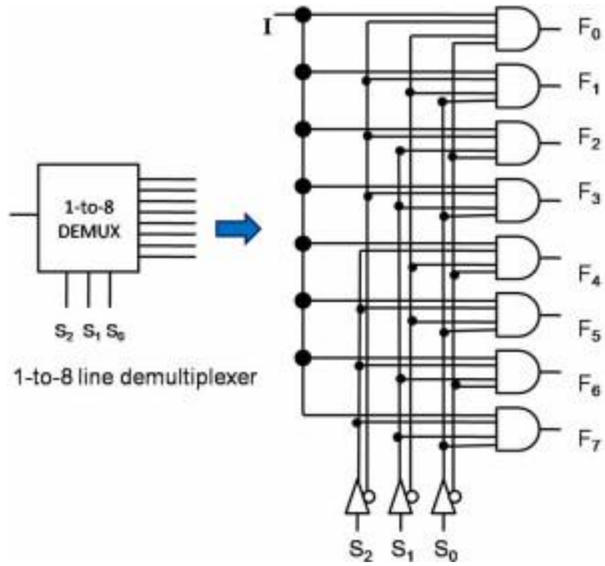


Fig 18: Demultiplexer

Applications of De multiplexer

De multiplexers are used to connect a single source to multiple destinations. These applications include the following:

- **Communication System**

Mux and demux both are used in communication system to carry out the process of data transmission. A De-multiplexer receives the output signals from the multiplexer and at the receiver end it converts them back to the original form.

- **Arithmetic Logic Unit**

The output of the ALU is fed as an input to the De-multiplexer, and the output of the demultiplexer is connected to a multiple register. The output of the ALU can be stored in multiple registers.

- **Serial to Parallel Converter**

This converter is used to reconstruct parallel data. In this technique, serial data is given as an input to the De-multiplexer at a regular interval, and a counter is attached to the demultiplexer at the control input to detect the data signal at the output of the demultiplexer. When all data signals are stored, the output of the demux can be read out in parallel.

This is the basic information about multiplexer and demultiplexers. Hope you might have got some fundamental concepts about this topic by observing the logic circuits and their applications. You can write your views about this topic in the comment section below.

2.5. INTRODUCTION TO MICROPROCESSOR AND MICROCOMPUTER ARCHITECTURE:

A *microprocessor* is a programmable electronics chip that has computing and decision making capabilities similar to central processing unit of a computer. Any microprocessor- based systems having limited number of resources are called *microcomputers*. Nowadays, microprocessor can be seen in almost all types of electronics devices like mobile phones, printers, washing machines etc. Microprocessors are also used in advanced applications like radars, satellites and flights. Due to the rapid advancements in electronic industry and large scale integration of devices results in a significant cost reduction and increase application of microprocessors and their derivatives.

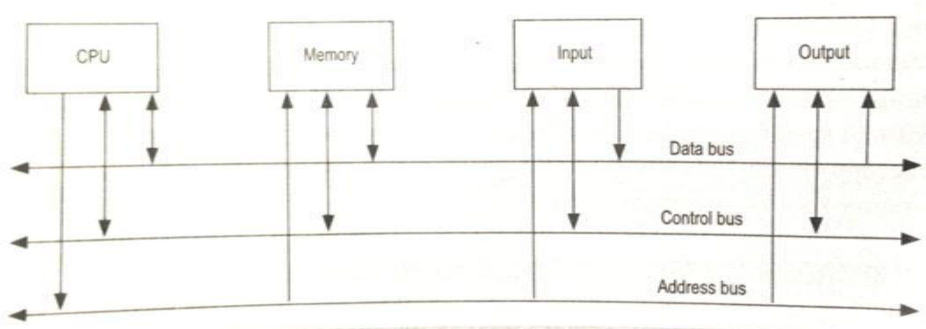


Fig 19: Microprocessor-based system

- ✓ **Bit**: A bit is a single binarydigit.
- ✓ **Word**: A word refers to the basic data size or bit size that can be processed by the arithmetic and logic unit of the processor. A 16-bit binary number is called a word in a 16-bitprocessor.
- ✓ **Bus**: A bus is a group of wires/lines that carry similarinformation.
- ✓ **System Bus**: The system bus is a group of wires/lines used for communication between the microprocessor andperipherals.
- ✓ **Memory Word**: The number of bits that can be stored in a register or memory element is called a memoryword.
- ✓ **Address Bus**: It carries the address, which is a unique binary pattern used to identify a memory location or an I/O port. For example, an eight bit address bus has eight lines and thus it can address $2^8 = 256$ different locations. The locations in hexadecimal format can be written as 00H –FFH.
- ✓ **Data Bus**: The data bus is used to transfer data between memory and processor or between I/O device and processor. For example, an 8-bit processor will generally have an 8-bit data bus and a 16-bit processor will have 16-bit databus.
- ✓ **Control Bus**: The control bus carry control signals, which consists of signals for selection of memory or I/O device from the given address, direction of data transfer and synchronization of data transfer in case of slowdevices.

A typical microprocessor consists of arithmetic and logic unit (ALU) in association with control unit to process the instruction execution. Almost all the microprocessors are based on the principle of store-program concept. In *store-program concept*, programs or instructions are sequentially stored in the memory locations that are to be executed. To do any task using a microprocessor, it is to be programmed by the user. So the programmer must have idea about its internal resources, features and supported instructions. Each microprocessor has a set of instructions, a list which is provided by the microprocessor manufacturer. The instruction set of a microprocessor is provided in two forms: *binary machine code and mnemonics*.

Microprocessor communicates and operates in binary numbers 0 and 1. The set of instructions in the form of binary patterns is called a *machine language* and it is difficult for us to understand. Therefore, the binary patterns are given abbreviated names, called mnemonics, which forms the *assembly language*. The conversion of assembly-level language into binary machine-level language is done by using an application called *assembler*.

Technology Used:

The semiconductor manufacturing technologies used for chips are:

- Transistor-Transistor Logic (TTL)
- Emitter Coupled Logic (ECL)
- Complementary Metal-Oxide Semiconductor (CMOS)

2.6. CLASSIFICATION OFMICROPROCESSORS

Based on their specification, application and architecture microprocessors are classified.

Based on size of data bus:

- 4-bitmicroprocessor
- 8-bitmicroprocessor
- 16-bitmicroprocessor
- 32-bitmicroprocessor

Based on application:

- General-purpose microprocessor- used in general computer system and can be used by programmer for any application. Examples, 8085 to IntelPentium.
- Microcontroller- microprocessor with built-in memory and ports and can be programmed for any generic control application. Example,8051.
- Special-purpose processors- designed to handle special functions required for an application. Examples, digital signal processors and application- specific integrated circuit (ASIC)chips.

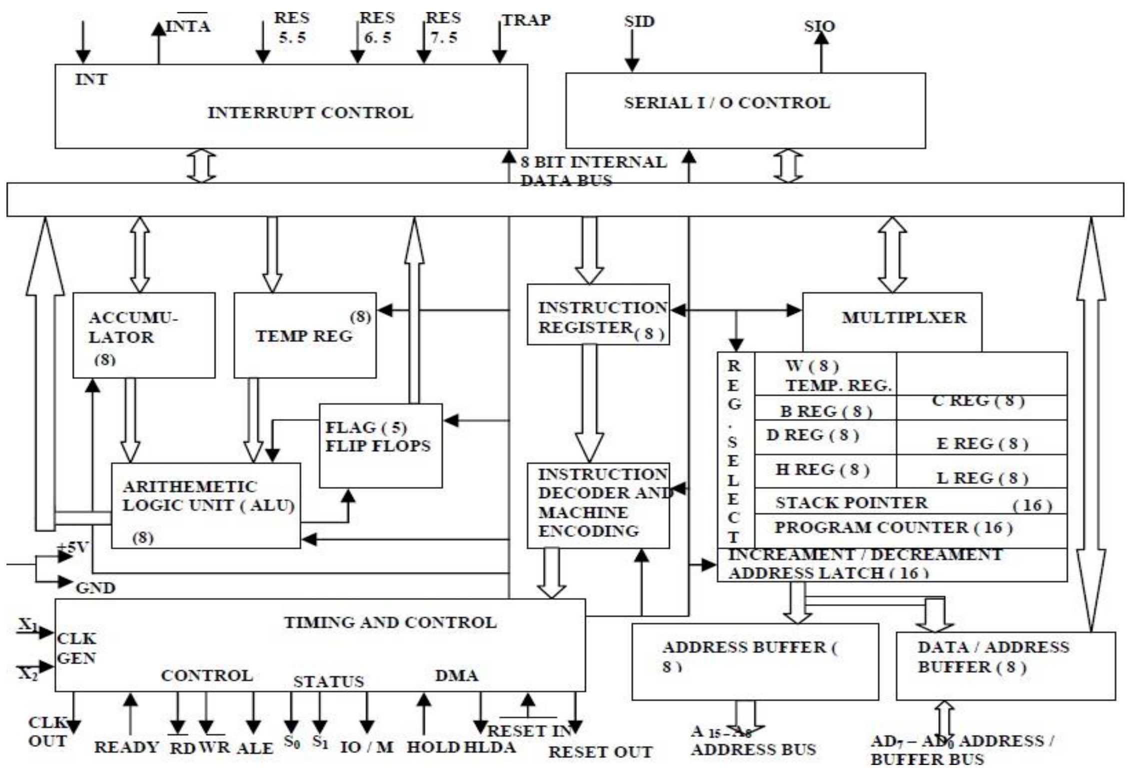


Fig 20:Architecture of a microcontroller

Based on architecture:

- Reduced Instruction Set Computer (RISC)processors
- Complex Instruction Set Computer (CISC)processors

2.7. 8085 MICROPROCESSORARCHITECTURE

The 8085 microprocessor is an 8-bit processor available as a 40-pin IC package and uses +5 V for power. It can run at a maximum frequency of 3 MHz. Its data bus width is 8-bit and address bus width is 16-bit, thus it can address 2^{16} = 64 KB of memory. The internal architecture of 8085 is shown is Fig. 20.

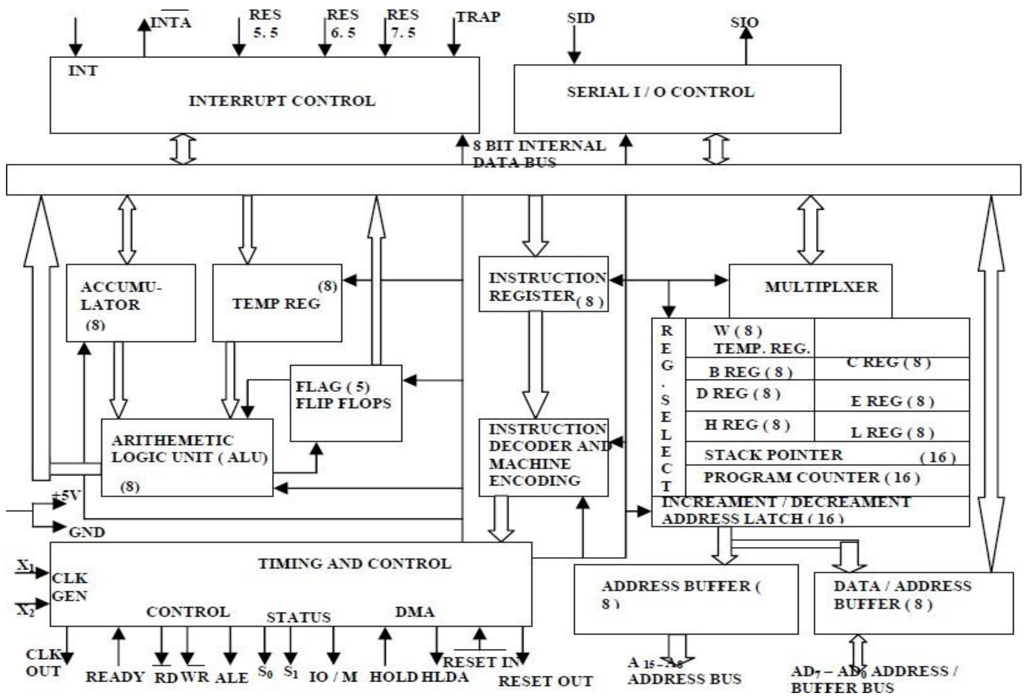


Fig 21: Internal Architecture of 8085

Arithmetic and Logic Unit

The ALU performs the actual numerical and logical operations such as Addition (ADD), Subtraction (SUB), AND, OR etc. It uses data from memory and from Accumulator to perform operations. The results of the arithmetic and logical operations are stored in the accumulator.

Registers

The 8085 includes six registers, one accumulator and one flag register, as shown in Fig. 3. In addition, it has two 16-bit registers: stack pointer and program counter. They are briefly described asfollows.

The 8085 has six general-purpose registers to store 8-bit data; these are identified as B, C, D,E,HandL.theycanbecombinedasregisterpairs-BC,DEandHLtoperformsomebit operations. The programmer can use these registers to store or copy data into the register by using data copyinstructions.

ACCUMULATOR

The accumulator is an 8-bit register that is a part of ALU. This register is used to store 8-bit data and to perform arithmetic and logical operations. The result of an operation is stored in the accumulator. The accumulator is also identified as register A.

Flag register

The ALU includes five flip-flops, which are set or reset after an operation according to data condition of the result in the accumulator and other registers. They are called Zero (Z), Carry (CY), Sign (S), Parity (P) and Auxiliary Carry (AC) flags. Their bit positions in the flag register are shown in Fig. . The microprocessor uses these flags to test dataconditions.

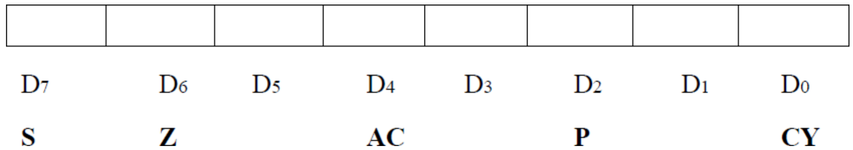


Fig 22: Flag Register

For example, after an addition of two numbers, if the result in the accumulator is larger than 8-bit, the flip-flop uses to indicate a carry by setting CY flag to 1. When an arithmetic operation results in zero, Z flag is set to 1. The S flag is just a copy of the bit D7 of the accumulator. A negative number has a 1 in bit D7 and a positive number has a 0 in 2's complement representation. The AC flag is set to 1, when a carry result from bit D3 and passes to bit D4. The P flag is set to 1, when the result in accumulator contains even number of 1s.

Program Counter (PC)

This 16-bit register deals with sequencing the execution of instructions. This register is a memory pointer. The microprocessor uses this register to sequence the execution of the instructions. The function of the program counter is to point to the memory address from which the next byte is to be fetched. When a byte is being fetched, the program counter is automatically incremented by one to point to the next memory location.

Stack Pointer (SP)

The stack pointer is also a 16-bit register, used as a memory pointer. It points to a memory location in R/W memory, called stack. The beginning of the stack is defined by loading 16- bit address in the stack pointer.

Instruction Register/Decoder

It is an 8-bit register that temporarily stores the current instruction of a program. Latest instruction sent here from memory prior to execution. Decoder then takes instruction and decodes or interprets the instruction. Decoded instruction then passed to next stage.

Control Unit

Generates signals on data bus, address bus and control bus within microprocessor to carry out the instruction, which has been decoded. Typical buses and their timing are described as follows:

- *Data Bus*: Data bus carries data in binary form between microprocessor and other external units such as memory. It is used to transmit data i.e. information, results of arithmetic etc between memory and the microprocessor. Data bus is bidirectional in nature. The data bus width of 8085 microprocessor is 8-bit i.e. 2^8 combination of binary digits and are typically identified as D0 – D7. Thus size of the data bus determines what arithmetic can be done. If only 8-bit wide then largest number is 11111111 (255 in decimal). Therefore, larger numbers have to be broken down into chunks of 255. This slowsmicroprocessor.
- *Address Bus*: The address bus carries addresses and is one way bus from microprocessor to the memory or other devices. 8085 microprocessor contain 16-bit address bus and are generally identified as A0 - A15. The higher order address lines (A8 – A15) are unidirectional and the lower order lines (A0 – A7) are multiplexed (time-shared) with the eight data bits (D0 – D7) and hence, they arebidirectional.

• *Control Bus*: Control bus are various lines which have specific functions for coordinating and controlling microprocessor operations. The control bus carries control signals partly unidirectional and partly bidirectional. The following control and status signals are used by 8085processor:

I. ALE (output): Address Latch Enable is a pulse that is provided when an address appears on the AD0 – AD7 lines, after which it becomes0.

II. RD (active low output): The Read signal indicates that data are being read from the selected I/O or memory device and that they are available on the data bus.

WR (active low output): The Write signal indicates that data on the data bus are to be written into a selected memory or I/Olocation.

III. IO/M (output): It is a signal that distinguished between a memoryoperationand an I/O operation. When IO/M= 0 it is a memory operation andIO/M = 1 it is an I/O operation

IV. S1 and S0 (output): These are status signals used to specify the type of operation being performed; they are listed in Table1.

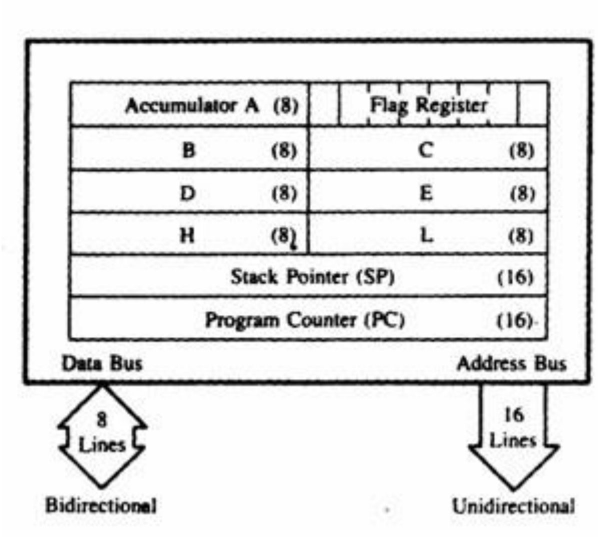


Fig 23: Control

(i) Accumulator (A):

- It is an 8-bit register that is part of the arithmetic/logic unit(ALU).
- Used to store 8-bit data and to perform arithmetic and logicaloperations.
- The result of an operation is stored in theaccumulator.

(ii) Flags:

- The ALU includes five flip-flops that are set or reset according to the result ofan operation.
- The microprocessor uses the flags for testing the dataconditions.
- TheyareZero(Z),Carry(CY),Sign(S),Parity(P),andAuxiliaryCarry(AC)flags.
- The most commonly used flags are Sign, Zero, and Carry. The

bit position for the flags in flag registeris,

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
S	Z		AC		P		CY

Table 1

a) Sign Flag(S):

- After execution of any arithmetic and logical operation, if D7 of the result is 1, the sign flag is set. Otherwise it is reset. D7 is reserved for indicatingthe sign; the remaining is the magnitude ofnumber.

- If D7 is 1, the number will be viewed as negative number. If D7 is 0,the number will be viewed as positivenumber.

b) Zero Flag (z):

- If the result of arithmetic and logical operation is zero, then zero flag isset
- otherwise it isreset.

c) Auxiliary Carry Flag(AC):

- If D3 generates any carry when doing any arithmetic andlogical
- operation, this flag is set. Otherwise it isreset.

d) Parity Flag(P):

- If the result of arithmetic and logical operation contains even number of 1's then this flag will be set and if it is odd number of 1's it will bereset.

e) Carry Flag(CY):

- If any arithmetic and logical operation result any carry then carry flag isset otherwise it isreset.

(iii) Program Counter(PC):

- This 16-bit register sequencing the execution of instructions. It is a memory pointer. Memory locations have 16-bit addresses, and that iswhy this is a 16-bitregister.
- The function of the program counter is to point to the memory addressof the next instruction to beexecuted.
- When an opcode is being fetched, the program counter is incrementedby one to point to the next memorylocation.

(iv) Stack Pointer(SP):

- The stack pointer is also a 16-bit register used as a memory pointer. It points to a memory location in R/W memory, called thestack.
- The beginning of the stack is defined by loading a 16-bit address in the stack pointer(register).

1) TemporaryRegister:

- It is used to hold the data during the arithmetic and logicaloperations.

2) InstructionRegister:

- When an instruction is fetched from the memory, it is loaded inthe
- instructionregister.

3) InstructionDecoder:

- It gets the instruction from the instruction register and decodesthe
- instruction. It identifies the instruction to beperformed.

4) Serial I/OControl:

- It has two control signals named SID and SOD for serial datatransmissiON

5) Timing and Controlunit:

- It has three control signals ALE, RD (Active low) and WR (Active low) and three status signals IO/M(Active low), S0 andS1.
- ALE is used for provide control signal to synchronize the componentsof
- microprocessor and timing for instruction to perform theoperation.
- RD(Activelow)andWR(Activelow)areusedtoindicatewhethertheoperationis reading the data from memory or writing the data into memoryrespectively.
- IO/M(Active low) is used to indicate whether the operation is belongs tothe memory or peripherals.

IO/M(Active Low)	S1	S2	Data Bus Status(Output)
0	0	0	Halt
0	0	1	Memory WRITE
0	1	0	Memory READ
1	0	1	IO WRITE
1	1	0	IO READ
0	1	1	Opcode fetch
1	1	1	Interrupt acknowledge

Table 2

8085 System Bus

Typical system uses a number of busses, collection of wires, which transmit BINARY numbers, one bit per wire. A typical microprocessor communicates with memory and other device (input and output) using three busses: Address Bus, Data Bus an control Bus.

Address Bus:

- The address bus is a group of 16 lines generally identified as A0 toA15
- The address bus is unidirectional: bits flow in one direction-from the MP Uperipheraldevices.
- TheMPUusestheaddressbustoperformthefirstfunction:identifyingaperipheral or a memorylocation.

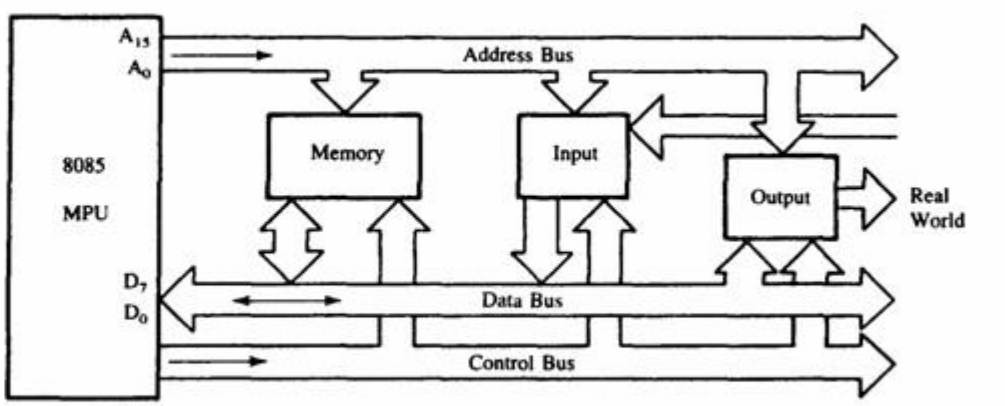


Fig 24: System bus

Data Bus:

- The data bus is a group of eight lines used for dataflow.
- These lines are bi-directional - data flow in both directions between the MPUand memory and peripheraldevices.
- The MPU uses the data bus to perform the second function: transferring binary information.
- The eight data lines enable the MPU to manipulate 8-bit data ranging from 00to FF (28 = 256 numbers).

- The largest number that can appear on the data bus is11111111.

Control Bus:

- The control bus carries synchronization signals and providing timingsignals.
- The MPU generates specific control signals for every operation itperforms.
- These signals are used to identify a device type with which the MPU wants to communicate.

8085 Pin description.

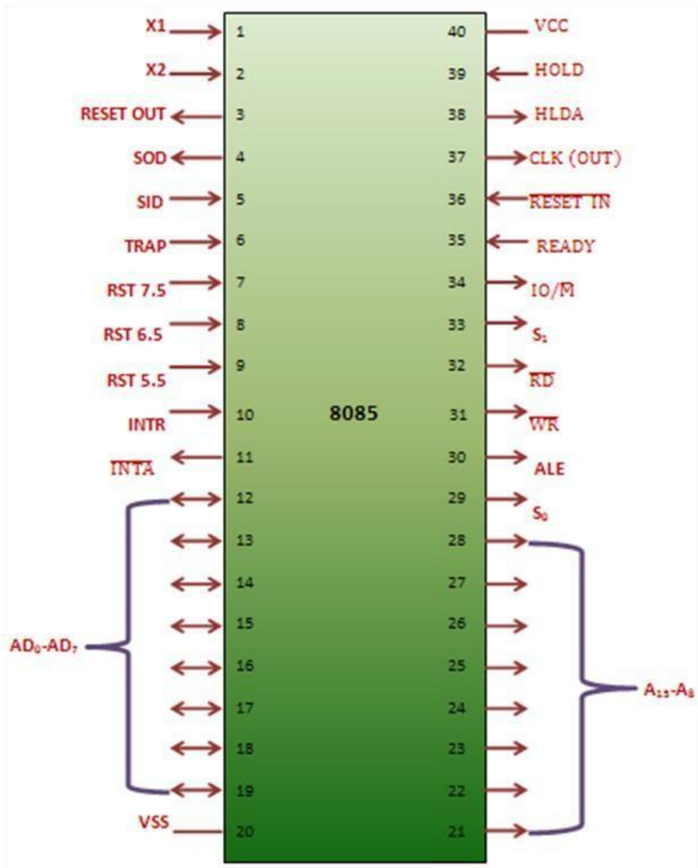


Fig 25: 8085 Pin configuration

Properties

Single + 5V Supply

4 Vectored Interrupts (One is Non Maskable) Serial In/Serial Out Port

Decimal, Binary, and Double Precision Arithmetic Direct Addressing Capability to 64K bytes of memory

The Intel 8085A is a new generation, complete 8 bit parallel central processing unit (CPU). The 8085A uses a multiplexed data bus. The address is split between the 8bit address bus and the 8bit data bus.

Pin Description

The following describes the function of each pin:

A6 - A1s (Output 3 State)- Address Bus: The most significant 8 bits of the memory address or the 8 bits of the I/0 address,3 stated during Hold and Halt modes.

AD0 - AD7 (Input/Output 3state) Multiplexed Address/Data Bus; Lower 8 bits of the memory address (or I/0 address) appear on the bus during the first clock cycle of a machine state. It then becomes the data bus during the second and third clock cycles. 3 stated during Hold and Halt modes.

ALE (Output)- Address Latch Enable: It occurs during the first clock cycle of a machine state and enables the address to get latched into the on chip latch of peripherals. The falling edge of ALE is set to guarantee setup and hold times for the address information. ALE can also be used to strobe the status information. ALE is never 3stated.

SO, S1 (Output)-Data Bus Status. Encoded status of the bus cycle:

S1 S0
0 0 HALT 0
1 WRITE 1 0
READ 1
1FETCH

S1 can be used as an advanced R/W status.

RD (Output 3state)- READ; indicates the selected memory or 1/0 device is to be read and that the Data Bus is available for the data transfer.

WR (Output 3state)- WRITE; indicates the data on the Data Bus is to be written into the selected memory or 1/0 location. Data is set up at the trailing edge of WR. 3stated during Hold and Halt modes.

READY (Input)-If Ready is high during a read or write cycle, it indicates that the memory or peripheral is ready to send or receive data. If Ready is low, the CPU will wait for Ready to go high before completing the read or write cycle.

S1 can be used as an advanced R/W status.

RD (Output 3state)- READ; indicates the selected memory or 1/0 device is to be read and that the Data Bus is available for the data transfer.

WR (Output 3state)- WRITE; indicates the data on the Data Bus is to be written into the selected memory or 1/0 location. Data is set up at the trailing edge of WR. 3stated during Hold and Halt modes.

READY (Input)-If Ready is high during a read or write cycle, it indicates that the memory or peripheral is ready to send or receive data. If Ready is low, the CPU will wait for Ready to go high before completing the read or write cycle.

HOLD (Input)-HOLD; indicates that another Master is requesting the use of the Address and Data Buses. The CPU, upon receiving the Hold request.will relinquish the use of buses as soon as the completion of the current machine cycle. Internal processing can continue. The processor can regain the buses only after the Hold is removed. When the Hold is acknowledged, the Address, Data, RD, WR, and IO/M lines are 3stated.

HLDA (Output)-HOLD ACKNOWLEDGE; indicates that the CPU has received the Hold request and that it will relinquish the buses in the next clock cycle. HLDA goes low after the Hold request is removed. The CPU takes the buses one half clock cycle after HLDA goes low.

INTR (Input)-INTERRUPT REQUEST; is used as a general purpose interrupt. It is sampled only during the next to the last clock cycle of the instruction. If it is active, the Program Counter (PC) will be inhibited from incrementing and an INTA will be issued. During this cycle a RESTART or CALL instruction can be inserted to jump to theinterrupt service routine. The INTR is enabled and disabled by software. It is disabled by Reset and immediately after an interrupt is accepted.

INTA (Output)-INTERRUPT ACKNOWLEDGE; is used instead of (and has thesame timing as) RD during the Instruction cycle after an INTR is accepted. It can be used to activate the 8259 Interrupt chip or some other interrupt port.

RST5.5

RST 6.5 - (Inputs) RST
7.5
RESTART INTERRUPTS; These three inputs have the same timing as I NTR except they cause an internal RESTART to be automatically inserted.
RST 7.5 Highest Priority
RST 6.5
RST 5.5 Lowest Priority
The priority of these interrupts is ordered as shown above. These interrupts have a higher priority than the INTR.
TRAP (Input)-Trap interrupt is a nonmaskable restart interrupt. It is recognized at the same time as INTR. It is unaffected by any mask or Interrupt Enable. It has the highest priority of any interrupt.
RESET IN (Input)-Reset sets the Program Counter to zero and resets the Interrupt Enable and HLDA flipflops. None of the other flags or registers (except the instruction register) are affected The CPU is held in the reset condition as long as Reset is applied. **RESET OUT (Output)-** Indicates CPlJ is being reset. Can be used as a system RESET. The signal is synchronized to the processor clock.
X1, X2 (Input)-Crystal or R/C network connections to set the internal clock generator X1 canalsobeanexternalclockinputinsteadofacrystal.Theinputfrequencyisdividedby 2 to give the internal operatingfrequency.
CLK (Output)-Clock Output for use as a system clock when a crystal or R/ C network is used as an input to the CPU. The period of CLK is twice the X1, X2 input period.
IO/M (Output)-IO/M indicates whether the Read/Write is to memory or l/O Tristated during Hold and Halt modes.
SID (Input)-Serial input data line The data on this line is loaded into accumulator bit 7 whenever a RIM instruction is executed.
SOD (output)-Serial output data line. The output SOD is set or reset as specified by the SIM instruction.
Vcc+5 volt supply.
VssGround Reference.

8085 Functional Description

The 8085A is a complete 8 bit parallel central processor. It requires a single +5 volt supply. Its basic clock speed is 3 MHz thus improving on the present 8080's performance with higher system speed. Also it is designed to fit into a minimum system of three IC's: The CPU, a RAM/ IO, and a ROM or PROM/IO chip.
The 8085A uses a multiplexed Data Bus. The address is split between the higher 8bit Address Bus and the lower 8bit Address/Data Bus. During the first cycle the address is sent out. The lower 8bits are latched into the peripherals by the Address Latch Enable (ALE). During the rest of the machine cycle the Data Bus is used for memory or l/O data.
The 8085A provides RD, WR, and lO/Memory signals for bus control. An Interrupt Acknowledge signal (INTA) is also provided. Hold, Ready, and all Interrupts are synchronized. The 8085A also provides serial input data (SID) and serial output data (SOD) lines for simple serial interface.
In addition to these features, the 8085A has three maskable, restart interrupts and one non-maskable trap interrupt. The 8085A provides RD, WR and IO/M signals for Bus control.
Status information is directly available from the 8085A. ALE serves as a status strobe. The status is partially encoded, and provides the user with advanced timing of the type of bus transfer being done. IO/M cycle status signal is provided directly also. Decoded So, S1 Carries the following status information:

HALT, WRITE, READ, FETCH

S1 can be interpreted as R/W in all bus transfers. In the 8085A the 8 LSB of address are multiplexed with the data instead of status. The ALE line is used as a strobe to enter the lower half of the address into the memory or peripheral address latch. This also frees extra pins for expanded interrupt capability.

2.8. DIFFERENCE BETWEEN MICROPROCESSOR AND MICROCONTROLLER

S.No	Microprocessor	Microcontroller
1	Microprocessor is heart of Computer system	Micro controller is a heart of embedded system
2	It is just a process. Memory and I/O components have to be connected externally	Micro controller has external processor along with internal memory and I/O components
3	Since memory and I/O has to be connected externally, the circuit becomes larger	Since memory and I/O are present internally, the circuit is small
4	Cannot be used in compact system and hence inefficient	Can be used in compact systems and hence it is an efficient technique
5	Due to external components, the entire power consumption is high. High it is not suitable to use with devices running on stored power like batteries	Since external components are low, total power consumption is less and can be used with devices running on stored power like batteries
6	Most of the microprocessor does not have power saving features	Most of the microcontroller have power saving features like idle mode and power saving mode
7	Since memory and I/O components are all external, each instruction will need external operation, hence it is relatively slower	Since components are internal, most of the operations are internal instruction, hence speed is fast
8	Microprocessor have less number of registers, hence more operations are memory based	Micro controller have more number of registers, hence the programs are easier to write.

2.9. ARCHITECTURE OF 8051

Features of 8051:

1. On chip data memory-128 bytes
2. On chip program memory-4096bytes.
3. Four registerbanks.
4. 64 kilobytes each program and external RAMaddressability.
5. 32 bidirectional I/O lines organized as four 8-bitports.
6. 16 bit Timer andcounter.
7. One microsecond instruction cycle with 12 MHZcrystal
8. Signed –overflow detection and paritycalculation
9. Multiple and divide in four micro second inHardware
10. Full depth stack for subroutine return linkage and datastorage.

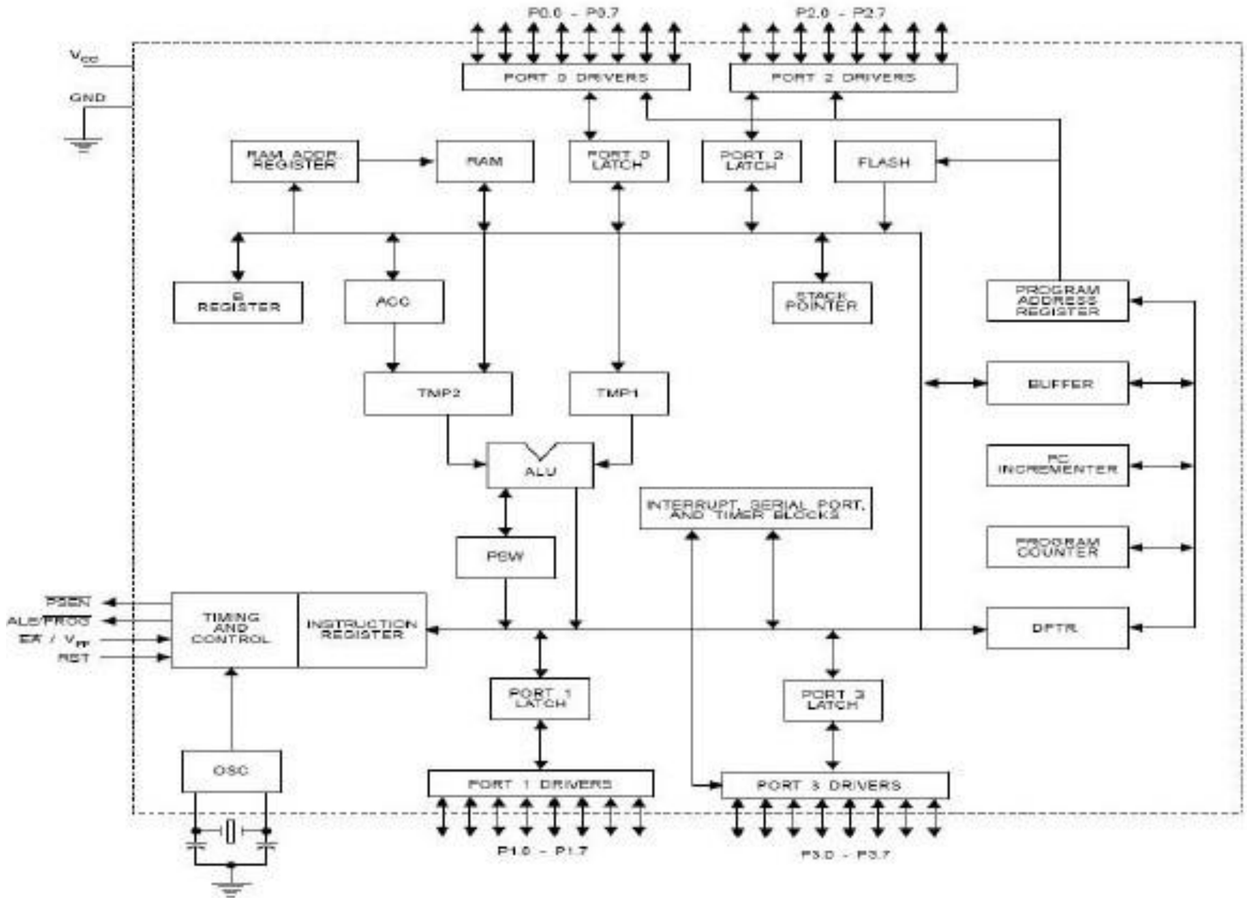


Fig 26:8051 architecture

ALU:

All arithmetic and logical functions are carried out by the ALU. Addition, subtraction with carry, and multiplication come under arithmetic operations. Logical operations are AND,OR and exclusive OR (XOR) come under logical operations.

Program Counter (PC):

A program counter is a 16-bit register and it has no internal address. The basic function of program counter is to fetch from memory the address of the next instruction to be executed.The PC holds the address of the next instruction residing in memory and when a command is encountered, it produces that instruction. This way the PC increments automatically, holding the address of the next instruction.

Registers:

Registers are usually known as data storage devices. 8051 microcontroller has 2 registers, namely Register A and Register B. Register A serves as an accumulator while Register B functions as a general purpose register. These registers are used to store the output of mathematical and logical instructions. The operations of addition, subtraction, multiplication anddivision are carried out by Register A. Register B is usually unused and comes into picture only when multiplication and division functions are carried out by Register A. Register A also involved in data transfers between the microcontroller and external memory.

Special Function Registers (SFRs):

1. Serial Port Data Buffer(SBUF)
2. Timer/Counter Control(TCON)
3. Timer/Counter Mode Control(TMOD)
4. Serial Port Control(SCON)
5. Power Control(PCON)
6. Interrupt Priority(IP)
7. Interrupt Enable Control(IE)

Timers and Counters:

Synchronization among internal operations can be achieved with the help of clock circuits which are responsible for generating clock pulses. During each clock pulse a particular operation will be carried out, thereby, assuring synchronization among operations. For the formation of an oscillator, we are provided with two pins XTAL1 and XTAL2 which are used for connecting a resonant network in 8051 microcontroller device. In addition to this, circuit also consists of four more pins. They are,Internal operations can be synchronized using clock circuits which produce clock pulses. With each clock pulse, a particular function will be accomplished and hence synchronization is achieved. There are two pins XTAL1 and XTAL2 which form an oscillator circuit which connect to a resonant network in the microcontroller.

The circuit also has 4 additional pins :

1. EA: Externalenable
2. ALE: Address latchenable
3. PSEN: Program store enableand
4. RST:Reset.

5 Quartz crystal is used to generate periodic clock pulses.

Internal RAM and ROM:

ROM:

A code of 4K memory is incorporated as on-chip ROM in 8051. The 8051 ROM is a nonvolatile Memory meaning that its contents cannot be altered and hence has a similar range of data And program memory, i.e, they can address program memory as well as a 64K separate block of data memory.

RAM:

The 8051 microcontroller is composed of 128 bytes of internal RAM. This is a volatile memory since its contents will be lost if power is switched off. These 128 bytes of internal RAM are divided into 32 working registers which in turn constitute 4 register banks (Bank 0-Bank 3) with each bank consisting of 8 registers (R0 - R7). There are 128 addressable bits in the internal RAM.

The 8051 microcontroller has four 8-bit input/output ports. These are:

PORT P0: When there is no external memory present, this port acts as a general purpose input/output port. In the presence of external memory, it functions as a multiplexed address anddata bus. It performs a dual role.

PORT P1: This port is used for various interfacing activities. This 8-bit port is a normal I/O port i.e. it does not perform dual functions.

PORT P2: Similar to PORT P0, this port can be used as a general purpose port when there is no external memory but when external memory is present it works in conjunction with PORT PO as an address bus. This is an 8-bit port and performs dual functions.

PORT P3: PORT P3 behaves as a dedicated I/O port

Interrupt Control

An event which is used to suspend or halt the normal program execution for a temporary period of time in order to serve the request of another program or hardware device is called an interrupt. An interrupt can either be an internal or external event which suspends the microcontroller for a while and thereby obstructs the sequential flow of a program. There are two ways of giving interrupts to a microcontroller – one is by sending software instructions and the other is by sending hardware signals. The interrupt mechanism keeps the normal program execution in a "put on hold" mode and executes a subroutine program and after the subroutine is executed, it gets back to its normal program execution. This subroutine program is also called an interrupt handler. A subroutine is executed when a certain event occurs.

In 8051, 5 sources of interrupts are provided. They are:

a) 2 external interrupt sources connected through INT0 and INT1

b) 3 external interrupt sources- serial port interrupt,Timer Flag 0 and Timer Flag 1.

The pins connected are asfollows:

1. ALE (Address Latch Enable) - Latches the address signals on PortP0
2. EA (External Address) - Holds the 4K bytes of programmemory
3. PSEN (Program Store Enable) - Reads external programmemory
4. RST (Reset) - Reset the ports and internal registers upon startup

Serial Data Communication:

A method of establishing communication among computers is by transmitting and receiving data bits is a serial connection network. In 8051, the SBUF (Serial Port Data Buffer) register holds the data; the SCON (Serial Control) register manages the data communication and the PCON (Power Control) register manages the data transfer rates. Further, two pins - RXD and TXD, establish the serial network.The SBUF register has 2 parts – one for storing the data to be transmitted and another for receiving data from outer sources. The first function is done using TXD pin and the second function is done using RXD pin.

There are 4 programmable modes in serial data communication. They are:

1. Serial Data mode 0 (shift registermode)
2. Serial Data mode 1 (standardUART)
3. Serial Data mode 2 (multiprocessormode)
4. Serial Data mode3

Data Pointer (DPTR):

The data pointer or DPTR is a 16-bit register. It is made up of two 8-bit registers called DPH and DPL. Separate addresses are assigned to each of DPH and DPL. These 8-bit registers are used for the storing the memory addresses that can be used to access internal and external data/code.

Stack Pointer (SP):

The stack pointer (SP) in 8051 is an 8-bit register. The main purpose of SP is to access the stack. As it has 8-bits it can take values in the range 00 H to FF H. Stack is a special area of data in memory. The SP acts as a pointer for an address that points to the top of the stack.

Data and Address Bus:

A bus is group of wires using which data transfer takes place from one location to another within a system. Buses reduce the number of paths or cables needed to set up connection between components.

There are mainly two kinds of buses - Data Bus and Address Bus
Data Bus:
The purpose of data bus is to transfer data. It acts as an electronic channel using which data travels. Wider the width of the bus, greater will be the transmission of data.

Address Bus:

The purpose of address bus is to transfer information but not data. The information tells from where within the components, the data should be sent to or received from. The capacity or memory of the address bus depends on the number of wires that transmit a single address bit.

Pin Diagram:

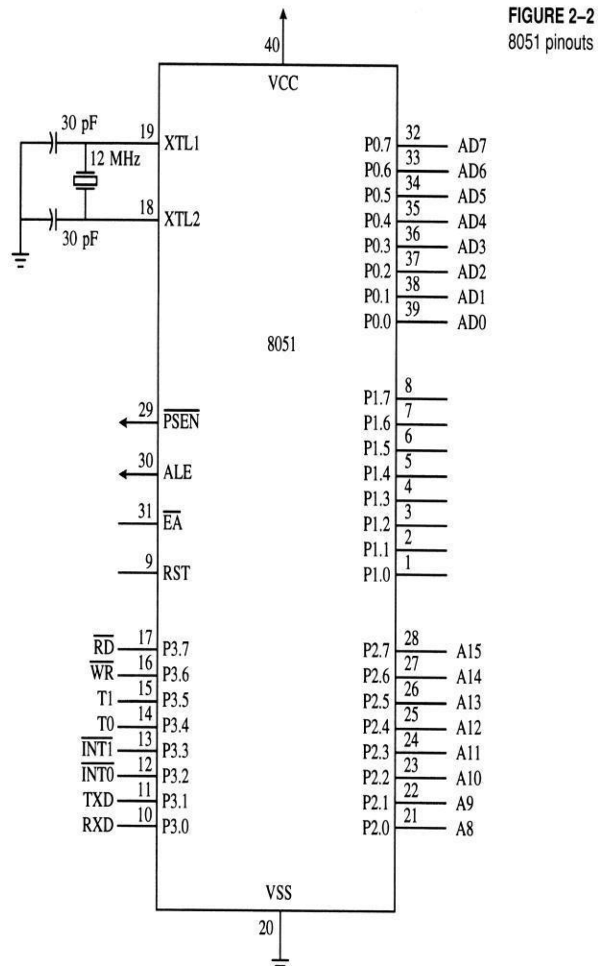


Fig 27: Pin configuration

One of the most useful features of the 8051 is that it contains four I/O ports (P0 - P3)

Port 0 (**pins 32-39**):P0(P0.0~P0.7)

8-bit R/W - General Purpose I/O Or acts as a multiplexed low byte address and data bus for external memory design

Port 1(**pins1-8**) :P1(P1.0~P1.7)

Only 8-bit R/W - General Purpose I/O

Port 2 (**pins 21-28**):P2(P2.0~P2.7)

8-bit R/W - General Purpose I/O Or high byte of the address bus for external memory design

Port 3 (**pins 10-17**):P3(P3.0~P3.7)

General Purpose I/O

if not using any of the internal peripherals (timers) or external interrupts. Each port can be used as input or output (bi-direction)

Table 3:

Port Pin	Alternate Function
P3.0	RXD (serial input port)
P3.1	TXD (serial output port)
P3.2	$\overline{INT0}$ (external interrupt 0)
P3.3	$\overline{INT1}$ (external interrupt 1)
P3.4	T0 (Timer 0 external input)
P3.5	T1 (Timer 1 external input)
P3.6	$\overline{WR}$ (external data memory write strobe)
P3.7	$\overline{RD}$ (external data memory read strobe)

PSEN (out): Program Store Enable, the read signal for external program memory (active low).
ALE (out): Address Latch Enable, to latch address outputs at Port0 and Port2
EA (in): External Access Enable, active low to access external program memory locations 0 to 4K
RXD,TXD: UART pins for serial I/O on Port 3
XTAL1 & XTAL2: Crystal inputs for internal oscillator.

8051 Clock and Instruction Cycle:

In 8051, one instruction cycle consists of twelve (12) clock cycles. Instruction cycle is sometimes called as Machine cycle by some authors.

128 bytes of Internal RAM Structure (lower address space)

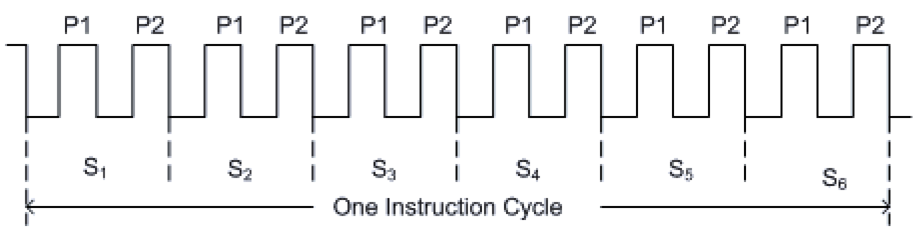


Fig 28: Clock cycle

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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 3 - SYSTEM MODELS - SPR1304

3. SYSTEM MODELS

This chapter determines how the systems behave with time when subjected to some disturbance. E.g. A microprocessor switches on a motor. The speed will not attain immediately but it will take some +time to attain full speed. In order to understand the behavior of the systems, mathematical models are needed. These models are equations which describe the relationship between the input and output of a system. The basis for any mathematical model is provided by the fundamental physical laws that govern the behavior of the system. In this chapter a range of systems will be considered including mechanical, electrical, thermal & fluid examples. Systems can be made up from a range of building blocks from a number of basic building blocks.

3.1. MECHANICAL SYSTEM BUILDING BLOCKS

SPRING

Springs represents the stiffness of the system. The fig. shows a spring subjected to force F

- The stiffness of a spring is described by: $F=k.x$

The object applying the force to stretch the spring is also acted on by a force **(Newton's third law),** this force will be in the opposite direction and equal in size to the force used to stretch the spring.

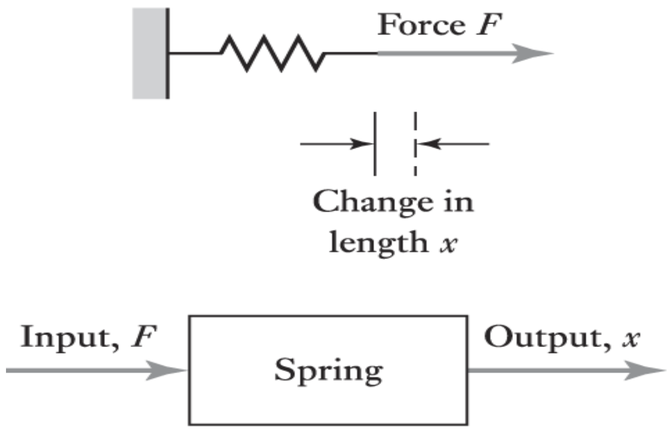


Fig 1: Spring

The spring when stretched stores energy, the energy being released when the spring springs back to its original length.

The energy stored when there is an extension x is:

$E= kx^2/2=$ $E = \frac{1}{2}\frac{F^2}{k}$

DASHPOT

Dashpotsbuildingblocksrepresentthetypesofforcesexperienced when we push the object through a fluid or move an object against frictionalforces.

c : speed of the body. It is a type of forces when we push an object through a fluid or move an object against friction forces.Thus the relation between the displacement x of the piston, i.e. the output and the force as input is a relationshipdepending on the rate of change of the output $F = c\frac{dx}{dt} = cv$

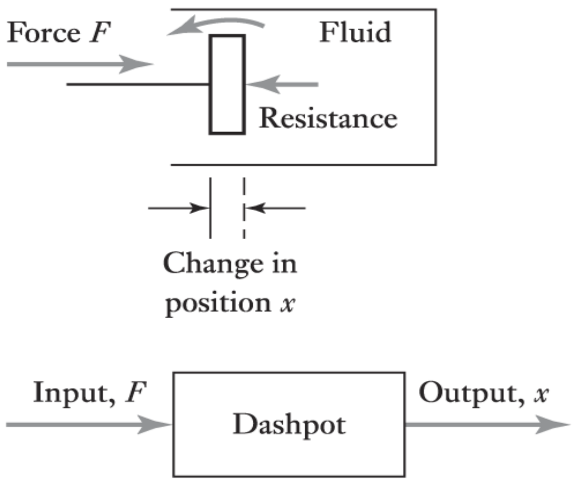


Fig 2: Dashpot

No stored energy in dashpot, it dissipates energy=cv^2

MASSES

Masses represent the inertia or resistance to acceleration

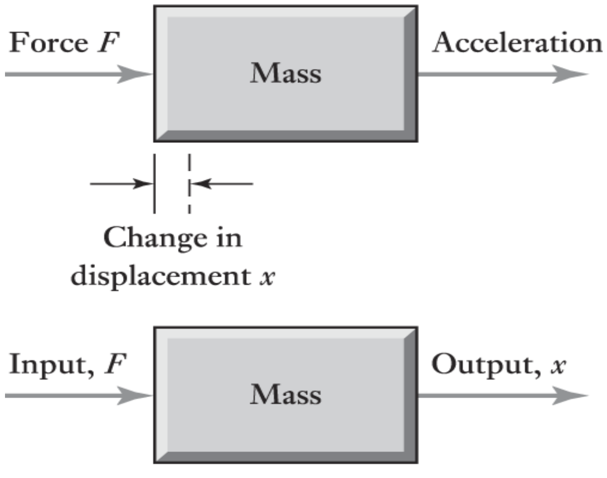


Fig 3: Masses

$$F = m\frac{d^2x}{dt^2} = m\frac{dv}{dt}$$

F=ma
m: mass, a: acceleration

Energy stored in the mass when its moving with a velocity v, its called kinetic energy, and released when it stops moving:
$E=mv^2/2$

ROTATIONAL SYSTEM
For rotational system, the equivalent three building blocks are: a Torsion spring, a rotary damper, and the moment of inertia. With such building blocks, the inputs are torque and the outputs angle rotated
With a torsional spring the angle θ rotated is proportional to the toque T.Hence
With a torsional spring $T = k\theta$

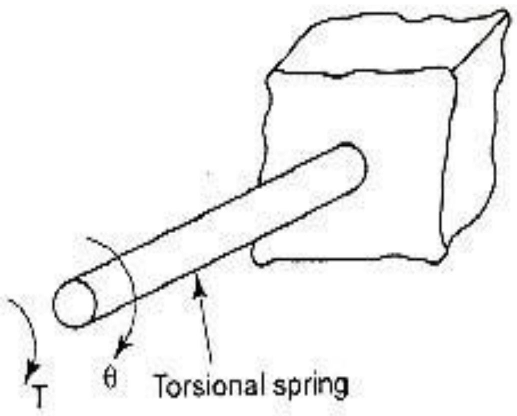


Fig 4: torsional spring

With the rotary damper a disc is rotated in a fluid and the resistive toque T is proportional to the angular velocity ω, and since angularvelocity is the rate at which angle changes. With a rotary damper a disc is rotated in a fluid and the resistive torque T is:

$$T = c\frac{d\theta}{dt} = c\omega$$

The *moment of inertia* building block exhibits the property that the greater the moment of inertia I the greater the torque needed to produce an angular acceleration α.Thus, since angular acceleration is the rate of change of angular velocity.
The moment of inertia has the property that the greater the moment of inertia I, the greater the torque needed to produce an angular acceleration

$$T = I\frac{d^2\theta}{dt^2} = I\frac{d\omega}{dt}$$

The stored energy in rotary system

For torsional spring $E = \frac{1}{2}\frac{T^2}{k}$

Energy stored in mass rotating is $E = \frac{1}{2}I\omega^2$

The power dissipated by rotary damper when rotating with angular velocity wis $P = c\omega^2$

Building block	Describing equation	Energy stored or power dissipated
Translational		
Spring	$F = kx$	$E = \frac{1}{2}\frac{F^2}{k}$
Dashpot	$F = c\frac{dx}{dt} = cv$	$P = cv^2$
Mass	$F = m\frac{d^2x}{dt^2} = m\frac{dv}{dt}$	$E = \frac{1}{2}mv^2$
Rotational		
Spring	$T = k\theta$	$E = \frac{1}{2}\frac{T^2}{k}$
Rotational damper	$T = c\frac{d\theta}{dt} = c\omega$	$P = c\omega^2$
Moment of inertia	$T = I\frac{d^2\theta}{dt^2} = I\frac{d\omega}{dt}$	$E = \frac{1}{2}I\omega^2$

Table 1: summary of mechanical building blocks

3.2. BUILDING UP A MECHANICAL SYSTEM TRANSLATIONAL MECHANICAL SYSTEM

Spring mass damper system:

A spring mass damper system is shown in fig. The system is fixed at one end and the mass is supported by a spring and damper. The mass is excited by force and free to oscillate. The equation of motion related to horizontal motion x of mass to applied force can be developed with of a free body diagram.

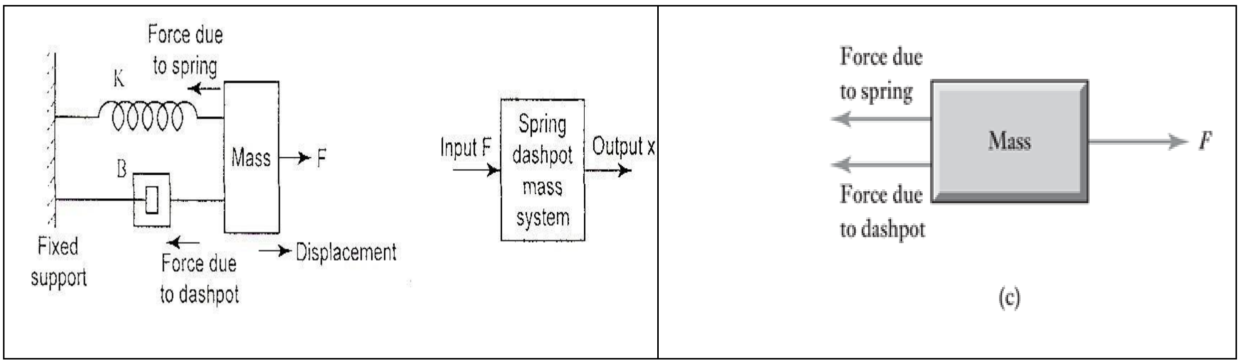


Fig 5: (a) Spring–dashpot–mass, (b) system, (c) free-body diagram

The net forced applied to the mass m = F-kx-cv

V: is the velocity with which the piston (mass) is moving

The net fore is the force applied to the mass to cause it to accelerate thus net force applied to mass=ma

$$F - kx - c\frac{dx}{dt} = m\frac{d^2x}{dt^2}$$

$$or \quad m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F$$

ILLUSTRATIONS

MATHEMATICAL MODEL FOR A MACHINE MOUNTED ON THE GROUND

Used to study the basics for studying the effects of ground disturbances on the displacements of a machine bed.

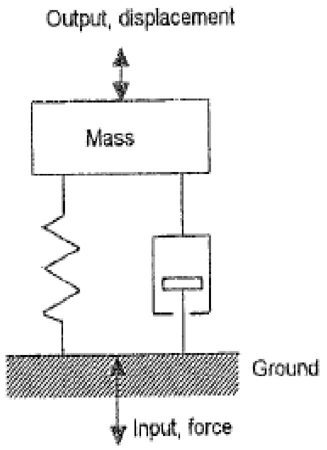


Fig 6: Machine mounted on a ground

ILLUSTRATION

Example: Derive the differential equations describing the motion of the mass m, in fig. when a force F is applied for the system in Figure

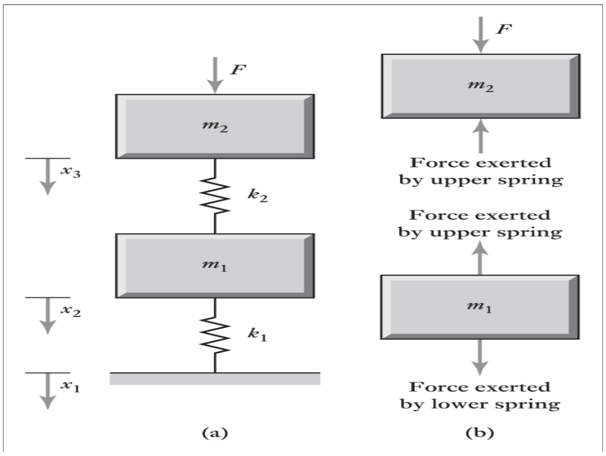
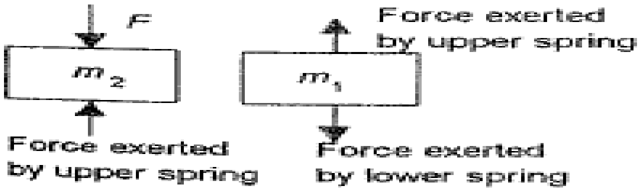


Fig 7: motion of mass

Consider the free body diagram For the mass m2, Force F & Force exerted by upper spring is due to stretched by

$$(x_2 - x_3)$$



$$k_2(x_3 - x_2).$$

$$\text{net force} = F - k_2(x_3 - x_2)$$

This force will cause the mass to accelerate and so

$$F - k_2(x_3 - x_2) = m_2 \frac{d^2x_3}{dt}$$

For the free body diagram ofmass m1, the force exerted by the upper spring is,

$k_2(x_3 - x_2)$ by the lower spring then the net force acting on the mass. $k_1(x_1 - x_2)$

$$\text{net force} = k_1(x_2 - x_1) - k_2(x_3 - x_2)$$

This force will cause the mass to accelerate and so

$$k_1(x_2 - x_1) - k_2(x_3 - x_2) = m_1 \frac{d^2x_2}{dt}$$

Rotary Systems

Spring, dashpot and mass are the basic building blocks for mechanical systems where forces and straight line displacement are involved without rotation. If rotation involves, then the equivalent three building blocks are a torsional spring, a rotary damper and the moment of inertia (inertia rotating mass). Inputs for such building blocks are torque and outputs are angle rotated. The same analysis procedures can also be applied to rotary system, so just one rotational mass block and just the torque acting on the body are considered. Torsional spring angle θrotated is proportional to torque T.

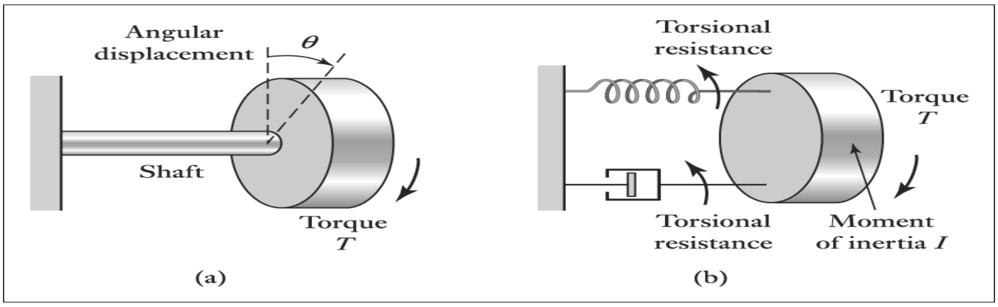


Fig 8: Rotating a mass on the end of a shaft: (a) physical situationb) building block model.

$$T = I\frac{d\omega}{dt} = I\frac{d(d\theta/dt)}{dt} = I\frac{d^2\theta}{dt^2}$$

$$I\frac{d^2\theta}{dt^2} + c\frac{d\theta}{dt} + k\theta = T$$

Greater the MOI, Greater the torque needed to produce angular acceleration α

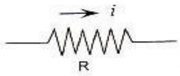
3.3. ELECTRICAL SYSTEM BUILDING BLOCKS

The basic building blocks of electrical building blocks are inductors, capacitors, andresisters.

Resistors:

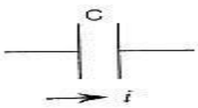
Resistance is an opposition to movement of flow of material or energy. An electric resistor opposes the flow of current, the voltage

V across the resistor is given by V= I R, WhereR= resistance



Capacitors

Capacitors are used to stored charge to increase the voltage by iV. A capacitor consists of two parallel plates separated by insulating material and capacitor act as a strong device of energy. The voltage equation for a capacitoris



$$V = \frac{1}{C}idt$$

Where C - capacitor

Inductors:

It consists of a coil wire. When current flows through the wire, a magnetic field surrounding the wire is produced. Any attempt to change the density of this magnetic field leads to the induction of voltage. The inductor equation

$$V = L\frac{di}{dt}$$

Table 2: summary of electrical building blocks

Element	Voltage	Current
Resistor	$V = iR$	$i = \frac{V}{R}$
Capacitor	$V = \frac{1}{C}\int i\,dt$	$i = C.\frac{dV}{dt}$
Inductor	$V = L\frac{di}{dt}$	$i = \frac{1}{L}\int V\,dt$

3.4. FLUID SYSTEM BUILDING BLOCKS

The three basic building blocks of a fluid flow system can be considered to be equivalent of electrical resistance, inductance and capacitance. Fluid systems can be considered to fall in to two categories.

1. Hydraulic. 2.Pneumatic

In hydraulic the fluid is a liquid and considered to be incompressible. In pneumatic gas is used and which can be compressed

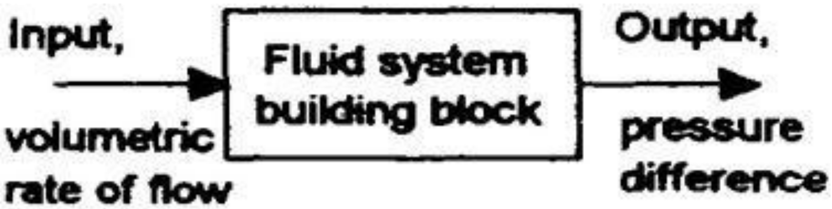


Fig 9: Fluid system

HYDRAULIC SYSTEMS

1. Hydraulicresistance(R)

It is the resistance to flow which occurs as a result of a liquid flowing through valves or changes in pipe diameter. The relationship between the volume flow rate and resistance element and theresulting pressure difference

$$p_1 - p_2 = Rq$$

Where R = Hydraulic Resistance

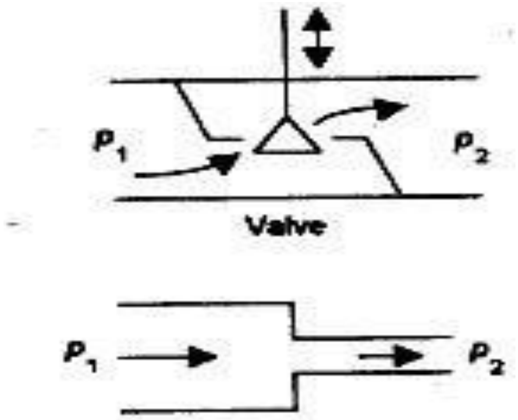


Fig 10: Hydraulic resistance

2. HYDRAULICCAPACITANCE

This term is used to describe energy storage with a liquid when it is stored in the form of potential energy.h = height of liquid.

q1,q2= rate of liquid flow.

P = pressure difference

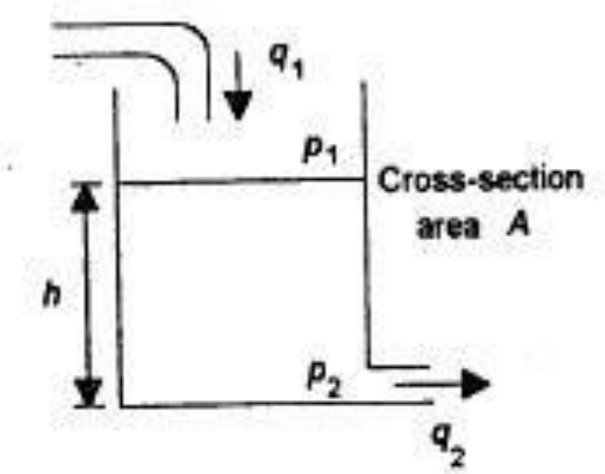


Fig 11: Hydraulic Capacitance

For such a capacitance, the rate of change of volume V in the container dV/dt,
is equal to the difference between the volumetric rate at which liquid enters the container q_1 and the rate at which it leaves q_2

$$q_1 - q_2 = \frac{dV}{dt}$$

But V = Ah, A – Cross – sectional area of the container and h – height of liquid in it.

$$q_1 - q_2 = \frac{d(Ah)}{dt} = A\frac{dh}{dt}$$

But the pressure difference between the input and output is p,
ρ – Density of liquid
P = hρg, g – acceleration due to gravity

Thus if the liquid is assumed to be incompressible (density does not changes).

$$q_1 - q_2 = A\frac{d(p/\rho g)}{dt} = \frac{A}{\rho g}\frac{dp}{dt}$$

The hydraulic capacitance C is defined as being $C = \frac{A}{\rho g}$

Thus $q_1 - q_2 = C\frac{dp}{dt}$

Integrating the above equation

$$p = \frac{1}{C}\int(q_1 - q_2)\,dt$$

3. Hydraulic Inertance

Hydraulic inertance – equivalent of inductance in electrical systems or a spring in mechanical systems.To accelerate a fluid and so increase its velocity a force is requires. Consider a block of liquid of mass m as shown in fig. The force acting on the liquid is

$$F_1 - F_2 = p_1 A - p_2 A = (p_1 - p_2)A$$

Pressure difference

This net force causes the mass to accelerate with acceleration and so

$$(p_1 - p_2)A = ma \qquad (p_1 - p_2)A = m\frac{dv}{dt}$$

But the mass of the liquid has a volume Of AL

L – length of the block of liquid or difference between the points in the liquid.

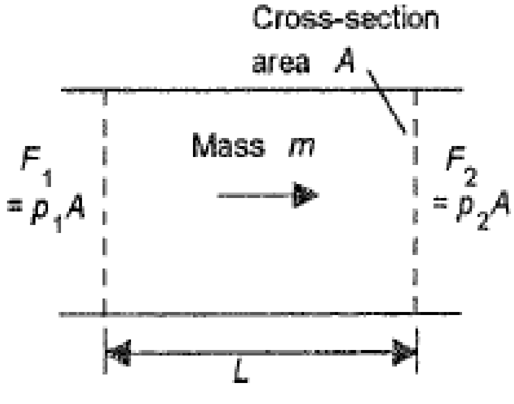


Fig 12: Hydraulic Intertance

If the liquid has a density ρ then m = Alρ

$$(p_1 - p_2)A = AL\rho \frac{dv}{dt}$$

But the volume rate of flow q = Av, hence

$$(p_1 - p_2)A = L\rho \frac{dq}{dt}$$

$$p_1 - p_2 = I \frac{dq}{dt}$$

Where the hydraulic inertance l is defined as

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

PNEUMATIC FLUID SYSTEM BUILDINGBLOCKS

- Pneumatic has the same three basic building blocks with hydraulic systems.
- Gases differ from liquids in being compressible i.e. change in pressure causes change in volume and hencedensity:
- The basic blocksare:
- PneumaticResistance,
- Pneumatic capacitance, &
- PneumaticInertance

Pneumatic Resistance:

It is defined in terms of the mass rate of flow

$$P_1 \square P_2$$

m: mass of the gas; P1-P2: pressure difference; R:resistance

Pneumatic capacitance C: is due to compressibility of the gas in somevolume& comparable to compression of spring stores energy. If a mass of rate of flow entering through a container of volume V and a mass flow rate of leaving it,

Rate of change of mass inside the containeris: Rate of change of mass in the container if gas with density

$$(dm_1/dt - dm_2/dt). = \frac{d(\rho V)}{dt} = \rho \frac{dV}{dt} + V \frac{d\rho}{dt}$$

Since $(dV/dt) = (dV/dp)(dp/dt)$ and, for an ideal gas, $pV = mRT$ with consequently $p = (m/V)RT = \rho RT$ and $d\rho/dt = (1/RT)(dp/dt)$, then

$$\text{rate of change of mass in container} = \rho \frac{dV}{dp}\frac{dp}{dt} + \frac{V}{RT}\frac{dp}{dt}$$

where R is the gas constant and T the temperature, assumed to be constant, on the Kelvin scale. Thus

$$\frac{dm_1}{dt} - \frac{dm_2}{dt} = \left(\rho \frac{dV}{dp} + \frac{V}{RT}\right)\frac{dp}{dt}$$

$$\frac{dm_1}{dt} - \frac{dm_2}{dt} = \left(\rho\frac{dV}{dp} + \frac{V}{RT}\right)\frac{dp}{dt}$$

The pneumatic capacitance due to the change in volume of the container C_1 is defined as

$$C_1 = \rho\frac{dV}{dp}$$

and the pneumatic capacitance due to the compressibility of the gas C_2 as

$$C_2 = \frac{V}{RT}$$

Hence

$$\frac{dm_1}{dt} - \frac{dm_2}{dt} = (C_1 + C_2)\frac{dp}{dt}$$

or

$$p_1 - p_2 = \frac{1}{C_1 + C_2}\int(\dot{m}_1 - \dot{m}_2)\,dt$$

Pneumatic inertance: is due to the pressure drop necessary to accelerate a block ofgas. According to Newton's second law the net force is ma = $\frac{d(mv)}{dt}$ Since the force is provided by the pressure difference $(p_1 - p_2)$, then if A is the cross-sectional. Areaofthe block of gas being accelerated.

But m, the mass of the gas b $(p_1 - p_2)A = \frac{d(mv)}{dt}$ me of flow

Q = Av, where v = velocity. Thus

$$mv = \rho LA\frac{q}{A} = \rho Lq$$

and so

$$(p_1 - p_2)A = L\frac{d(\rho q)}{dt}$$

But $\dot{m} = \rho q$ and so

$$p_1 - p_2 = \frac{L}{A}\frac{d\dot{m}}{dt}$$

$$p_1 - p_2 = I\frac{d\dot{m}}{dt}$$

with the pneumatic inertance I being $I = L/A$.

3.5. BUILDING UP A MODEL FOR A FLUID SYSTEM

Example 1:

For the shown simple hydraulic system derive an expression for the height of the fluid in the container. Consider the system consist of a capacitor, the liquid inthe container, with a resistor and a valve.

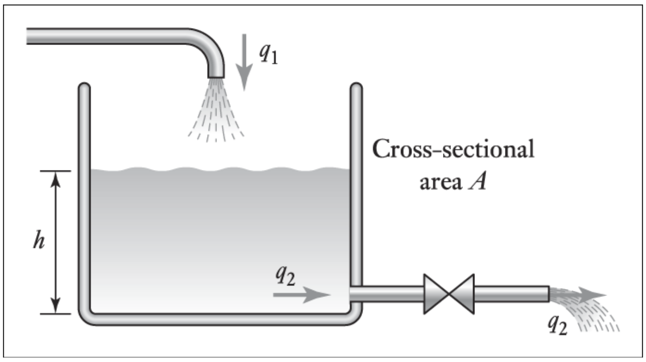


Fig 13: Liquid in a container

Inertance can be neglected since flow rates change only very slowly. For the capacitor we can write

$$q_1 - q_2 = C\frac{\mathrm{d}p}{\mathrm{d}t}$$

The rate at which liquid leaves the container q_2 equals the rate at which it leaves the valve. Thus for the resistor

$$p_1 - p_2 = Rq_2$$

The pressure difference $(p_1 - p_2)$ is the pressure due to the height of liquid in the container and is thus $h\rho g$. Thus $q_2 = h\rho g/R$ and so substituting for q_2 in the first equation gives

$$q_1 - \frac{h\rho g}{R} = C\frac{\mathrm{d}(h\rho g)}{\mathrm{d}t}$$

and, since $C = A/\rho g$,

$$q_1 = A\frac{\mathrm{d}h}{\mathrm{d}t} + \frac{\rho g h}{R}$$

This equation describes how the height of liquid in the container depends on the rate of input of liquid into the container.

Example 2:

For the shown hydraulic system derive expression for the fluid level in the twocontainers

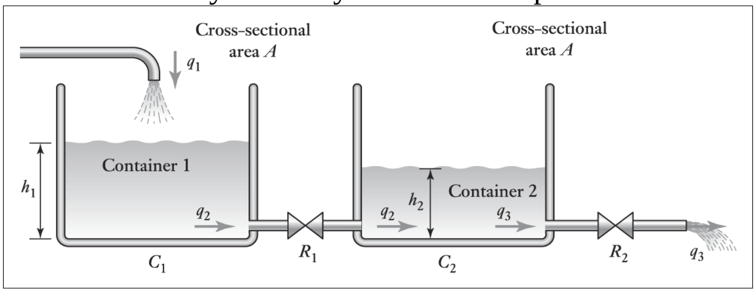


Fig 14: Liquid in two containers

Container 1 is a capacitor and thus

$$q_1 - q_2 = C_1 \frac{dp}{dt}$$

where $p = h_1 \rho g$ and $C_1 = A_1/\rho g$ and so

$$q_1 - q_2 = A_1 \frac{dh_1}{dt}$$

The rate at which liquid leaves the container q_2 equals the rate at which it leaves the valve R_1. Thus for the resistor,

$$p_1 - p_2 = R_1 q_2$$

The pressures are $h_1 \rho g$ and $h_2 \rho g$. Thus
Using the value of q_2 given by this equation and substituting it into the earlier equation gives

$$q_1 - \frac{(h_1 - h_2)\rho g}{R_1} = A_1 \frac{dh_1}{dt}$$

This equation describes how the height of the liquid in container 1 depends on the input rate of flow.

For container 2 a similar set of equations can be derived. Thus for the capacitor C_2,

$$q_2 - q_3 = C_2 \frac{dp}{dt}$$

where $p = h_2 \rho g$ and $C_2 = A_2/\rho g$ and so

$$q_2 - q_3 = A_2 \frac{dh_2}{dt}$$

The rate at which liquid leaves the container q_3 equals the rate at which it leaves the valve R_2. Thus for the resistor,

$$p_2 - 0 = R_2 q_3$$

This assumes that the liquid exits into the atmosphere. Thus, using the value of q_3 given by this equation and substituting it into the earlier equation gives

$$q_2 - \frac{h_2 \rho g}{R_2} = A_2 \frac{dh_2}{dt}$$

Substituting for q_2 in this equation using the value given by the equation derived for the first container gives

$$\frac{(h_1 - h_2)\rho g}{R_1} - \frac{h_2 \rho g}{R_2} = A_2 \frac{dh_2}{dt}$$

This equation describes how the height of liquid in container 2 changes.

Example 3:

A bellows is an example of a simple pneumatic system (Figure 10.15). Resistance is provided by a constriction which restricts the rate of flow of gas into the bellows and capacitance is provided by the bellows itself. Inertance can be neglected since the flow rate changes only slowly.

The mass flow rate into the bellows is given by

$$p_1 - p_2 = R\dot{m}$$

capacitance of the bellows is given by

$$\dot{m}_1 - \dot{m}_2 = (C_1 + C_2)\frac{dp_2}{dt}$$

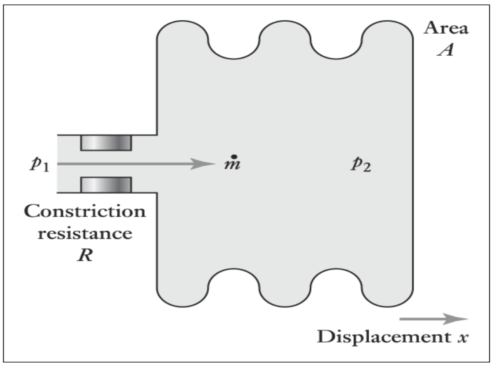


Fig 15:Bellows

The mass flow rate entering the bellows is given by the equation for the resistance and the mass leaving the bellows is zero. Thus

$$\frac{p_1 - p_2}{R} = (C_1 + C_2)\frac{dp_2}{dt}$$

Hence

$$p_1 = R(C_1 + C_2)\frac{dp_2}{dt} + p_2$$

This equation describes how the pressure in the bellows P_2 varies with time when there is an input of a pressure P_1.

3.6. THERMAL SYSTEM BUILDING BLOCKS

For thermal system, there are only two building blocks.

1. Thermal Resistance. 2. Thermal Capacitance.

Thermal resistance

If Q is the rate of heat flow and (T_2-T_1) is the temperature difference, thenR_{th}

$$Q_{th}=\frac{T2-T1}{Rth}$$

The value of R_{th}depends on mode of heat transfer. In case ofconduction through solid

$$Q = KA\,\frac{T2-T1}{L}, \text{ For this } R_{th} = \frac{L}{KA}$$

When mode of heat transfer is convection

$Q = Ah\ T_2-T_1$, For this mode $R_{th} = \frac{1}{Ah}$

Thermal capacitance

It is a measure of the store of energy in a system

$$Q_1 - Q_2 = mc\,\frac{dT}{dt}$$

Q1= rate of flow of heat into the system. Q2= rate of flow of heat out from thesystem

M=mass C=specificheat. Ch= thermalcapacitance

$\frac{dT}{dt}$ Rate of change of temperature

Building up a Model for a Thermal system

Example 1:

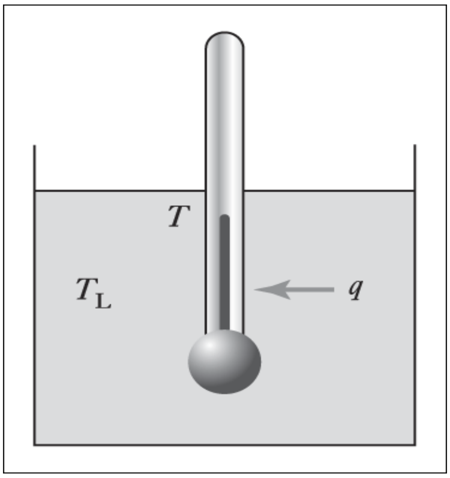


Fig 16:Thermometer in a liquid

Consider a thermometer at temperature T which has just been inserted in a liquid at temperature T_L

If the thermal resistance to heat flow from the liquid to the thermomet
is R, then

$$q = \frac{T_L - T}{R}$$

where q is the net rate of heat flow from liquid to thermometer. The therm
capacitance C of the thermometer is given by the equation

$$q_1 - q_2 = C\frac{dT}{dt}$$

Since there is only a net flow of heat from the liquid to the thermomet
$q_1 = q$ and $q_2 = 0$. Thus

$$q = C\frac{dT}{dt}$$

Substituting this value of q in the earlier equation gives

$$C\frac{dT}{dt} = \frac{T_L - T}{R}$$

Rearranging this equation gives

$$RC\frac{dT}{dt} + T = T_L$$

This equation, a first-order differential equation, describes how the temperat

Example 2:

Consider the figure which shows a thermal system consisting of an electric free in a room. The fire emits heat at the rate q_1 and the room loses heat at the rate q_2. Assuming that the air in the room is at a uniform temperature T and that there is no heat storage in the walls of the room, derive an equation describing how the room temperature will change with time.

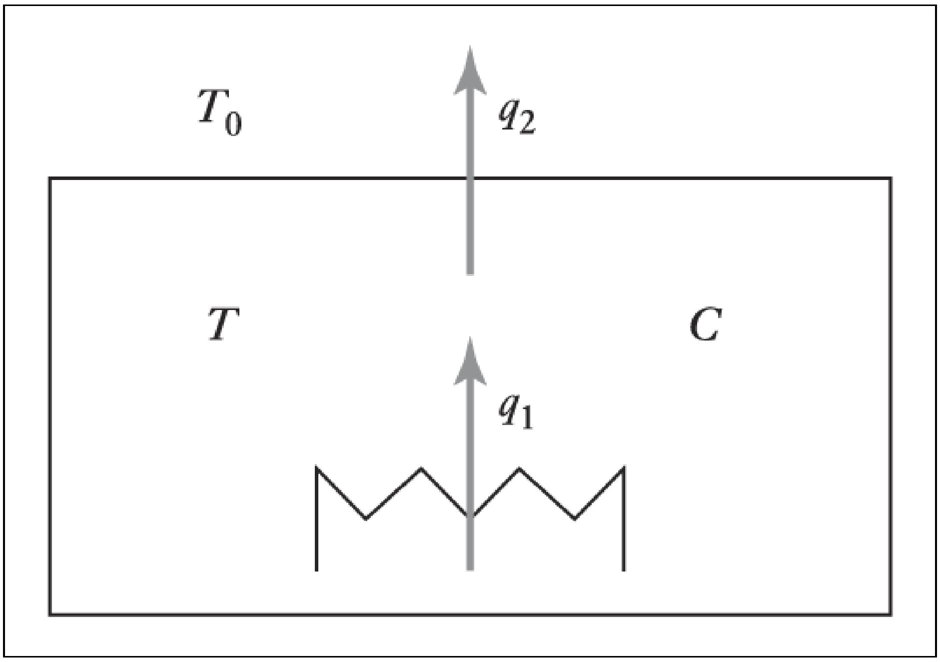


Fig 17: Thermal system with an electric fire

If the air in the room has a thermal capacity C then

$$q_1 - q_2 = C\frac{dT}{dt}$$

If the temperature inside the room is T and that outside the room T_0 then

$$q_2 = \frac{T - T_0}{R}$$

where R is the resistivity of the walls. Substituting for q_2 gives

$$q_1 - \frac{T - T_0}{R} = C\frac{dT}{dt}$$

Hence

$$RC\frac{dT}{dt} + T = Rq_1 + T_0$$

	Mechanical (translational)	Mechanical (rotational)	Electrical	Fluid (hydraulic)	Thermal
Element	Mass	Moment of inertia	Capacitor	Capacitor	Capacitor
Equation	$F = m\frac{d^2x}{dt^2}$	$T = I\frac{d^2\theta}{dt^2}$			
	$F = m\frac{dv}{dt}$	$T = I\frac{d\omega}{dt}$	$i = C\frac{dv}{dt}$	$q = C\frac{d(p_1 - p_2)}{dt}$	$q_1 - q_2 = C\frac{dT}{dt}$
Energy	$E = \frac{1}{2}mv^2$	$E = \frac{1}{2}I\omega^2$	$E = \frac{1}{2}Cv^2$	$E = \frac{1}{2}C(p_1 - p_2)^2$	$E = CT$
Element	Spring	Spring	Inductor	Inertance	None
Equation	$F = kx$	$T = k\theta$	$v = L\frac{di}{dt}$	$p = L\frac{dq}{dt}$	
Energy	$E = \frac{1}{2}\frac{F^2}{k}$	$E = \frac{1}{2}\frac{T^2}{k}$	$E = \frac{1}{2}Li^2$	$E = \frac{1}{2}Iq^2$	
Element	Dashpot	Rotational damper	Resistor	Resistance	Resistance
Equation	$F = c\frac{dx}{dt} = cv$	$T = c\frac{d\theta}{dt} = c\omega$	$i = \frac{v}{R}$	$q = \frac{p_1 - p_2}{R}$	$q = \frac{T_1 - T_2}{R}$
Power	$P = cv^2$	$P = c\omega^2$	$P = \frac{v^2}{R}$	$P = \frac{1}{R}(p_1 - p_2)^2$	

Table 3: Summary of Mechanical, electrical, Fluid And thermal systems

3.7. CONTINUOUS AND DISCRETE PROCESSES

Open loop control is essentially just a switch on-switch off form of control.E.g: an electric fire is either switched on or switched off in order to heat a room.With closed-loop control systems, a controller is used to compare the output of a system with the required condition and convert the error into a control action designed to reduce the error.Error may arise as a result of some changes in the conditions being controlled or because the set value is changed,

E.g: if there is a step input to the system to change the set value to a new value.

In this, the control modes, a discussion on how they termed, which occur with continuous processes.

E.g: pneumatic system or operational amplifier systems.

Computer systems are rapidly replacing these nowadays.Digital control, when the computer is in the feedback loop and exercising control in this way.Many processes not only involve controlling some variable, E.g: temperature, to a required value but also involve the sequencing of operations.

A domestic washing machine where a number of actions have to be carried out in a predetermined sequence is an example.Manufacture of a product which involves the assembly of a number of parts in a specific sequence by some controlled event-based or a combination of the two. With a clock-based system the actions are carried out at specific times, with an event-based system the actions are carried out when there is feedback to indicate a particular event has occurred.

The term programmable logic controller (PLC) is used for a simple controller based on a microprocessor and operates by examining the input signal from sensors and carrying out logic instructions which have been programmed into its memory.

The output after such processing is signals which feed into correcting/actuator units.

Thus it can carry sequences of operations.

The main difference between a PLC and a computer is that programming is predominantly concerned with logic and switching operations.

Interfacing for input and output devices is inside the controller.

In many processes, mixture of continuous and discrete control are there.

E.g: domestic washing machine – sequence control for various parts of washing cycle with feedback loop control of temp for hot water & level of water

In any control system there are lags.

E.g: a change in the condition being controlled does not immediately produce a correcting response from the control system.

Because time is required for the system to make the necessary responses.

E.g: control of temperature in a room by means of a central heating system, a lag will occur between the room temperature falling below the required temperature and the control system responding and switching on the heater.

This is not only lag, even when the control system has responded there is a lag in room temperature responding as time is taken for the heat to transfer from the heater to the air in the room

3.8. CONTROL MODES

There are a number of ways by which a control unit can react to an error signal and supply an output for correcting elements.

1. **The two-step mode**: the controller is essentially just a switch which is activated by the error signal and supplies just an on-off correcting signal.
2. **The proportional mode (P):** produces a control action that is proportional in the error. The correcting signal thus has becomes bigger the bigger the error. Thus the error is reduced the amount of correction is reduced and the correcting process slows down.
3. **The derivative mode (D):** produces a control action that is proportional to the rate at which the error occur is changing when there is a sudden change in the error signal the controller gives a larger correcting signal, when there is gradual change only a small correcting signal is produced
4. Derivative control can be considered to be a form of anticipatory control in that the existing rate of change of error is measured, a coming larger error is anticipated and correction applied before the larger error has arrived.Derivative control is not used alone but always in conjuction with proportional control and often, integral control.
5. **The integral mode (I):** produces a control action that is proportional to the integral of the error with time. Thus a constant error signal will produce an increasing correction signal. The correction continues to increase as long the error persists. The integral controller can be

considered to be “looking-back”, summing all the errors and thus responding in changes that have controlled.
The controller can achieve these modes by means of pneumatic circuits, analogue electronic circuits involving operational amplifiers or by the programming of a microprocessor or computer.
Two step mode
E.G: Bimetallic thermostat

- Used with a simple temperature control system.
- This is just a switch which is switched on or off according to the temperature.
- If the room temperature is above the required then the bimetallic strip is in an off position and the heater is off.
- If the room temperature falls below the required temperature then the bimetallic strip moves into an position and the heater is switched fully on. The controller in this case can be in only two positions, on or off as indicated in fig..

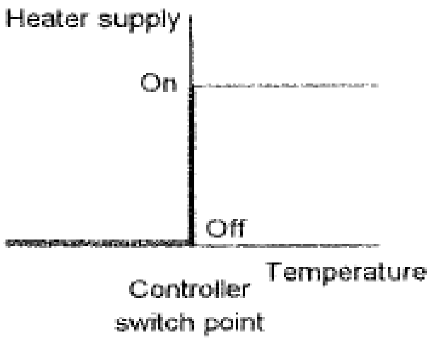


Fig 17:

With two step mode the control action discontinuous.
A consequence of this that oscillations of the controlled variable occur about the required conditions. This is because of lags in the time the control system and the process take to respond.
E.g: in case of the temperature control for a domestic central heating system, when the room temperature drops below the required level the time that elapses before the heater begins to have an effort on the room temperature. In the meantime the temperature has fallen even more.The reverse situation occurs when the temperature has risen to the required temperature.Since time elapses before the control system reacts and switches the heater off, and yet more time while the heater cools and stops heating the room, the room temperature goes beyond the required value. The result is that the room temperature oscillates above and below the required temperature.
With the simple two-step system described above there is the problem that when the room temperature is hovering about the set value the thermostat might be almost continually switching on or off, reacting to very slight changes in temperature.
This can be avoided if, instead of just a single temperature value at which the controller switches the heater on or off, two values are used and the heater is switched off.
The term dead band is used for the values between the on and off values.

A large dead band results in large fluctuations of the temperature about the set temperature, a small dead band will result in an increased frequency of switching.
The bimetallic element shown in fig has a permanent magnet for a switch contact, this has the effect of producing a dead band.

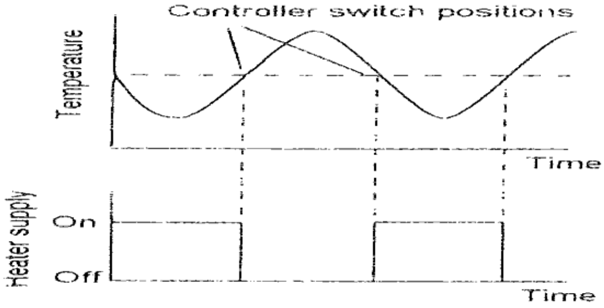


Fig 18: Oscillation with two step control

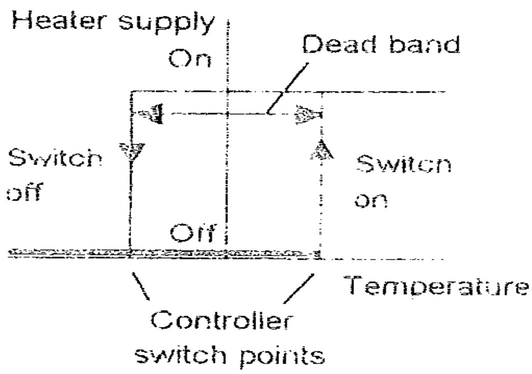


Fig 19: Two step control with controllers switch points

TWO STEP MODES

Two-step control actions tends to be used where changes are taking place very slowly i.e. with a process with a large capacitance.Thus in case of heating a room, the effect of switching the heater on or off on the room temperature is only a slow change.The result of this is an oscillation with a long periodic time.Two-step control is thus fairly cheap.On-off control is not restricted to mechanical switches such as bimetallic strips or relays rapid switching can be achieved with the use of thyristor circuits.Such a circuit might be used for controlling the speed of a motor and operational amplifier.

CLASSIFICATION OF CONTROLLERS

- Two position or ON-OFF controllers
- Proportional (P) controllers
- Proportional (P) + Integral (I) i.e. PI controllers
- Proportional (P) + Derivative(D) i.e. PD controllers
- Proportional (P) + Integral (I) + Derivative (D) i.e. PID controllers

A sensor measures and transmits the current value of the **process variable(PV)** back to thecontroller.

- **Controller error(e(t))** at current time t is computed as **set-point(SP)** minus measured process variable as in (1).

e(t) = SP – PV (1)

- The controller uses this e(t) in a control algorithm to compute a new controller output signal.
- The controller output signal is sent to the final control element (e.g.**valve**, **pump, heater**, **fan**) causing it to change.
- The change in the final control element causes a change in a manipulated variable
- The change in the manipulated variable (e.g. flow rate of liquid or gas) causes a change in the PV

PID CONTROLLER

A proportional-integral-derivative controller (PID controller or three term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value e(t) as the difference between a desired set point (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively) which give the controller its name.

The first theoretical analysis and practical application was in the field of automatic steering systems for ships, developed from the early 1920s onwards. It was then used for automatic process control in manufacturing industry, where it was widely implemented in pneumatic, and then electronic, controllers. Today there is universal use of the PID concept in applications requiring accurate and optimized automatic control.PID control is widely used in all areas where control is applied.

- P – Controller = P depends on the **present error**
- I – Controller = I on the accumulation of **past errors**
- D Controller = D isapredictionof**futureerrors**, based on current rate of change

Characteristics of PID controller

A proportional controller (Kp) will have the effect of **reducing the rise time** and will reduce but never eliminate the steady state error.

An integral control (Ki) will have the effect of eliminating the steady- state error for a constant or step input, but it may make the transient response slower.

A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

In fact, changing one of these variables can change the effect of the other two.

With the PID controller we can set the P+I+D values so that we will not have any Over or undershoot and reach set point directly.PID controller has all the necessary dynamics: fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). This combination of{Present + Past + Future} makes it possible to control the application very well.

Proportional Controller

In a proportional controller the output (also called the actuating/control signal) is directly proportional to the error signal. The position of Kpcan be as shown in Fig.

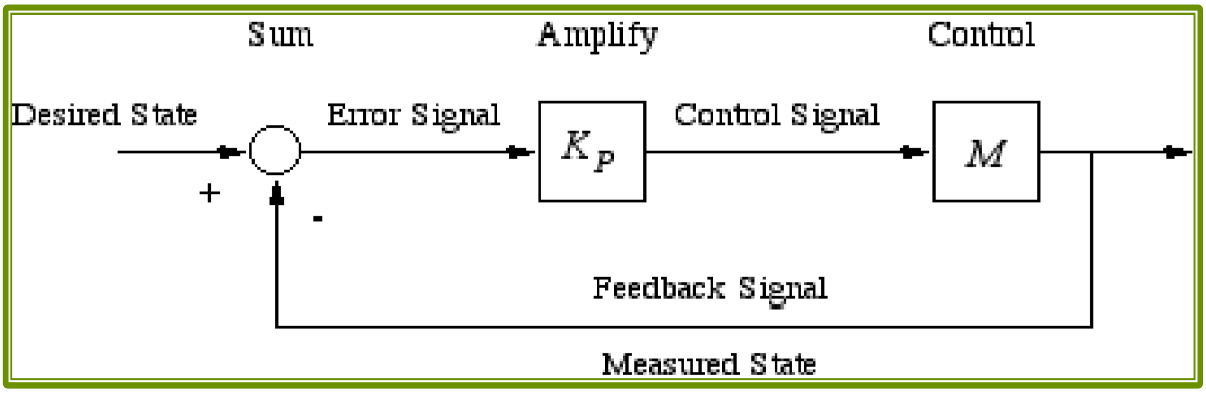


Fig20 :Proportional controller

Control signal = Kp * e(t) (2)

If the error signal is a voltage, and the control signal is also a voltage, then a proportional controller **is just an amplifier**.

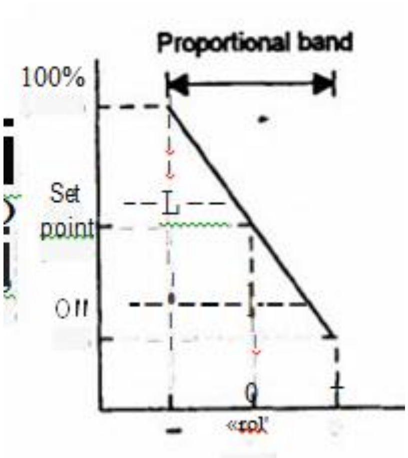


Fig 21: Proportional mode

With the two-step method of control, the controller output iseither an on or an off signal, regardless of the magnitude of the error. With the proportional mode, the size ofthecontroller output is proportional to the size of the error. This means the correction element of the control system, e.g.a valve, will receive a signal which is proportional to the size of the correction required.

Figure shows how the output of such a controller varies with the sizeand sign of theerror. The linear relationship betweencontrolleroutputanderrortendstoexistonlyoveracertain range of errors, this range being called theproportionalband.Withintheproportionalbandtheequationofthestraightline can be represented by

Change in controller output from set point = K,e

whereeistheerrorandKₚaconstant.K,isthusthe gradientofthe straight line in Fig.

Thecontrolleroutputisgenerallyexpressedasapercentageof thefullrangeofpossibleoutputswithintheproportionalband.This output can then correspond to, say, a correction valve changingfromfullyclosedtofullyopen.Similarly,theerroris expressed as a percentage of the full-range value, i.e. the error rangecorrespondingtothe0to100%controlleroutput.Thus

% change in controller output from set point

=K» x % change in error

Hence,since100%controlleroutputcorrespondstoanerror percentage equal to the proportional band

$K_p = \frac{100}{Proportional \quad band}$

We can rewrite the equation as changeinoutput=I_{out}–1_O=Kpe

where I_0 is the controller output percentage at zero error, I_{out} the output percentage at percentage error e. Thus taking Laplace transforms:

Change in output $(s) = K_P E(s)$

and so, since

$$\text{Transfer function} = \frac{\text{change in output }(s)}{E(s)}$$

K_P is, within the proportional band, the transfer function of the controller.

Derivative Controller (D)

With the derivative mode of control the change in controller output from the set point value is proportional to the rate of change with time of the error signal. This can be represented by the equation

$$I_{out} = I_0 = K_D \frac{de}{dt}$$

Where I_0 is the set point output value, I_{out} the output value that will occur when the error e is the rate $\frac{de}{dt}$. It is usual to express these controller outputs as a percentage of full range. K_D is the constant of proportionality.

The transfer function is obtained by taking Laplace transforms, thus

$(I_{out} - I_0)(s) = K_D sE(s)$

Hence the transfer function is $K_D s$. With derivative control, as soon as the error signal begins to change there can be quite a large controller output. Since it is proportional to the rate of change of the error signal and not its value. Rapid initial responses to error signals thus occur.

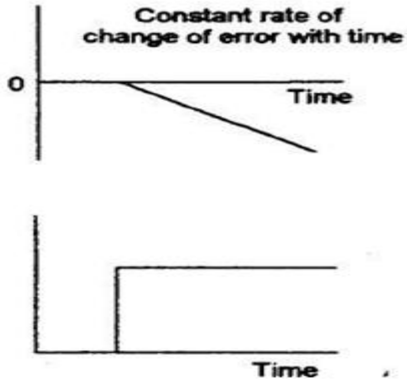


Fig 22: Derivative mode

Proportional plus Derivative control (PD)

Derivative control is never used alone because it is not capable of giving an output when there is a steady error signal and so no correction is possible. It is thus invariably used in conjunction with proportional control so that this problem can be resolved. With proportional plus derivative control the change in controller output from the set point value is given by

Change in output from set point = $K_p e + K_D \frac{de}{dt}$

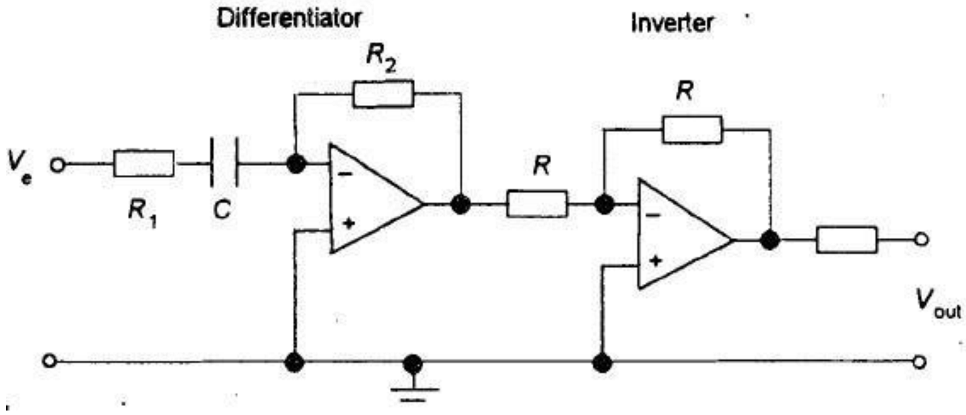


Fig 22: PD controller

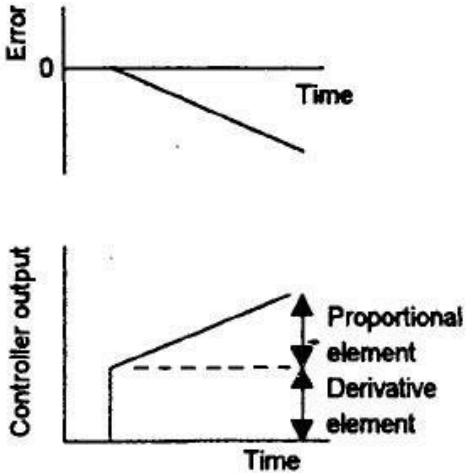


Fig 23: PD mode

Hence

$I_{out} = K_p e + K_D \frac{de}{dt} + I_0$

where I_0 is the output at the set point, I_{out} the output when the error is e, K_P is the proportionality constant and K_D the derivative constant. de/dt is the rate of change of error. The system has a transfer function given by

$(I_{out} - I_0)(s) = K_P E(s) + K_D s E(s)$

Hence the transfer function is $K_P + K_D s$. This is often written as: transfer function $= K_D(s + T_D)$

where $T_D = K_P/K_D$ and is the *derivative time constant*. Figure shows how the controller output can vary when there is a constantly changing error. There is an initial quick change in controller output because of the derivative action followed by the gradual change due to proportional action. This form of control can thus deal with fast process changes; however, a change in set value will require an offset error (see earlier discussion of proportional control).

Integral Control (I)

The *integral mode* of control is one where the rate of change of the control output I is proportional to the input error signal e.

$$\frac{dI}{dt} = K_I e$$

K_I is the constant of proportionality and, when the controller output is expressed as a percentage and the error as a percentage, has units of s^{-1}. Integrating the above equation gives

K is the constant of proportionality and when the controller output is expressed as a percentage and the error as a percentage has unit of s. integrating the above equation gives

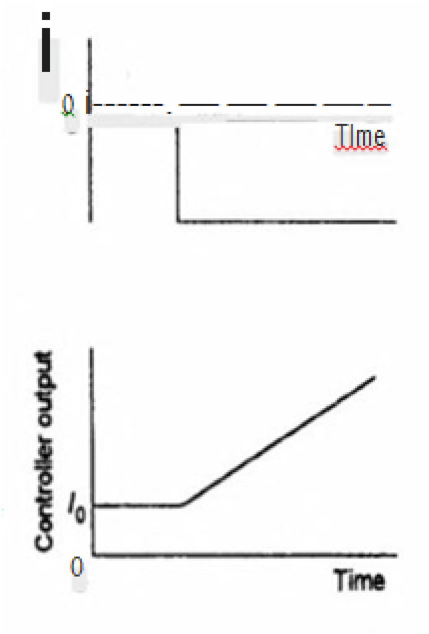


Fig 24:Integral mode

J',•0 di=J' KaedJ

IN -1, = J:K,edt

1isthecontrolleroutputatzerotime.J.,.istheoutputatumer,The transfer function is obtained bytaking Laplacetransforn.Thus
(/...–1,Xs)•tKaE(s)and so

Transferfunction=tK1

Figurellustralcstheactionofanintegralcontrollerwhen thereisaconstanterrorinputlothecontroller.'Wecanconsider the graphs in two ways. When the controller output is constant theerroriszero;whenthecontrolleroutputvariesataconstant rate the error has a constant value. The alternative way of consideringthegraphsisin termsofthe areaunderthe errorgraph.

Area undertheerrorgraphbetweent•0andt•Jedi

Thus up to the time when the error occurs the value of the integral iszero.Hence/0tll.=/0.Whenthe erroroccursit maintains a constant value. Thus the area under the graph isincreasing as the time increases. Since the area increases at a constant rate the controller output increases at a constant rate

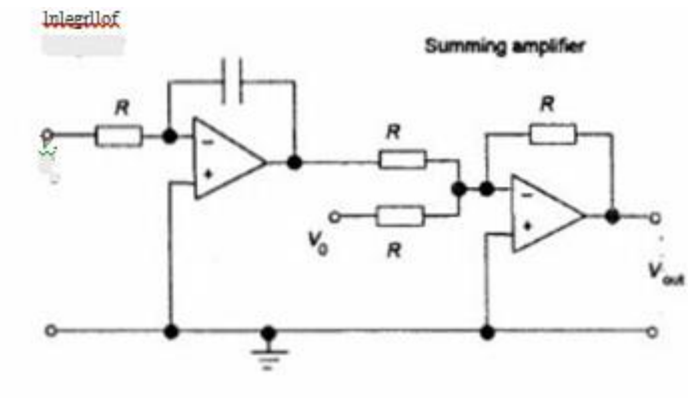


Fig 25: Integral controller

Proportional plus Integral Control (PI)

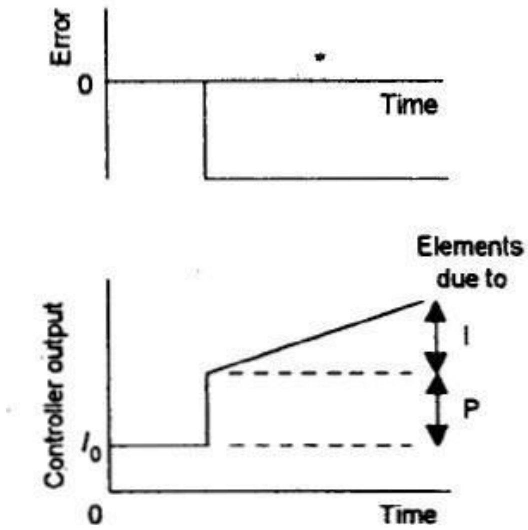


Fig 26: PI mode

The integral mode of control is not usually used alone but is frequently used in conjunction with the proportional mode. When integral action is added to a proportional control system the controller output I_{out} is given by

I_{out}– $K_pe + K_I \int ed_t + I_0$

Where $K_p$is the proportional control, $K_I$the integral control constant, $I_{out}$the output when ther is an error e and $I_0$the output at the set point when the error is zero. The transfer function is thus

Transfer function = $K_p + \frac{KI}{s} = \frac{Kp}{ds\,t} = \frac{Kp}{s}(s + \frac{1}{T1})$

Where $T_1 = K_p / K_I$ and is the integral time constant.

Fig shows how the system reacts when there is an abrubt change to a constant error. The error gives rise to a proportional controller output which remains constant since the error does not change. There is then superimposed on this a steadily increasing controller output due to the integral action.

PID Controllers

Combining all three modes of control (proportional, Intergral and derivative) enables a controller to be produced which has no offset error and reduces the tendency for oscillations.

Such a controller is known as a three-mode controller or PID controller. The equation describing its action can be written as

$$I_{out} = K_P e + K_I \int e \, dt + K_D \frac{de}{dt} + I_0$$

Where I_{out} is the output from the controller when there is an error e which is changing with time t, I_0 is the set point output when there is no error, K_p is the proportionality constant, K_I the integral constant and K_D the derivative constant. One way of considering a three-mode controller is an a proportional controller which has integral control to eliminate the offset error and derivative control to reduce time lags. Taking the laplace transform gives

$$(I_{out} - I_0)(s) = K_P E(s) + \frac{1}{s} K_I E(s) + sK_D(s)$$

And so

Transfer function = $K_P e + \frac{1}{s} K_I + sK_D = K_P\left(1 + \frac{1}{T_I s} + T_D s\right)$

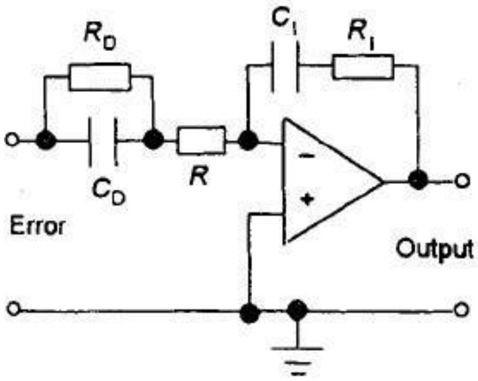


Fig 27: PID controller

Digital Controllers

The digital controller requiring inputs which are digital, process the information in digital form and give an output in digital form. The controller performs the followingfunctions:

1) Receives input fromsensors.

2) Executes controlprograms

3) Provides the output to the correctionelements.

As several control systems have analog measurements an analog – to digital converters (ADC) is used for the inputs. The fig shows the digital closed – loop control system which can be used with a continuous process.

The clock supplies a pulse at regular time intervals, and dictates when samples of controlled variables are taken by ADC.These samples are then converted into digital signals which are compared by the microprocessor with the set point value to give the error signal. The error signal is processed by a control mode and digital output is produced.

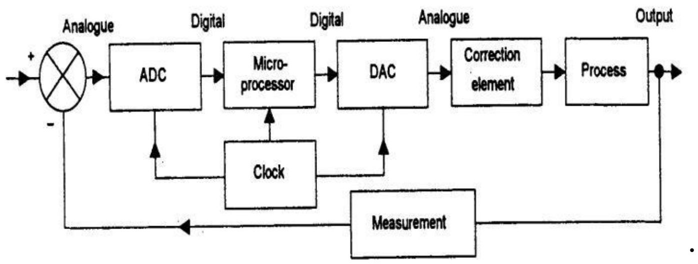


Fig 28: Digital control

The digital output, generally offer processing by an DAC since correction elements generally require analog signals, can be used to initiate the corrective action.

Sequence of operation

1) Samples the measuredvalue.
2) Compares this measured value with the set value and stored valuesofpreviousinputsandoutputstoobtaintheoutputsignal.
3) Send the output signal toDAC
4) Waits until the next samples time before repeating thecycle.

3.9. VELOCITY CONTROL

A second order system with proportional control system will take more time to reach the required output when step input is given.Consider the problem of controlling the movement of a load by means of a motor. This is an example to control velocity, because the motor system is likely to be second order, proportional control will lead to the system output taking time to reach the required displacement when step input is given. Such a system is shown in thefig.

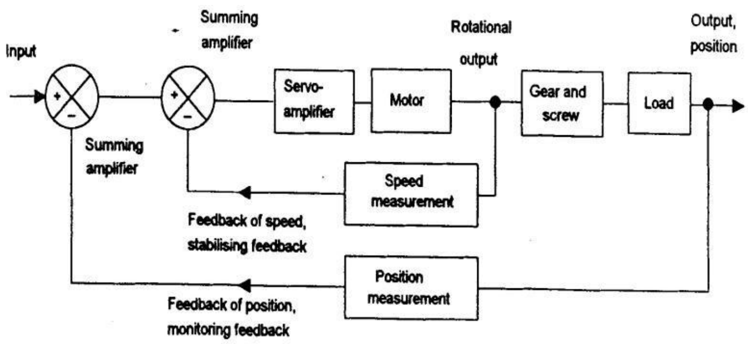


Fig 29: Velocity control

A higher speed response, with fewer oscillations, can be obtainedbyusingthePDcontrol.Analternativeofachievingthesame effect and this is by the use of a second feedback loop that gives a measurement related to the rate at which the displacement is changing. This is termed as velocity feedback.The velocity feedback might involve the use of a tacho-generator giving a signal proportional to the rotational speed of the motor shaft and hence the rate at which the displacement is changing and the displacement might be monitoring using a rotary potentiometer.

3.10. ADAPTIVE CONTROL

The adaptive controllers change the controller parameter to adapt to the changes and fit the prevailing circumstances. Often the control parameters of the process changes with time (or) load. This will alter the transfer functions of the system. Therefore returning of the system is desirable, for the controllers.OR

For a control system it has been assumed that the system once tunedretainsitsvalueofproportional,derivative,andintegralconstant until the operator decides to retune. The alternative to this is an adaptive control system which adapts to changes and changes its parameters to fit the circumstancesprevailing.

The adaptive control system can be considered to have three stages of operation,

1) Starts to operate with controller conditions set on the basis of an assumedcondition.

2) The designed performance in continuously compared withthe actual system performance.

3) The control system mode and parameters are automatically and continuously adjusted in order to minimize the difference between the desired and actual systemperformance.

Adaptive control system can take a number of forms. The three commonly used forms are:

1. Gain schedulingcontrol
2. Self – tuningcontrol
3. Model – reference adaptivecontrol.

Gain scheduling control

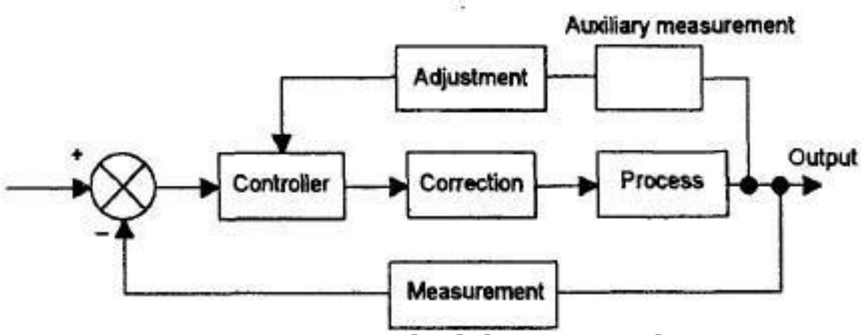


Fig 30: Gain scheduling Control

With gain scheduling control, present changes in the parameter of the controller are made on the basis of some auxiliary measurement ofsomeprocessvariable.Thetermgain–scheduledcontrolwasused because the only parameter originally adjusted was to gain is kp

Selftuning.

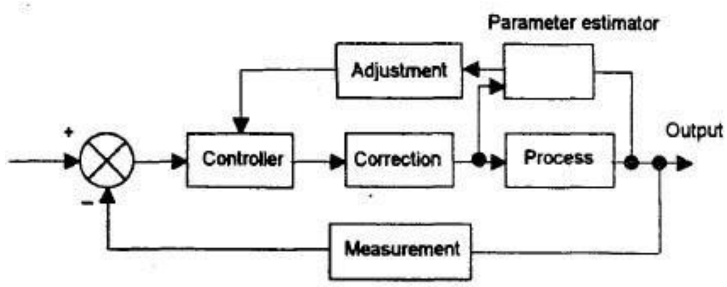


Fig 31:Self tuning

With self tuning control system continuously tunes its own parameter based on monitoring the variable that the system is controlling.

Self- tuning is found in PID controllers. It is generally refers to auto-tuning.Whentheoperatorpressesabutton,thecontrollerinjects a small disturbance into the system and measures the response.This response is compared to the desired response and the control parameters areadjusted.

Model – reference control

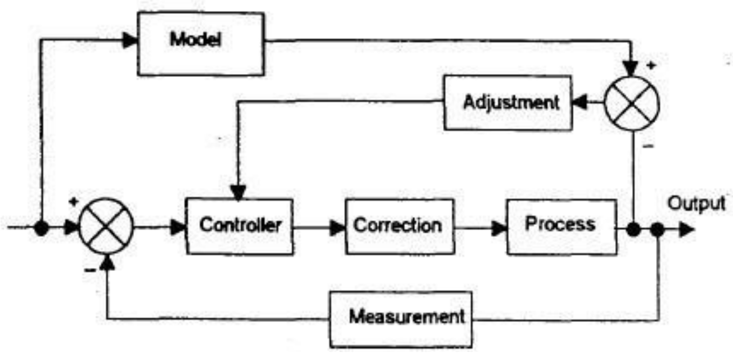


Fig 32:Moderl reference control

Model reference system is an accurate model of the system is developed. The set value is then used as input to both model systems and actual systems and the difference between the actual output and output from the model compared. The difference in these signals is then used to adjust the parameters of the controller to minimize the difference.

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DEPARTMENT OF MECHANICAL ENGINEERING

UNIT - 4 - PROGRAMMABLE LOGIC CONTROL - SPR1304

4. PROGRAMMABLE LOGIC CONTROLLER

4.1. INTRODUCTION TO PLC

A programmable Logic Controller (PLC) is defined as a digital electronic device that uses a programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes.

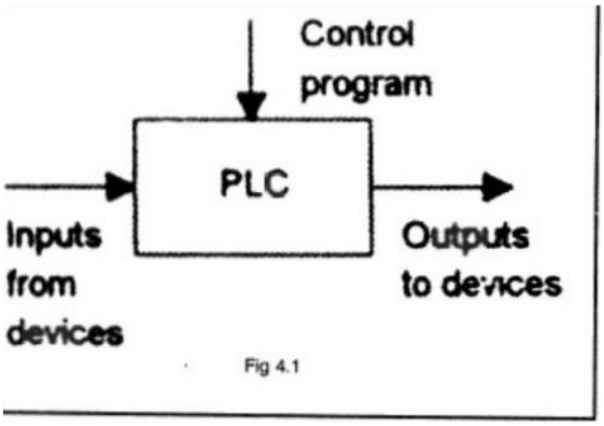


Fig 1: Basic components of PLC

Features of PLC as a Controller:

PLC's are rugged and designed to withstand vibrations, temperature, humidity and noise. The interfacing for inputs and output is inside the controller. PLC's are easily programmable and have an easily understandable programming language. Programming is primarily concerned with logic and Switching operations.

4.2. BASICSTRUCTURE

The fig. shows the basic internal structure of a PLC. It consists essentially of a central processing unit (CPU), memory and input/output (I/0) circuitry. The CPU controls and processes all the operations within the PLC. It is supplied with a clock of frequency typically between 1 and 8 MHz. This frequency determines the operating speed of the PLC and provides the timing and synchronization for all elements in the system. A bus system carries information and data to and from the CPU, memory and input/output units. There are several memory elements: a system ROM to give permanent storage for the operating system and fixed data; RAM for the user's program, and temporary buffer storage for I/0 channels. The programs in RAM can be changed by the user. However, to prevent the loss of these programs during power failure, a battery is likely to be used in the PLC to hold the RAM contents for a period of time.

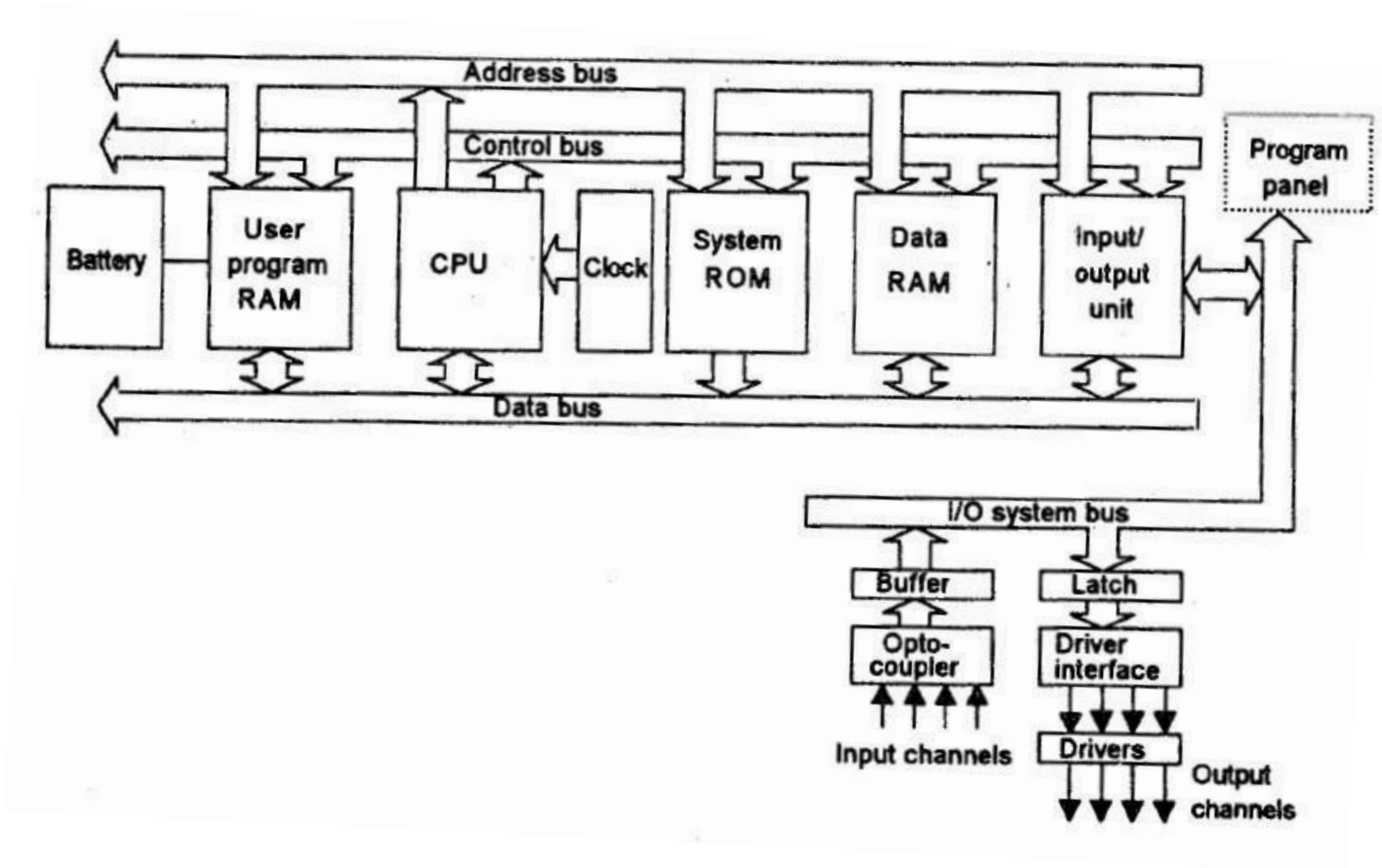


Fig 2: Basic Architecture of PLC

After a program has been developed in RAM, it may be loaded into an EPROM memory chip and so made permanent. The I/0 unit provides the interface between the system and the outside world. Programs are entered into the system through input devices like key pad or sometimes through Personal Computer (PC) which is loaded with an appropriate software package. The I/0 channels have signal conditioning and isolation units, so that sensors and actuators can be generally directly connected to them without the need for any other circuitry. The figure shows the basic form of an input channel. Common input voltages are 5V and 24VCommon output voltages are
24V and 240V.

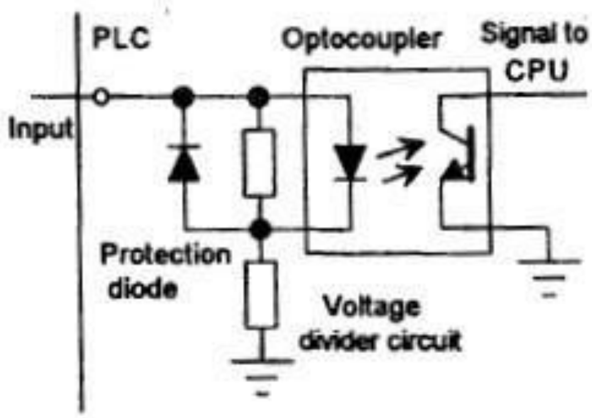


Fig 3:Input channel

There are three types of output

1) Relay type.
2) Transistortype.
3) Triac type

1) RelayType

Withrelaytype,thesignalfromthe**PLC**outputisusedtooperatearelayandsoisable to switch currents of the order of few amperes in an external circuit. The relay isolates the **PLC** from the external circuit and can be used for both d.c and a.c switching Relays are relatively slow to operate.

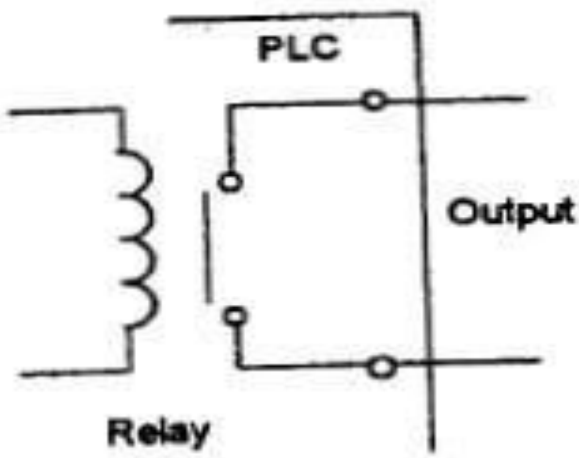


Fig 4: Relay type

2) Transistor type

The transistor type of output (fig) uses a transistor to switch current through the external circuit. This provides a faster switching action. Optoisolators are used with transistor switches to provide isolation between the external circuit and the **PLC.** The transistor output is only for D.C. switching.

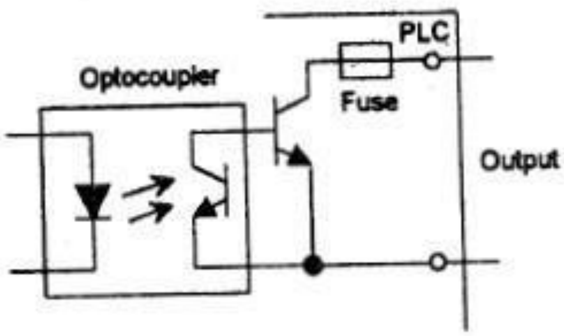


Fig 5: Transistor type

3) Triactype:

Triac outputs can be used to control external loads which are connected to the a.c. power supply. Opto isolators are again used to provide isolation.

4.3. INPUT / OUTPUT PROCESSING

The programming commonly used with PLC is ladder programming. This involves each program task being specified as through a rung of a ladder. This each rung could be specify that the state of switches A&B.The inputs, be examined and if A&B are both closed then a solenoid, the output is energized. The sequence followed by a PLC when carrying out a program can be as follows

1. Scan the inputs associated with one rung of the ladder program.
2. Solve the logic operation involving those inputs.
3. Set/reset the output for that rung.
4. Move on the next rung and repeat the operations 1, 2,3.

Thus a PLC is continuously running through its program and updating it as a result of input signal. Each such loop is termed as cycle. This continues until the program is completed.

There are two methods that can be used for I/O processing:

1. Continuous updating

In this method, the **CPU** scans input channels as they occurring the program instructions. Each input is examined individually and its effect on the program determined. there involves a time delay, typically about 3 ms, when each input is scanned in order to ensure that only valid input signals are read by the microprocessor. This delay enable **CPU** to avoid counting an input signal twice, A number of inputs may have to be scanned, each with a 3ms delay, before the program has the instruction for a logic operation to be executed and an output to occur. The outputs are latched so that they retain their status until the next update. The 3ms built-in delay for each input is, for ensuring the signals read by the **CPU** is the valid one. or more frequently, if there is contact bounce at a switch.

2. Mass I/O Copying

In the above method, with 3 ms delay on each input, the time taken to examine several hundred I/0 points can become comparatively long. To allow a more rapid execution of a program, a specific area of RAM is used as a buffer store between the control logic and I/0 units. Each I/0 have and address in this memory. At the start of each program is executed the stored input data is read, as required, from RAM and the logic operations carried out. The resulting output signals are stored in the reserved I/0 section RAM. At the end of each program cycle, all the outputs are transferred from RAM to the output channels. The outputs are latched so that they retain their status until the next update.

4.4. PROGRAMMING

Ladder diagram

PLC'sareprogrammedusingladderdiagramtechniques.Aspecialstandardschematic representation of the physical components arrangement (hardware) and its way of connections made between them is called as ladder diagram. These are line diagram the represent both the system hardware and the processcontroller.
A ladder diagram consists of two vertical lines called power power rails are connected along with I/O devices and other components as horizontal lines between the two vertical lines known as rungs.

Rules followed in ladder diagram

1. The vertical lines of the diagram represent the power rails, and the horizontal lines representing therungs.
2. Each rung on the ladder defines one operation in the controlprocess.
3. A ladder diagram must read from left to right and from top to bottom. whenthe scanning of first rung is completed then the second rung starts from left toright.
4. Each rung must start with an input and must end with anoutput.
5. Each rung must have more than one input but only oneoutput.
6. The input must always located at the rung left and the output at the right end of the rung.
7. Electrical devices are shown in their normalcondition.

Ladder diagram can be entering from a monitor screen by using mouse. When entered, they translated by the PLC into machine language for microprocessor to understand it. The nature of input determines whether the output is to be energized or not.

The Ladder programming is one of the basic forms of programming commonly used with PLC's. In this type of programming, each program task being specified as though a rung of ladder. Circuits are connected between these two vertical lines as horizontal lines, i.e. the rungs of the ladder. Fig. shows the basic symbols that are used in the ladder diagram.

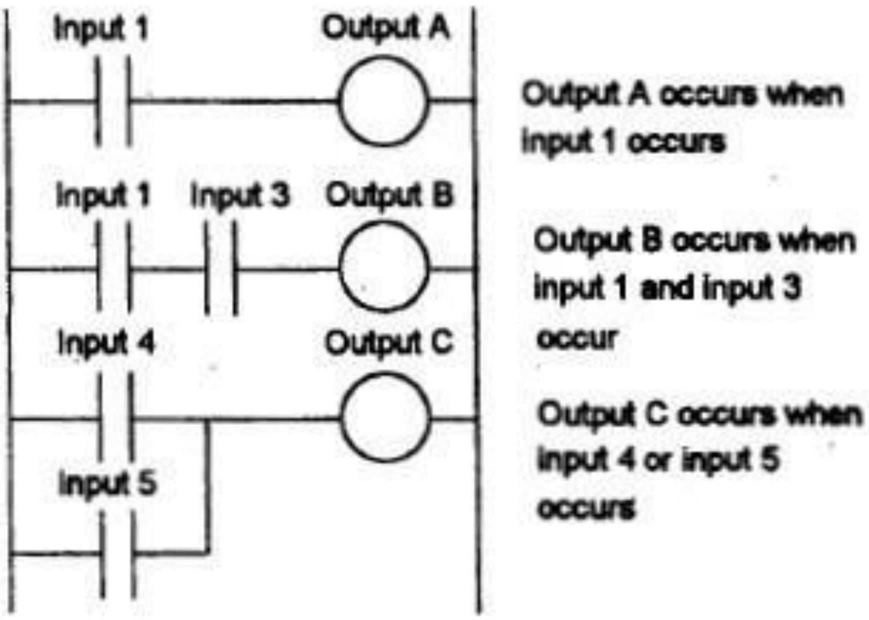


Fig 7: Ladder Programme

Ladder Symbols

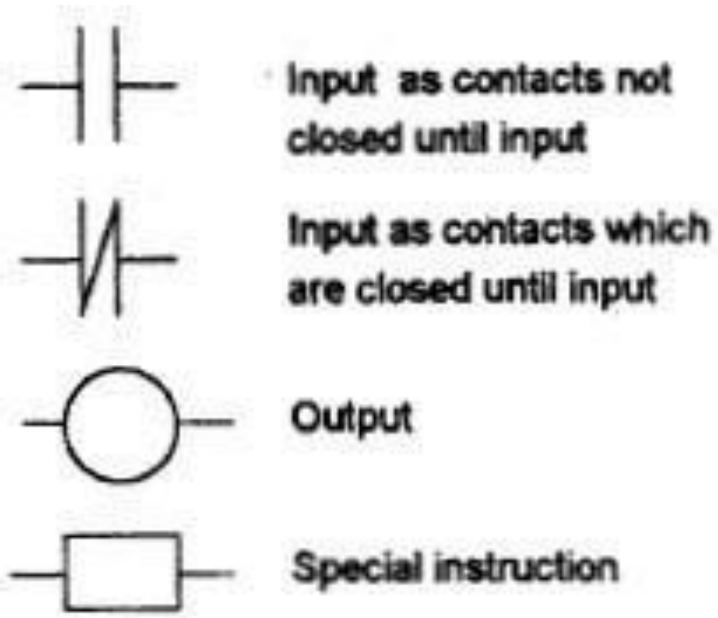


Fig 8: Ladder symbol

Precede outputs and depending on, the different **PLC** manufacturer, different notations are used. For example, the Mitsubishi F series of PLC's precedes inputs elements by an X and output elements by a Y and uses the following numbers: Numbering schemes are followed for inputs and outputs and depending on, the different PLC manufacturer, different notations are used. For example, the Mitsubishi F series of PLC's precedes inputs elements by an X and output elements by a Y and uses the following numbers:

Inputs X300 - 307,310 -313

X600 - 607,610 - 61 3

(24 possible inputs) Outputs Y330-337

Y 430 - 437
(1 6 possible outputs)

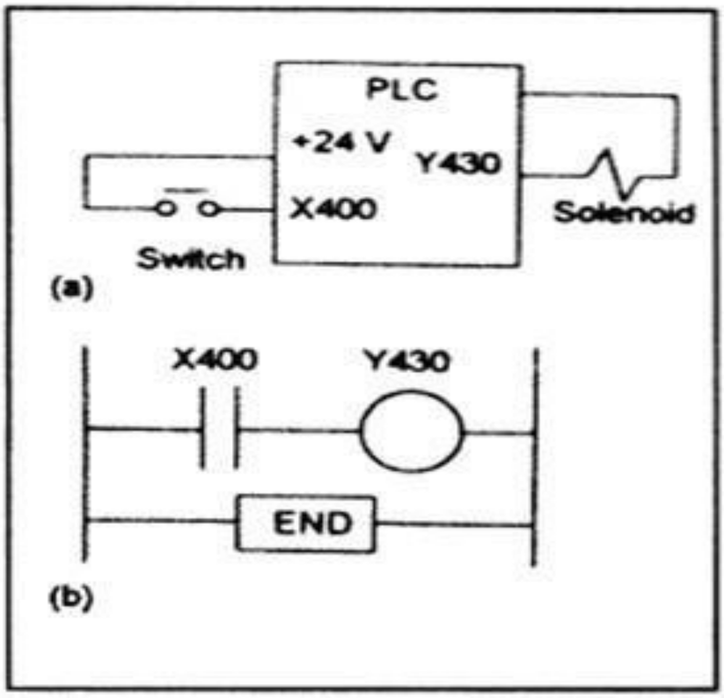


Fig 9: Ladder diagram example

To illustrate the drawing of a ladder diagram, consider a situation where the output from the PLC is to energies a solenoid when a normally open start switch connected to the input is activated by being closed (Fig. (a)). the program required is shown in Fig.(b).

Starting with the input, we have the normally open symbol 11. This might have an input addressX400. The line terminates withthe output, the solenoid, with the symbol

0. This might have the output address Y430. To indicate the end of the program the end rung is marked. When the switch is closed the solenoid is activated. This might, for example, be a solenoid valve which opens to allow water to enter avessel.

4.5. LOGIC FUNCTIONS

Logic functions may be obtained through various combinations of switches. Also it is explained how one can write ladder program using such combinations.

1. And function

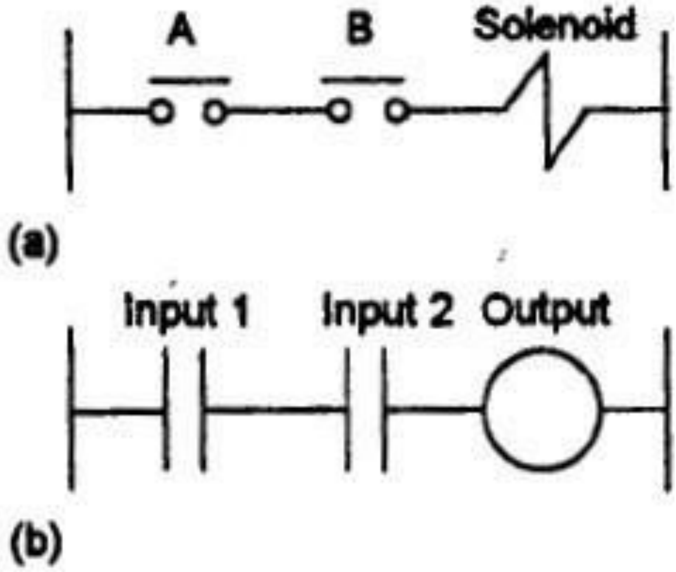


Fig 10: AND Function

Only when both the switches are closed simultaneously, the lamp will be lit, otherwise it is put off. Thus, this situation corresponds to an **AND** logic function. The ladder diagram representing the **AND** function is shown in Fig.(b). The switches A and B are represented as input 1 and input 2 and lamp is represented as an output.

2. OR function

Consider a situation shown in Fig.

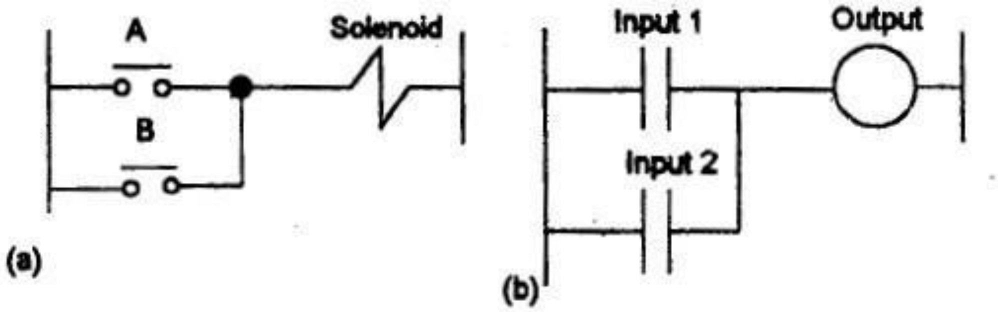


Fig 11: OR function

If either one of the switch A or B is closed, then the lamp will be lit. If both switches are opened simultaneously, then lamp will be put off. This situation Corresponds to an OR system. The ladder diagram representing the OR function is shown in fig.(b) The switches A and B are represented as output.

3. Nor function

Consider a situation show in Fig. (a) When neither A nor B have an input (i.e., neither switch A nor switch B is opened) the lamp will be lit. When there is input to A or B (i.e., if switch A or B is opened) the lamp will be put off. This situation corresponds to a NOR system. The ladder diagram representing NOR function is shown in Fig. (b) Switch A and B are represented as input 1 and input

2; and lamp is represented as output. In this case the switches A and B are normally closed. When input occurs, the corresponding switch is opened. There will be output if neither of the input occurs. There will not be output if any of the input occurs.

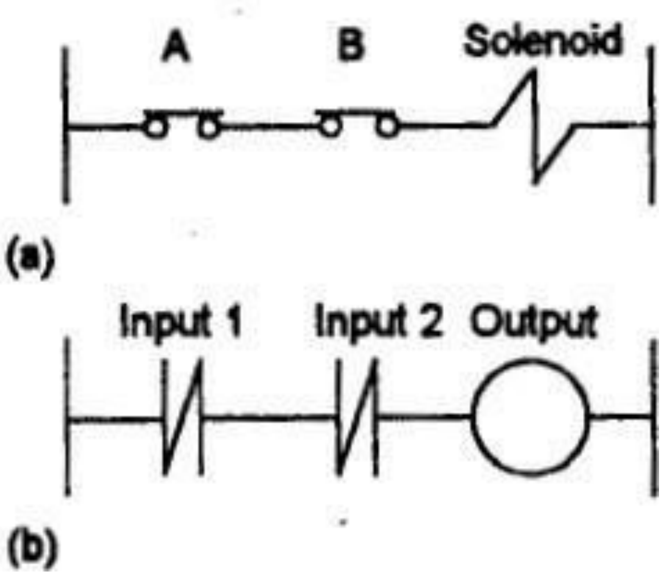


Fig 12: NOR function

4. NAND Function

Consider a situation show in Fig. (a)

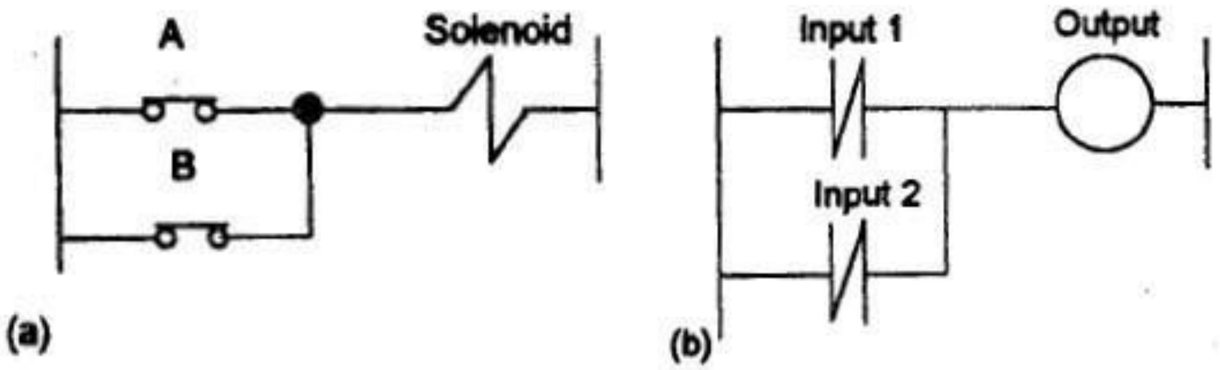


Fig 13: NAND function

The lamp will not be lit, when both A and B have input simultaneously (i.e., when both are opened simultaneously the lamp will be lit if both inputs did not occur simultaneously (i.e., when both are not opened simultaneously). The ladder diagram is shown in Fig. (b)

5. EXCLUSIVE-OR (XOR)function

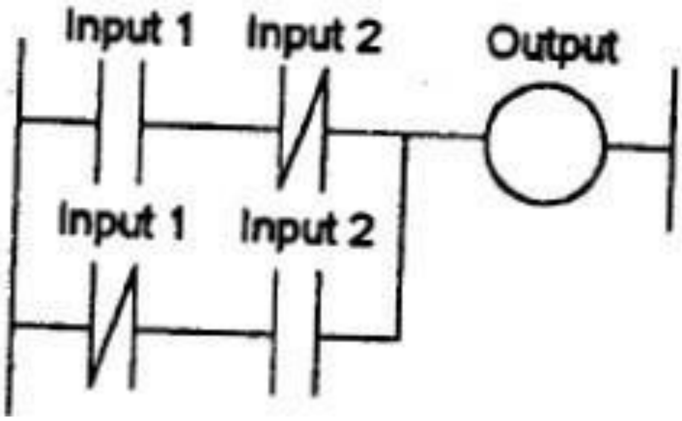


Fig 14: XOR function

Consider a situation shown in Fig. (a) In this system, there will be output (i.e., the lamp will be lit) if any one of the input occurs. There will not be output if both inputs occur or if both do not occur. The ladder diagram is shown in Fig (b) Note that, it is represented, each input by two sets of contacts, one normally open and one normally closed.

4.6. LATCHING

There are often situation where it is necessary to hold a coil energized, even when the input which energized it ceases. The term latch circuit is used for the circuit used to carry out such and operation. It is a self-maintaining circuit in that, after being energizedher input is received. It remembers its last state.

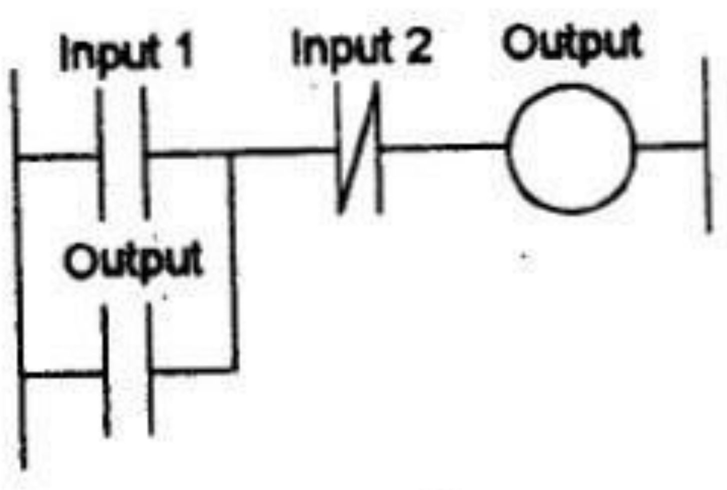


Fig 15: Latching

An example of a latch circuit is shown in Fig (a) when input 1 is energized and closes, there is an output. However, when there is an output, a set of contacts associated with the output is energized and closes. These contact OR the input 1 contacts. Thus, even if input 1 contact open, the circuit will still maintain the output energized. The only way to release the output is by operating the normally closed contact input 2.As an example of the use of a latching circuit, consider the requirement for a PLC to control a motor so that when the start signal button is momentarily pressed the motor starts and when the stop switch is used the motor switches off, signal lamps indicating when the motor is off and when on. Figure shows a possible program. With no inputs, the signal lamp for the motor indicates that it is off.

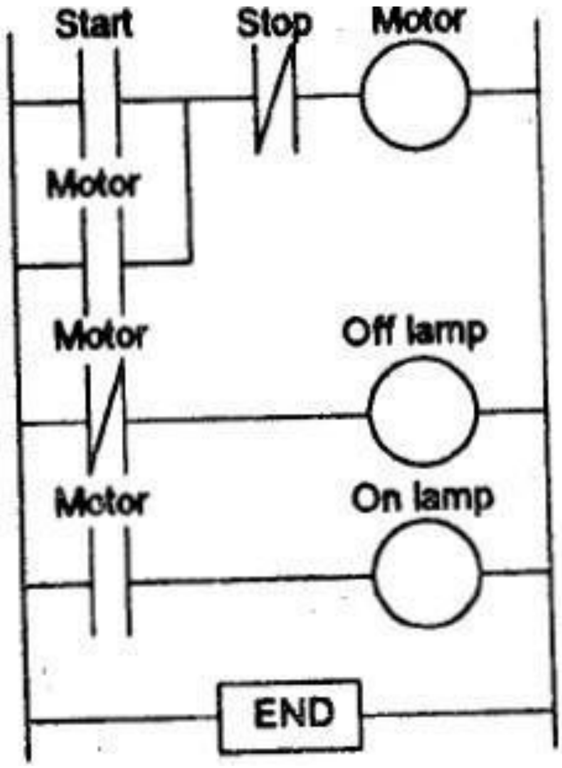


Fig 16: Example of Latching

The motor contacts which are normally closed have the off lamp on. When the start button is pressed, the normally open contacts are closed and the motor switched on. This is latched on by the motors contact in parallel with the start contacts. Also, other motor contacts which are normally closed opens and the off lamp goes off and motor contacts which are normally open closes and the on lamp goes on. The motor is stopped by the stop switch which opens the previously closed contacts.

4.7. SEQUENCING

There are often control situations where sequences of outputs are required, with the switch from one output to another being controlled by sensors.

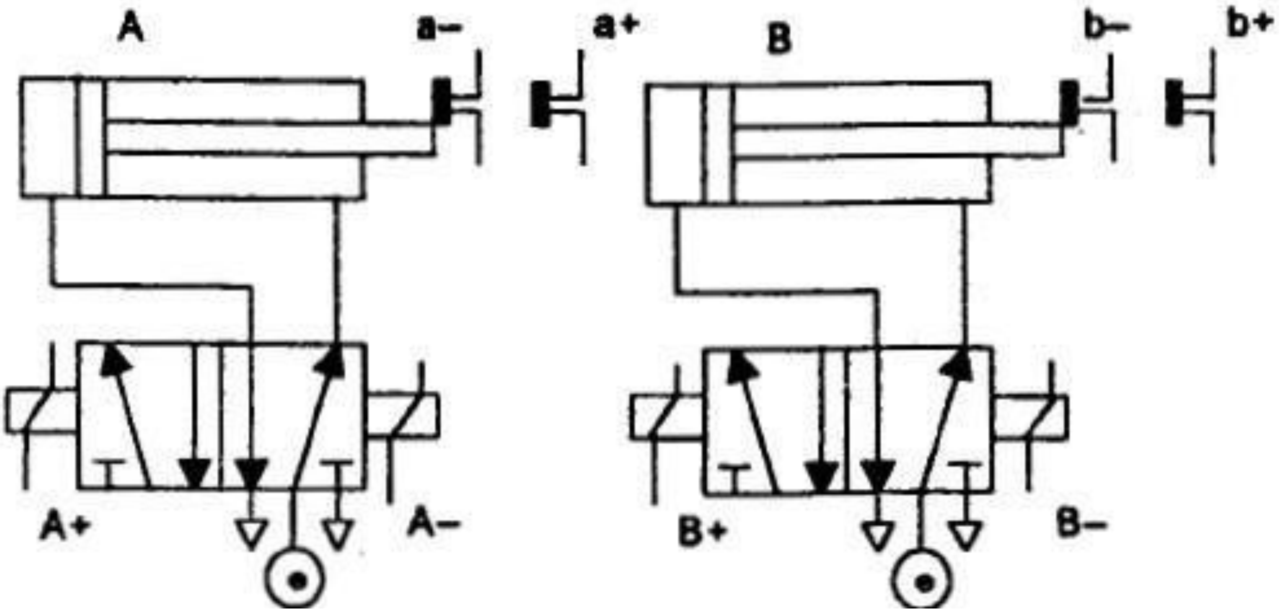


Fig 17: Sequencing

Consider the requirement for a ladder program for a pneumatic system (Fig) with double solenoid valves controlling two double-acting cylinders A and B if limitswitches a-, a+, b-, b+ are used to detect the limits of the piston rod movements in the cylinders and the cylinder activation sequence A+, B+, A-, B- is required. Fig. shows a possible program. **A** start switch input has been included in the first rung. Thus cylinder extension for A, i.e., the solenoid A+ energized, only occurs when the start switch is closed and the b- switch is closed, this switch indicating that the B cylinder is retracted. When cylinder A is extended, the switch a+, which indicates the extension of A, is activated. This then leads to an output to solenoid B+ which results in B extending. This closes the switch indicating the extension of B, i.e. the **b+** switch, and leads to the output to solenoid **A-.** and the retraction of cylinder A. This retraction closes limit switch a-and so gives the output to solenoid B- which results in B retracting. This concludes the program cycle and leads to the first rung again, which await the closure of the start switch before being repeated.

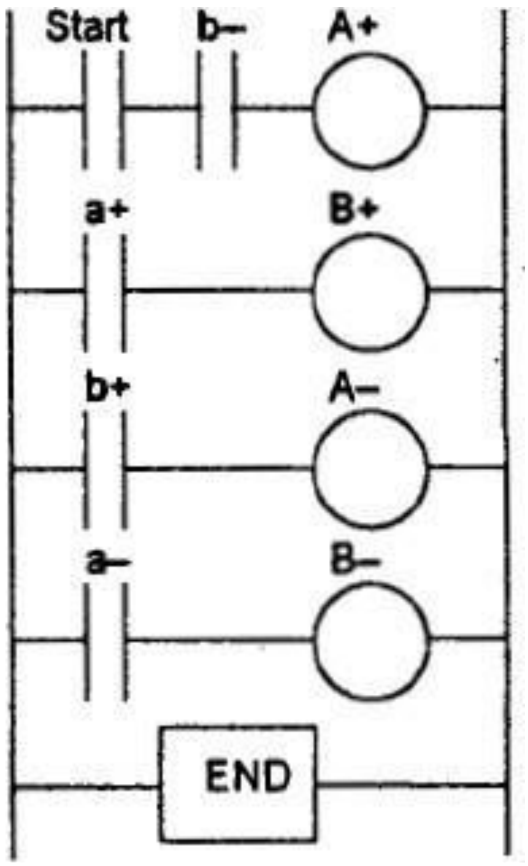


Fig 18: Sequencing of Cylinder in a engine

4.8. MNEMONICS

Each horizontal rug on the ladder in a ladder program represents a line in the program and the entire ladder gives the complete program in 'ladder language'. The programmer can enter the program into the PLC using a keyboard with the graphic symbols for the ladder elements, or using a computer screen and a mouse to select symbols, and the program panel or computer then translates these symbols into machine language that can be stored in the PLC memory.

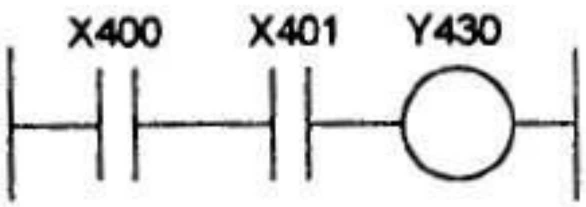
There is an alternative way of entering a program and that is to translate the ladder program into mnemonics, each code corresponding to a ladder element, and then enter these into the programming panel or computer. These are then translated into machine language. The mnemonics used by different PLC manufacturers differ.

For the Mitsubishi F series PLCs, mnemonics used are:

LD	-Start a rung with an open contact
OUT	-An output
AND	-A series element and so an AND logic instruction
OR	-Parallel elements and so an OR logic instruction
I	-A NOT logic instruction

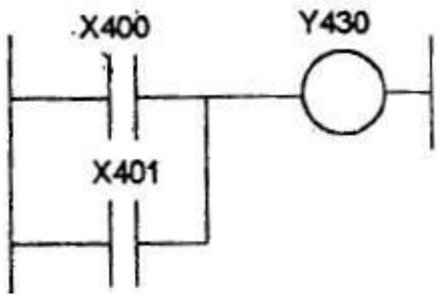
....I	-Used in conjunction with other instructions to indicate the inverse
OR1	-An OR NOT logic function
AN1	-An AND NOT logic function
LDI	- Start a rung with a closed contact
ANB	-AND used with two sub-circuits
ORB	-OR used with two sub-circuits
RST	-Reset shift register/counter
SHF	-Shift
K	- Insert a constant
END	-End ladder

The following examples show how individual rungs on a ladder are entered.



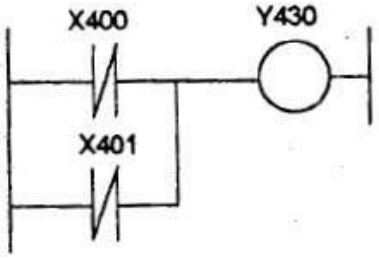
Step	Instruction	
0	LD	X400
1	AND	X401
2	OUT	Y430

An AND System



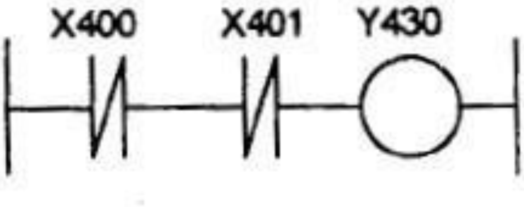
Step	Instruction	
0	LD	X400
1	OR	X401
2	OUT	Y430

An OR System



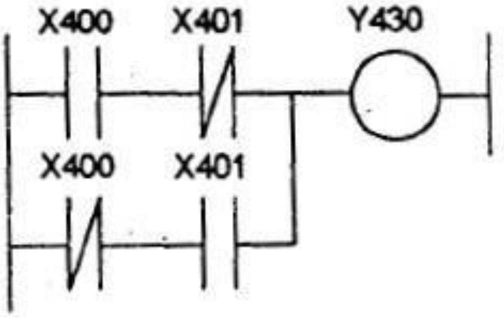
Step	Instruction	
0	LDI	X400
1	ORI	X401
2	OUT	Y430

An NAND System



Step	Instruction	
0	LDI	X400
1	ANI	X401
2	OUT	Y430

An NOR System



Step	Instruction	
0	LD	X400
1	ANI	X401
2	LDI	X400
3	AND	X401
4	ORB	
5	OUT	Y430

An XOR System

4.9. TIMERS

When timer circuits are activated, they result in closing or opening of input contacts after some preset time. Fig. shows part of a program involving a delay-on timer. When input occurs, the timer is activated, and after some preset time, the contacts associated with timers close and output occurs. When we want to introduce larger time delays, it may not be possible with one timer circuit, hence we may cascade more timers as shown in Fig.

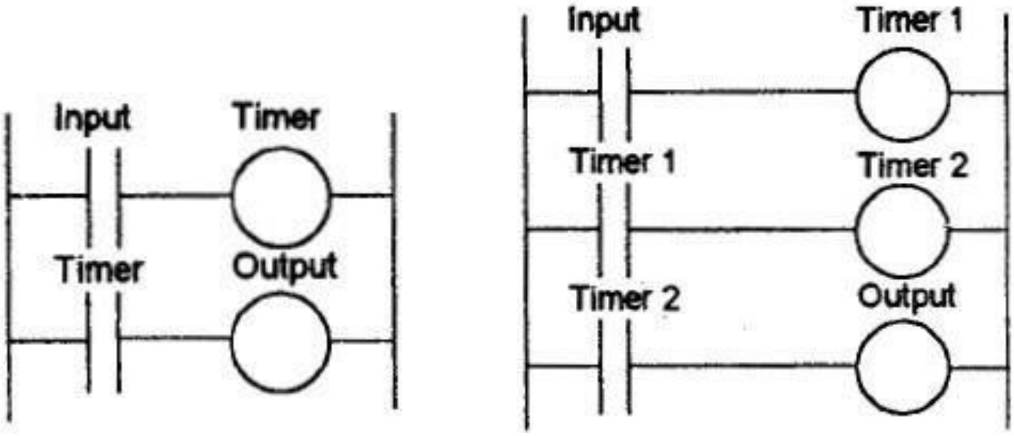


Fig 19: Timers

When input contacts close, timer 1 is activated; after its time delay, its contacts close and timer 2 is activated; after its time delay, its contacts close and output occurs.

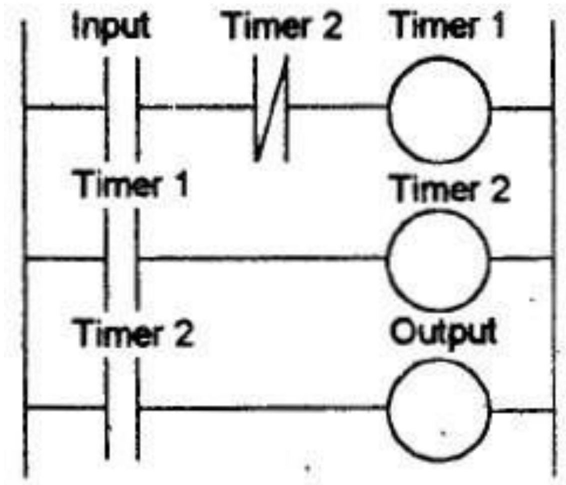


Fig 20: On-Off cyclic timer

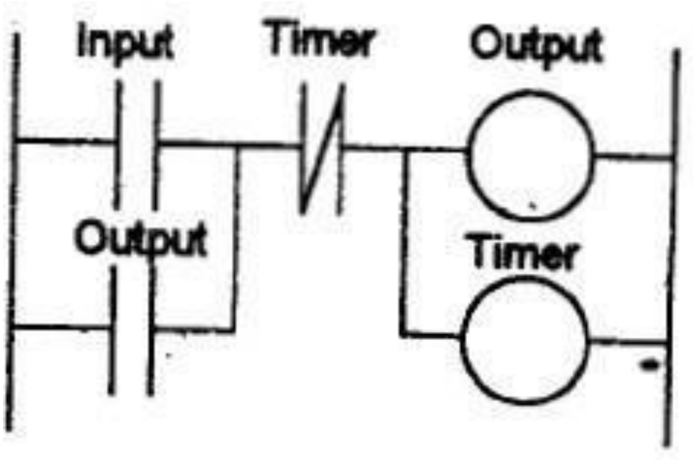


Fig 21: Timer circuit

Normally PLC's are provided with delay-on timer. The diagram shown in Fig. Explains how a delay-off timer can be devised. When the input contacts are momentarily closed, the output is energized and the timer is activated. The outputs contacts and latch the input and keep the output on. After the reset time of the timer, the timer contact breaks the latch circuits and hence the output is put off.

4.10. INTERNAL RELAYS

The terms internal relay, auxiliary relay and marker is considered as internal relay in the PLC**.** In reality they are not Relays. However they are simulated by the software within the PLC**.** They are useful in implementing switching sequences. Internal relays are used in a situation where occurrence of output depends on two different input arrangements. Fig. shows the ladder diagram for such an arrangement. In the diagram, first rung shows one input arrangement used to control the internal relay IR1. The second rung shows the other input arrangement used to control the internal relay IR2. The contacts of the two relays are to control the output. Another use of internal relays is for the starting of multiple outputs.

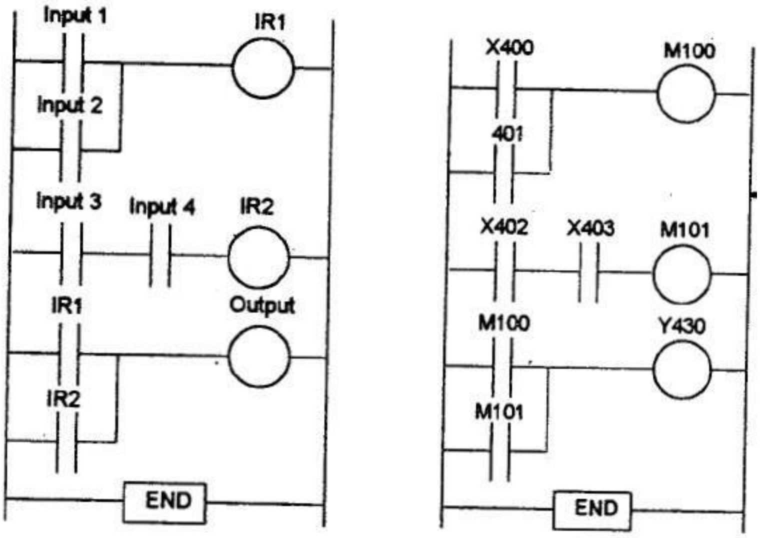


Fig 22: Internal Relays

Fig. shows the ladder diagram. When start contacts are closed, the internal relay is activated and latches the input. It also starts output1 and makes it possible for outputs **2** and 3 to be activated.

Another example of use of internal relay is resetting a latch. Fig. shows the ladder diagram. When the input 1 is momentarily pressed, the output occurs. Then the output is latched. The output can be unlatched by opening the internal relay contact. This can happen by the close of input 2contacts.

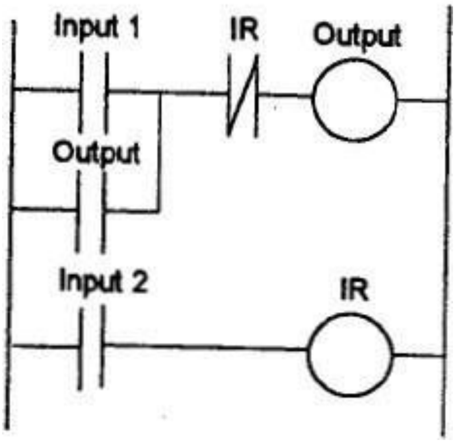
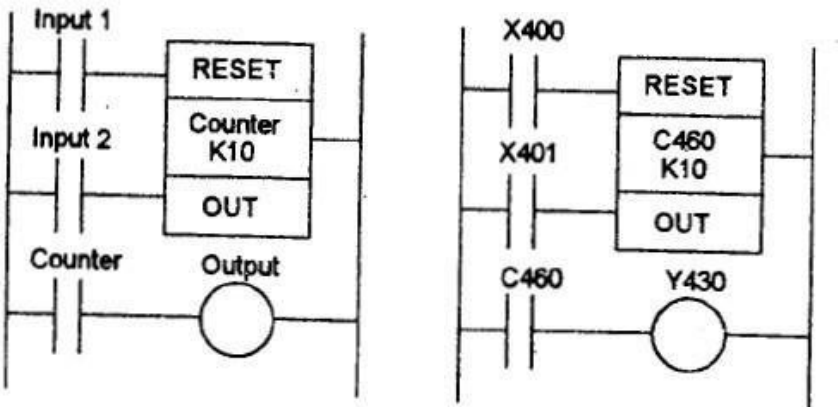


Fig 23:Resetting Latch

4.11. COUNTERS

As the name implies, counters are used for counting operations. It is an in-built operation in any **PLC.** For example, in a packaging section of an industry, assume that the finished products are passing along a conveyor into boxes. The counters can be used to count how many products have passed into one box, so that the next box can be replaced after a particular count.

Two types of counters are possible, namely, up-counter and down-counter. In the down counter the counter counts down a preset value to zero, whereas in the up counter the counter starts from zero and count up to a preset value. In both the cases, as tie counter operation comes to an end, its 'contact' changes state, i.e., it may close or open.



Step	Instruction	
0	LD	X400
1	RST	C460
2	LD	X401
3	OUT	C460
4	K	10
5	LD	C460
6	OUT	Y430

Fig 24: Counters

The counter is basically represented by a rectangle spanning two lines. (Refer fig.) One line is used to reset the counter. The other line is used as 'OUT' line and the symbol K10 indicates that the counter contact will change state on the 10^{th} count. When the input 1 closes momentarily, the counter is reset to the set value, in this case '10'. Now the counter starts counting as the input 2 closes and opens. When the input 2closes and opens for 10 times, then the counter contact close and the output is switched on. In case, before 10 pulses are received from input 2, if input 1 momentarily closes, then the counter will reset back to10.

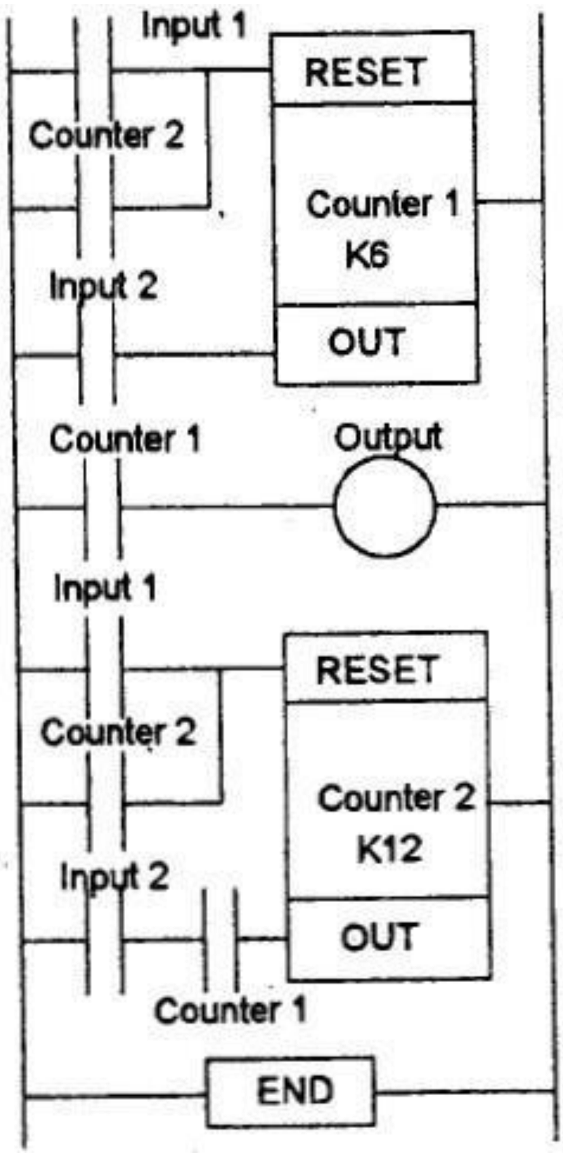
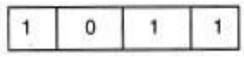
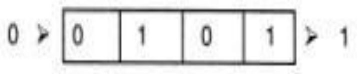


Fig 25: Lader programmer for counters

Example: Draw a ladder diagram to direct 6 items along path 1 for packaging in a box and then 12 items along path 2for packaging in another box. Two counters are used. One counter is used to count six and another to count twelve. When input1 momentarily closes, both counters are reset and preset to their respective counts 6 and 12. As items pass up to the junction in the paths, input 2contacts can be made to close and open. After 6 items pass into one box, counter 1 contact closes and activates the output which in turn closes one path and opens another. Counter 1also has contacts which close and enables counter 2 to start counting. When counter 2 has counted 12 items it resets both counters and opens counter 1 contacts which deactivates the output and the items will start falling into 6 items box.

4.12. SHIFT REGISTERS:

Anumberofinternalrelayscanbegroupedtogethertoformaregisterwhichcanprovide a storage area for a series of sequence of individual bits. Registers are used to store a bit sequence, for example a4-bit sequence 1101 can be stored using 4 internal registers. Similarly an eight-bit sequence can be stored using eight internal registers. **A** number of internal relays can be grouped together to form a register array. In shift registers the bits are shifted along the register array by one bit when there is a suitable input fed to the register. Consider a 4 bit shift register with its bit sequence as 

Assume. a 0 is fet to this shift register, then the bits are shifted along the register by one bit and the last bit overflows: 

When the 'shift register' function is selected at the control panel of a PLC, then a number of auxiliary registers are automatically grouped together to form a shift register. In Mitsubishi PLC a programming function 'SFT' is to be used against the auxiliary relay number, which is the first in the register array. For example if it is a 4- bit register to be formed, and if we select M 140 to be the first relay number then automatically, the **4**consecutive relays fromM140 will be assigned to form a 4-bit shift register, i.e. M140, MI41, MI42 andMI43. A shift register has three inputs, namely OUT SFT1 and RST. OUT is used to load data into the first element of the shift register. SFT in used to shift the bits by one bit and RST (Reset) in used to clear all the bits of the shift register to 0.

4.13. MASTER AND JUMP CONTROLS:

Master Relay:

More than one output or a block outputs arranged in each output rung can be simultaneously turn off or on by using one internal relay contact. If this single relay contact is switched on or off, then it affects every one of the rungs. When the contact input 1 close then master relay MC1 is activated and simultaneously the block program rungs controlled by the relay MC1 follows. In the ladder shown, OUTI, OUT2 & OUT3 also simultaneously activated. The end of master relay controller section is indicated by the reset MCR.

When contact input 2 close then master relay MC2 is activated and simultaneously the block program rungs controlled by the relay MC2 follows. If there are no inputs to input 1 &2, then the next input to be checked is for input 9 whose controlled output is OUT 6. Therefore this branching program operates as -there is input I, then branch to follow MC1 controlled path, input 2, then branch to follow MC2 controlled path, otherwise neither input occurs follow the rest of the program & ignore the branches.

In a Mitsubishi PLC, an internal relay can be assigned as a master control relay by programming it. The instruction MCMI00 is used to program as internal relay MI00 as master control relay. To indicate the end of master relay controlled section, the instruction MCR MI00 is used.

Jumps

Conditional Jump is a function provided in PLCs. If a certain condition exists, then a section of the program is ignored and the program control is jumped. In the ladder diagram shown, program A is followed by input1 and the conditional jump relay CJP. If input 1 is OFF,theprogram B follows. The end of program B is indicated by EJP end of jump relay coil. If input 1 is ON, then the program jumps to the program 'C' skipping program B.

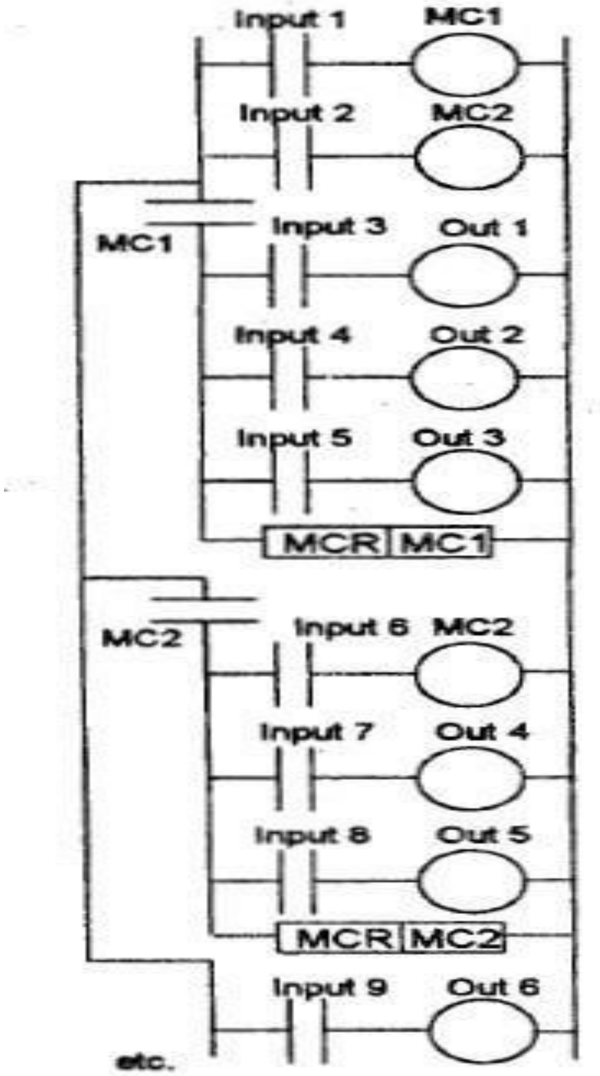


Fig 26: Master control

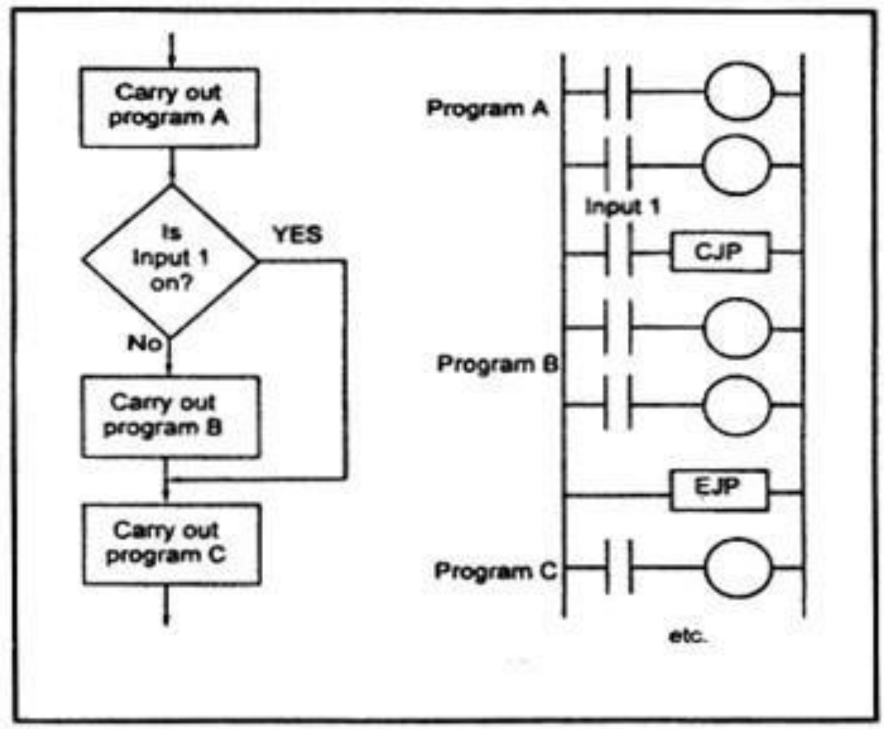


Fig 27: Jump control

4.14. DATA HANDLING:

In some cases, it may be required to deal with related group of bits, i.e. a block of eight inputs and operate on them as data word. The operations that may be carried out with a PLC on data words normally include.

1. Datamovement
2. Datacomparison
3. Arithmeticoperations
4. Conversions between BCD, binary &octal.

We know that the individual bits are stored in memory locations specified by unique addresses. These addresses are preceded by the letter 'A'. The PLC memory locations allocate for data storage are called data registers. Each data register can store either **8** bits or 16 bits & its address may be specified as DO, Dl, D2 etc. Every instruction has three parts-one specify the source data register, second to specify the destinationdataregisterandthirdtospecifythe'operation'tobeperformedonthedata.

Data movement

Data movement instruction has move instruction, source address of the data and destination address of the data. For example, to move from Dl to D2.

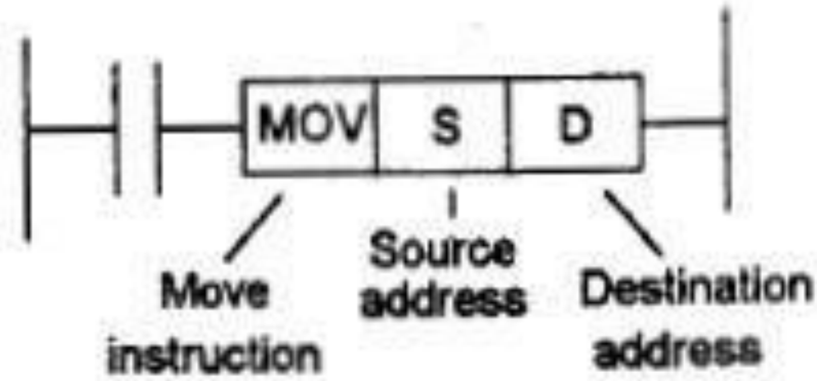


Fig 28: Data movement

Data Comparison:

Data comparisons include less than (<or LES), equal to (=orEQU), less than or equal to (or LEQ), greater than (> or GRT), greater than or equal to *(* or GEQ) and not equal to (# or <> orNEQ)

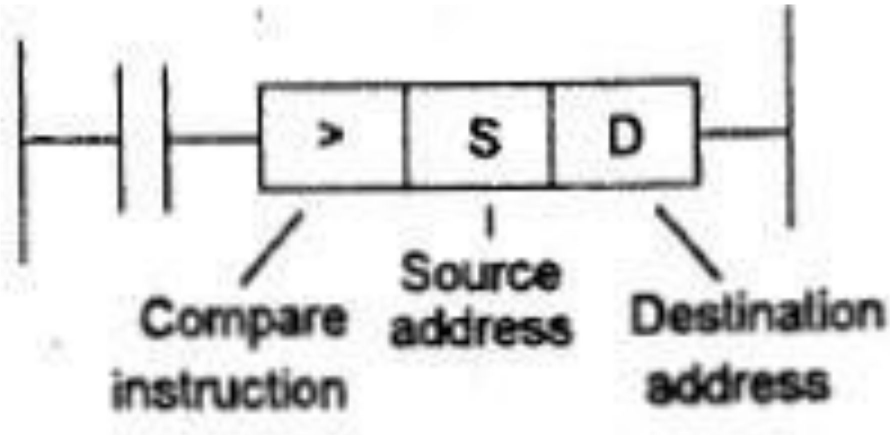
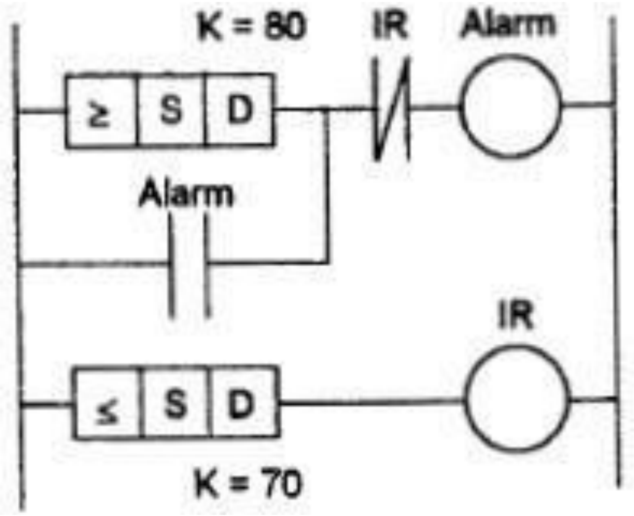


Fig 29: Data comparision

For example to compare the data available in Dl & D2, the ladder program rung would be of the form shown in fig.

Example: Draw a ladder diagram that the alarm keeps sounding when the sensor temperature is above 80°C and stops sounding when the temperature falls below 70°C. The sensor temperature is fed as input data to the source address. The destination address has the set value, here it **80°C.** When the input temperature rises to 80°C or above, the source data becomes greater than or equal to destination data and output alarm sound which in turn is latched in the input. When the temperature falls to 70°C or lower, the source data is less than or equal to destination data (shown in second rung of the ladder) and IR output occurs. Now in the first line (the ladder, the IR contact opens and alarm is switched off.



Arithmetic Operations:

Addition and subtraction operations are commonly found in all PLCs. Even more arithmetic operations are possible in some PLCs. ADDISUB instruction contains address of the addend, augend and the result registers along with the arithmetic operation to be performed. These operations may be used to change the preset values of the timers orcounters.

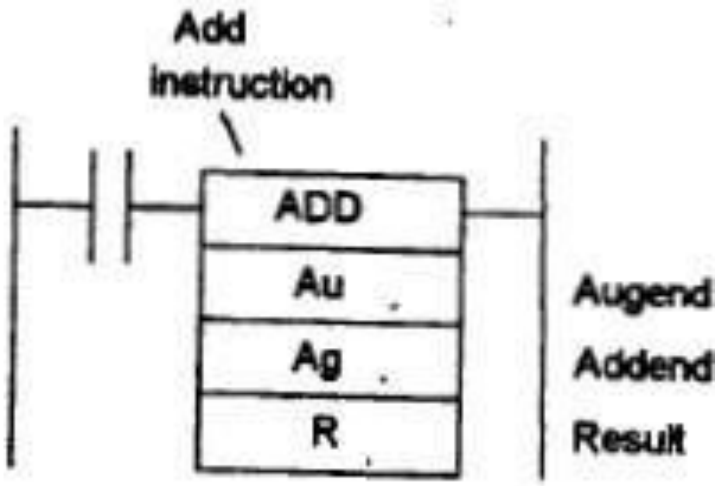


Fig 30: Arithmetic operation

Code Conversions:

In a PLC, all the internal operations are carried out in binary format only. However, it may be required to handle decimal or octal numbers at the input or output in which case a conversion from binary to decimal to octal or a conversion from decimal/octal to binary is required. For example to convert a BCD number in the source register to a binary number and store the result in destination register, refer the fig.

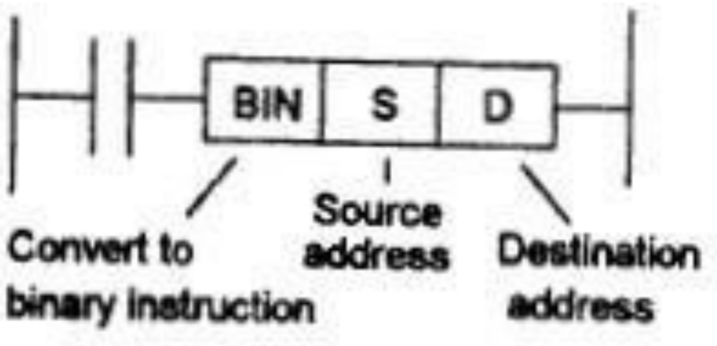


Fig 31: Code conversion

4.15. ANALOG INPUT/OUTPUT:

In PLCs, analog signals might be given as inputs and the actuators at the output might also require analogue signals. in such cases, an analog-to-digital converters & digital-to-analog converters may be used at the input & output channelrespectively.

Example : Draw a ladder diagram to show the speed of motor increasing at a steady rate from zero to its maximum value:

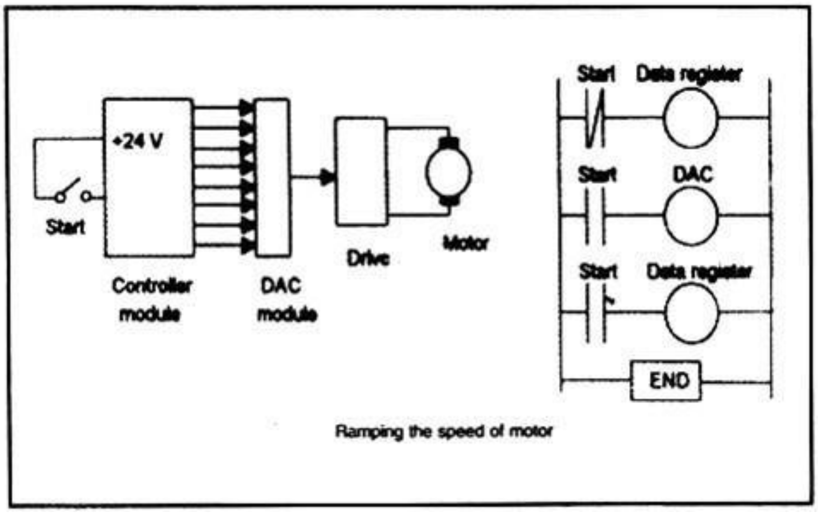


Fig 32: Analogue input and output

An on/off switch is used at the input. When the switch is in OFF position, the data register has 'OO', as its contents and hence DAC output is zero &so the motor is at zero speed. But as the switch closes, the data register is incremented. As the program loops through thesestwo rungs of the ladder, the data register keeps incrementing by one, &the DAC output increases steadily and hence the motor speeds up at a steady rate. The motor reaches its full speed when the data register contents has the word11111111.

4.16. SELECTION OF A PLC:

The factors to be considered in selecting a PLC for a particular task are:

1. Input/output capacity and its expansion capability for future needs.
2. Types of inputs/outputs required, i.e. isolation, on-board power supply for I/O, signal conditioning, etc.
3. The size of memory required.
4. The speed and power of the CPU. This is related to the number of instructions that can be handled by a PLC. As the types of I10 increases or/and the number of I/0 increases, the faster CPU is required.

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SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 5 - DESIGN OF MECHATRONICS SYSTEMS - SPR1304

5. DESIGN OF MECHATRONICS SYSTEMS

5.1 STAGES IN DESIGNING MECHATRONIC SYSTEMS

The design of mechatronic systems can be divided into a number of stages.

The Need:

The design process starts with the need of a customer.

- By adequate market research and knowledge, the potential needs of a customer can be clearly identified.
- In some cases, company may create a market need but failures are more in thisarea.
- Hence, market research technology isnecessary.

Analysis of the Problem:

- This is the first stage and also the critical stage in the designprocess.
- After knowing the customer need, analysis should be done to know the true nature of theproblem.
- To define the problem accurately, analysis should be donecareful.

Preparation of a Specification:

- The second stage of the mechatronic process involves in the preparation of a specification
- The specification must be given to understand the requirements and the functions to bemet.
- The specification gives mass dimensions, types, accuracy, power requirements, load, praying environments, velocity, speed, lifeetc.

Conceptualization:

- The possible solution should be generated for each of the functionsrequired
- It is generated by verifying the old problems or some newly developed techniques may beused

Optimization:

- This stage involves in a selection of a best solution for theproblem
- Optimization is defined as a technique in which a best solution is selected among a group of solutions to solve aproblem.
- The various possible solutions are evaluated and the most suitable solution is selected.

Detail Design

- Once optimizing a solution is completed, the detail design of that solution is developed.
- This may require a production of prototypeetc.

- Mechanical layout is to be made whether physically all component can be accommodated.
- Also whether components are accessible for replacement / maintenance are to be checked.

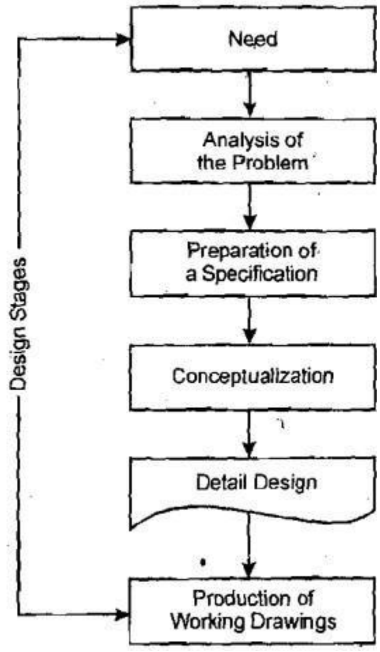

Fig 1: Stages of design

Production of working Drawings:

- The selected design or solution is then translated into working drawings, circuit diagrams, etc. So that the item can bemade.
- Drawings also include the manufacturing tolerances for eachcomponent.

5.2. DIFFERENCE BETWEEN TRADITIONAL AND MECHATRONIC APPROACHES

Engineering design is a complex process which involves interaction between many skills and discipline. In traditional design, the components are designed through mechanical, hydraulic or pneumatic components and principles. But in mechatronics approach, mechanical, electronics, computer technology and control engineering principles are included to design asystem.

For example design of weighing scale might be considered only in terms of the compression of springs and a mechanism used to convert the motion of spring into rotation of shaft and hence movements of a pointer across a scale. In this design measurement of weight is depended on the position of weight on the scale. If we want to overcome foresaid problem, other possibilities can be considered. In mechatronics design, the spring might be replaced by load cells with strain gauges and output from them used with a microprocessor to provide a digital readout of the weight on an LED display. This scale might be mechanically simpler, involving fewer components and moving parts. But the software is somewhat complex.

Similarly the traditional design of the temperature control for a central AC system involves a bimetallic thermostat in a closed loop control system. The basic principle behind this system is that the bending of the bimetallic strip changes as the temperature change andis used to operate an ON/OFF switch for the temperature control of the ACsystem

The same system can be modified by mechatronics approach. This system uses a microprocessor controlled thermo couple as the sensor. Such a system has may advantages over traditional system. The bimetallic thermostat is less sensitive compared to the thermo diode. Therefore the temperature is not accurately controlled. Also it is not suitable for having different temperature at different time of the day because it is very difficult to achieve.

But the microprocessor controlled thermo diode system can overcome fore said difficulties and is giving precision and programmed control. This system is much more flexible. This improvement in flexibility is a common characteristic of the mechatronics system when compared with traditional system.

S.No	Traditional Approach	Mechatronics Approach
1.	Bulky system	Compact
2.	It is a complex process involving interactions between many skills and disciplines.	It is the basic of integration of various emerging technology with mechanical engineering.
3.	The control is accomplished by manually.	A microprocessor is used a controller by programming it.
4.	Complex mechanisms	Simplified mechanism may transferred to the software through programs.
5.	Non-adjustable movement cycles	Programmed movements.
6.	Constant speed drives	Variable speed drives
7.	Mechanical Synchronization	Electronic Synchronization
8.	Rigid heavy structures	Lighter Structures.
9.	Accuracy determined by tolerance of mechanism	Accuracy achieved by feedback
10.	Flexibility is less	Flexibility is more.
11.	Less accurate	More accurate.
12.	It consists of more components and moving parts.	It involves less components and moving parts
13.	Less cost.	High cost.

5.3. CASE STUDY 1 - PICK AND PLACE ROBOT

The robot has three axes and about these three axes only motion occurs. The following movements are required for this robot.

1. Clockwise and Anti-clockwise rotation of the robot unit on itsbase
2. Horizontal linear movement of the arm to extend orcontraction
3. Up and down movement of the armand
4. Open or close movement of thegripper

The above movements are accomplished by the use of pneumatic cylinders operated by solenoid controlled values with limit switches. The limit switches are used to indicate when a motion is completed. Thus, a clockwise rotation of the robot unit can be obtained from a piston and cylinder arrangement during its extension and that of counter clockwise during its retraction, Likewise, the upward and downward movement of the arm can be obtained from a piston and cylinder arrangement during the extension and retraction of a pistonrespectively

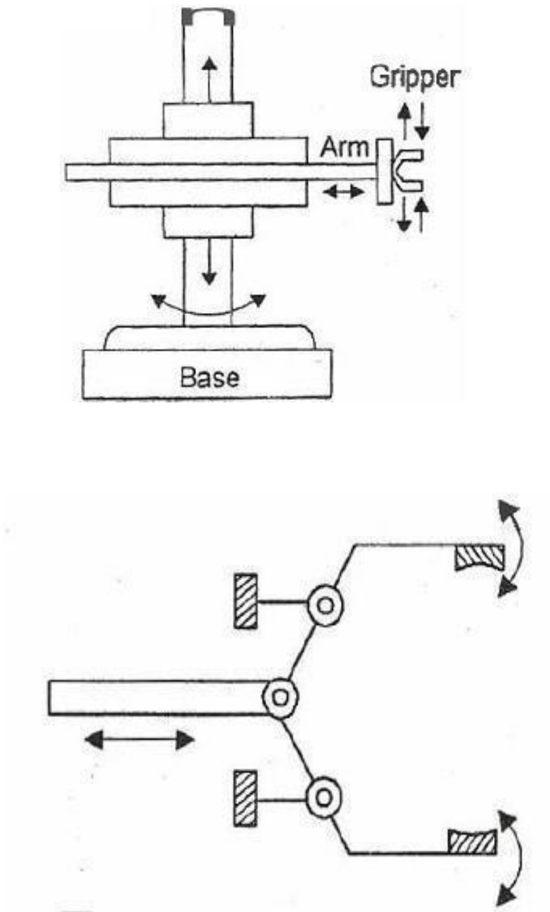

Fig 2: Pick and Place robot

Similarly,thegrippercanbeopenedorclosedbythepistoninalinearcylinderduring its extension is shown in figure. Another figure shows the micro controller used to control the solenoid values and hence the movements of the robot unit. The type of microcontroller used in M68C11. A software program is used to control the robot. Eight c port lines PC0, -PC7, are used to sense the position of eight separate limit switches used for eight different robotic movements. Also one line from port D is used to start or stop the robot operation. The switch in its one position will provide +5V (a logic high signal), tothe corresponding port lines and the switch in its position will provide 0V (a logic low signal), to the port lines. So the two positions of a switch will provide either a logic high or logic low to the corresponding PC0, - PC7, and PD0, lines. Eight part B lines (PB0,-PB7,) areusedtocontroleight differentmovements.TheseareBaseCW,BaseCEW,Armextends, Arm retract, Arm up, Arm down Gripper close and Gripper open of the robot. PB0,is connected to the Triacopto isolator through aresistor.

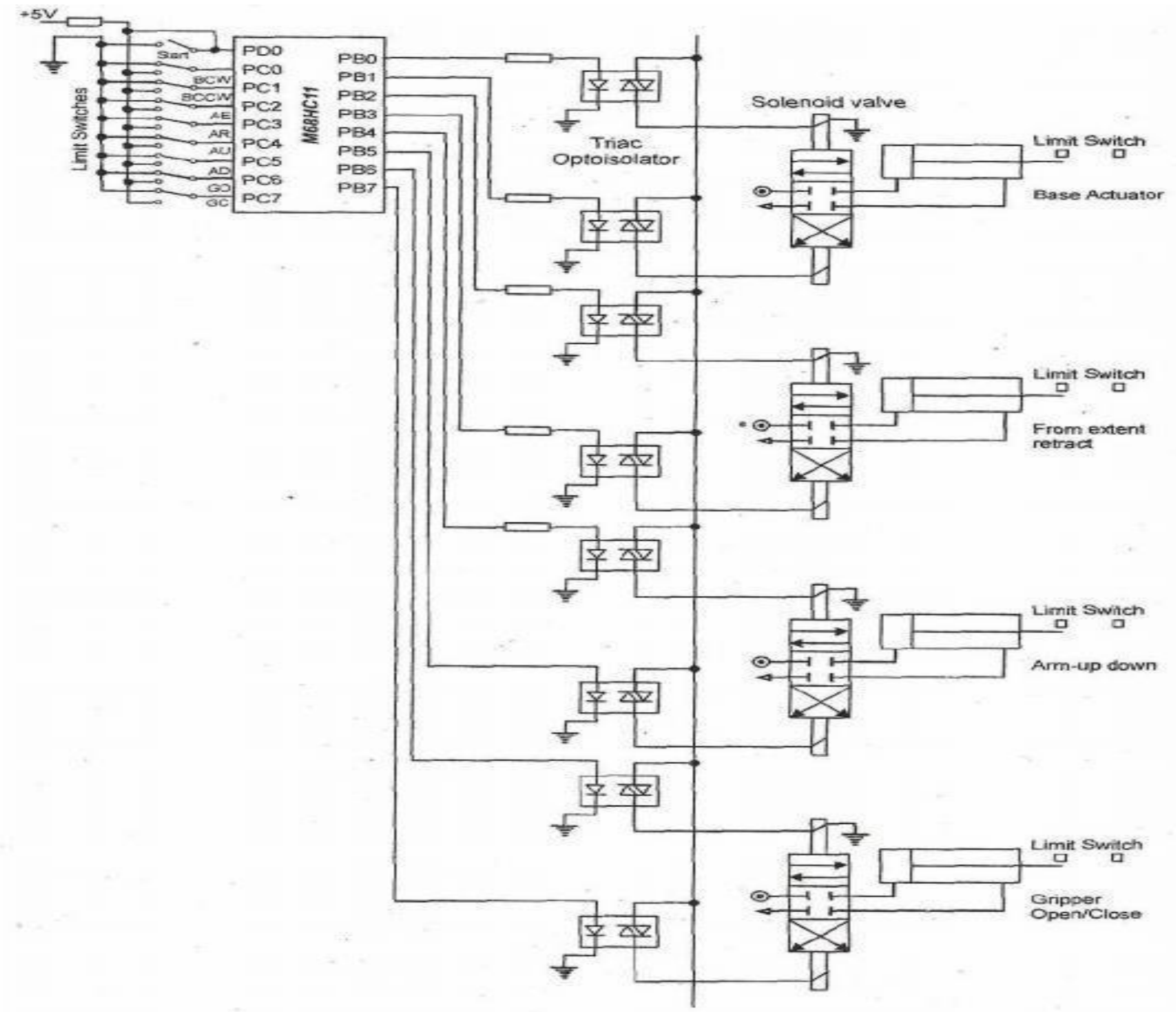

Fig 2: Gripper position

5.4. CASE STUDY 2 - AUTOMATIC CAR PARK SYSTEM

- The main requirement of the system is that, the in-barrier is to be opened to allow the car inside if correct money (coin) is inserted in the collectionbox.
- The out barrier is to be opened to allow the car outside, if the car is detected at the car park side of thebarrier.
- The automatic car park barrier along with the mechanism to lift and lowerit.
- When the current flows through the solenoid A & the piston in the cylinder extends to move upward and causes the barrier to rotate about its pivot and thus the barrier raisesto allow the carinside.
- When the current flows through the solenoid A ceases, the spring on the solenoid valve makes the contacts to open and thus makes the valve to its originalposition.
- When the current flows through solenoid B, the piston in the cylinder moves downward end causes the barrier to getdown.
- Limit switches are used to detect when the barrier is down and also when fullyup.
- This control can be controlled byPLC

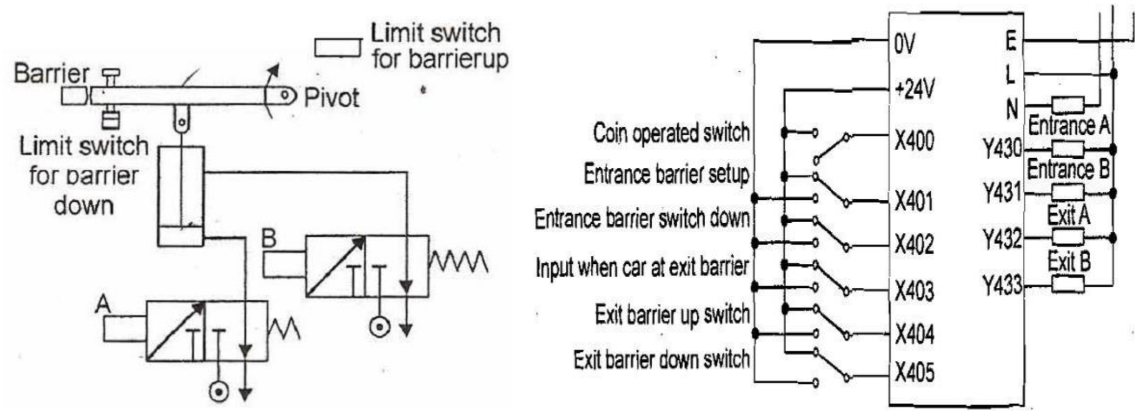

Fig 3: Car park barrier

X400 – coin operated switch at entrance to car park
X401 – switch activated when entrance barrier is out
X402 – switch activated when entrance barrier is down
X403 – switch activated when car at exit barrier
X404 – switch activated when exit barrier is -up
X405 – switch activated when exit barrier is down
Y430 – solenoid on valve A for entrance barrier
Y431 – solenoid on valve B for entrance barrier
Y432 – solenoid on valve A for exitbarrier
Y433 – solenoid on valve B for exitbarrier

- Six inputs **(X400** to **X405)** is required for the PLC to sense the six limit switch position namely coin-operated switch, entrance barrier up switch, down switch, car at exit barrier switch, exit barrier up switch, Exit barrier downswitch
- Whenever, a switch is operated, **0V** signal is provided to the corresponding inputs andotherwise**+24v**signalisprovidedtotheinputs.Fouroutputs**(Y430**to**Y433)**are required to operate the two solenoid valves A andB.

Program:

```
LD    X400
OR    Y430
ANI   M100
ANI   Y431
OUT   Y430
LD    X401
OUT   T450
K10
LD    T450
OUT   M100
LD    M100
OR    Y431
ANI   X402
ANI   Y430
OUT   Y431
LD    X403
OR    Y432
ANI   M101
ANI   Y433
OUT   Y432
LD    X404
OUT   T451
K10
LD    T451
OUT   M101
LD    M101
OR    Y433
ANI   X405
```

ANI Y432
OUT Y433
END

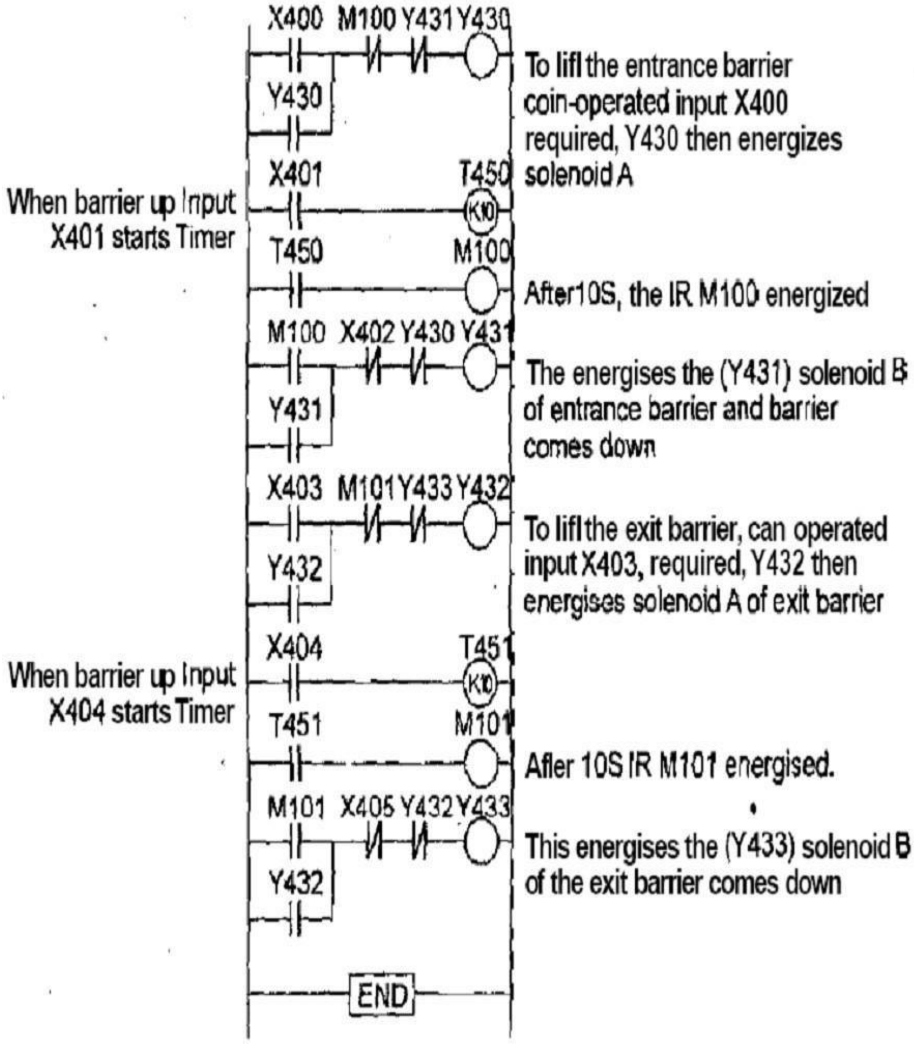

Fig 4: Ladder circuit for car park barrier

5.5. CASE STUDY 3 - ENGINE MANAGEMENT SYSTEM

- Engine management system is now-a-days, used in many of the modemcars
- This car includes many electronic control systems such as microcontrollers for the control of various enginefactors.
- The main objective of the system is to ensure that the engine is operated at its optimumsettings.
- The engine management system of a car is responsible for managing the ignition and
  fuelling requirements of the engine.
- The power and speed of the engine are controlled by varying the ignition timing and the Air fue1mixture.

- In modern cars, this is done bymicroprocessor.
- To control the ignition delay, the crank shaft drives a distribution which makes electrical contacts for each spark plug in turn and a timingwheel.
- This timing wheel generates pulses - to indicate the crankshaftposition.
- The microprocessor then adjusts the timing at which high voltage pulses are sent to the distributor so that they occur at right moments oftime.
- To control the amount of air-fuel mixture entering into a cylinder during the suction stroke,themicroprocessorvariesthetimeforwhichasolenoidisactivatedtotheinlet valve on the basis of inputs received by the engine temperature and the throttle position.
- The amount of fuel to be injected into the air stream can be determined on input from a sensor of the mass rate of air, or computed from othermeasurements.
- The microprocessor then gives as output to control of fuel injectvalve.
- The system hence consists of number of sensor for observing vehicle speed, Engine temperature, oil and fuel pressure, air flowetc.,
- These sensors supplies input signals to the microprocessor after suitable signal conditioning and provides output signals via drivers to actuate corresponding actuators.
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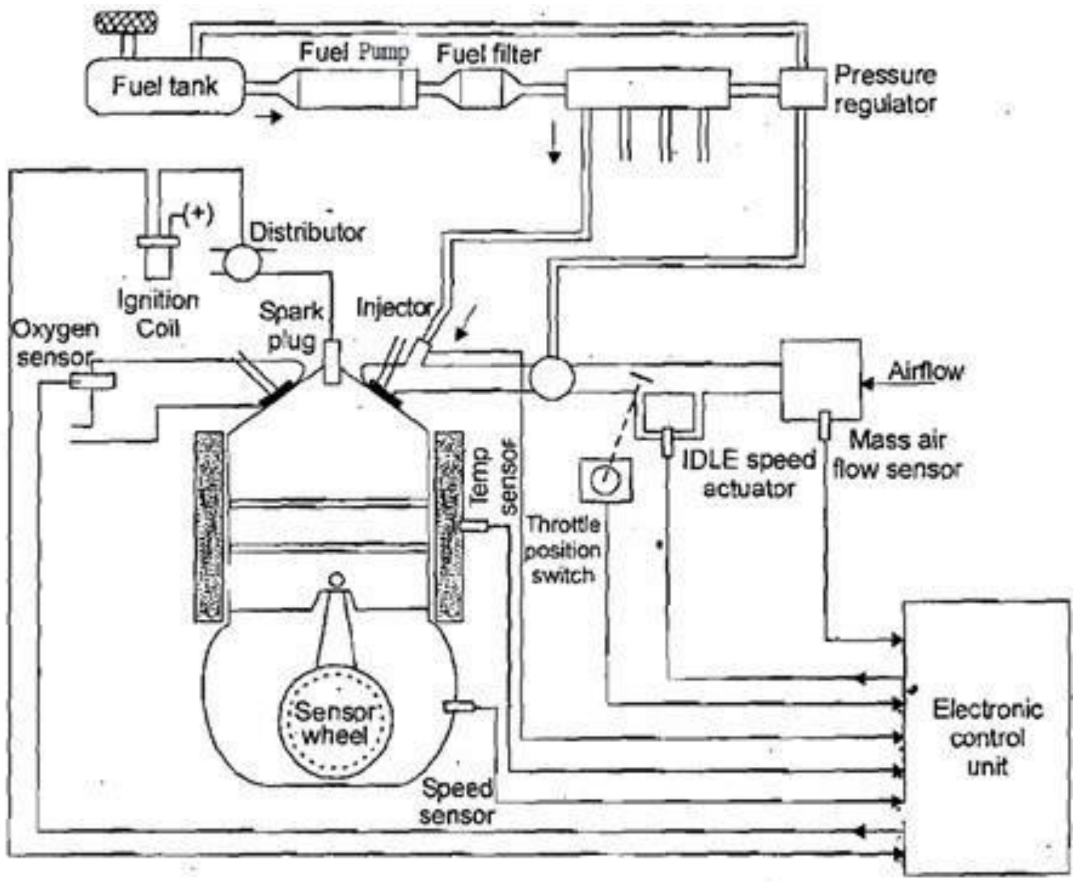

Fig 5: Engine management system

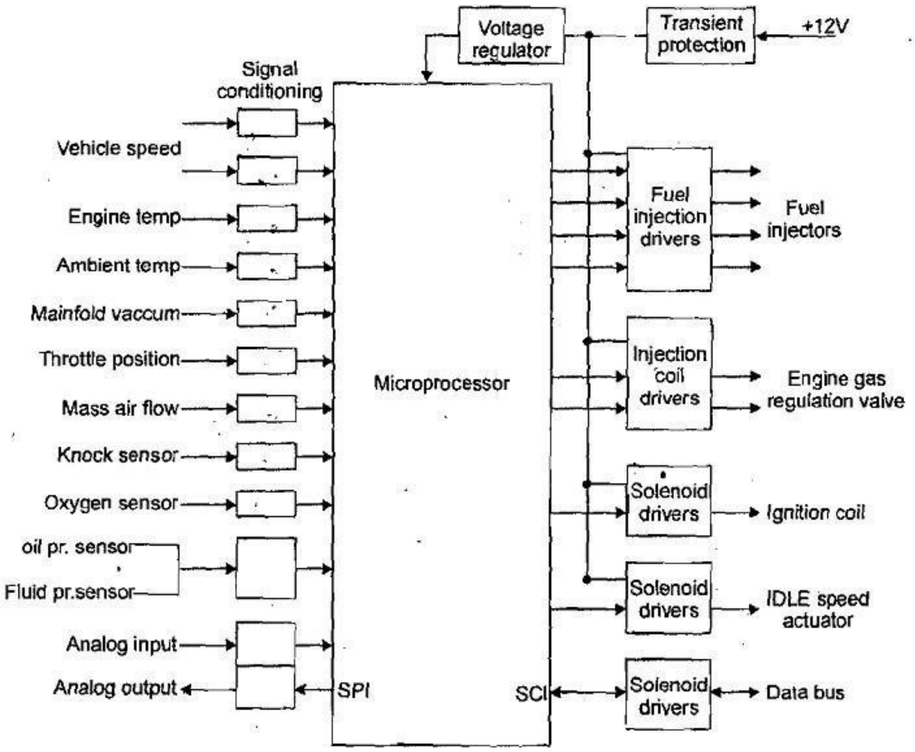

Fig 6: Ladder circuit engine management system

5.6. CASE STUDY 4 - AUTONOMOUS MOBILE ROBOT

A fully autonomous mobile robot has the ability to:

- Gain information about theenvironment
- Work for an extended period without humanintervention
- Move either all or part of itself throughout its operating environment without human assistance. Avoid situations that are harmful to people, property, or itself unless those are part of its designspecifications.

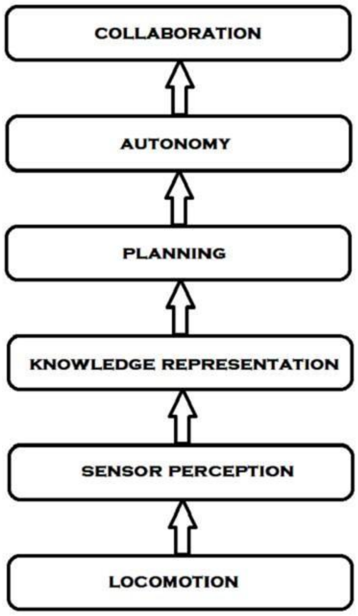

Fig 7: Autonomous mobile robot

Elements of Autonomous Mobile Robot:

- Locomotion
- Sensorperception
- Knowledge representation
- Planning
- Autonomy
- Collaboration

Locomotion:

- Locomotion is the act of moving from place to place. Locomotion relies on the physical interaction between the vehicle and its environment. It is concerned with the interaction forces, along with the mechanisms and actuators that generatethem.
- The different types of locomotionare:
    - LeggedLocomotion
    - Snake Locomotion
    - Free-FloatingMotion
    - WheeledLocomotion

Sensor Perception:

- The robots have to sense their environment in order to navigate in it, detect hazards, and identifygoals.
- Sensor fusion is an important capability, as no single sensor will be able to identify or classify all aspects of thearenas.
- The simulated victims are represented by a collection of different sensory signatures. They have shape and colourcharacteristics.
- Some simulated victims have motions such as waving, and some emit sounds such as low moans, calls for help, or simpletapping.
- All of the signals of life should be detected, identified, investigated further, and if confirmed as a victim, the location should bemapped.
- For obstacle detection, the sensors need to see far and only a logic response is required.
- Common sensors used in mobile robots for detecting obstacles are the digital infra-red (IR) sensor.
- Line tracing is normally required to distinguish between a white surface and a black one in order to provide guidance by thedemarcation.
- For direction monitoring the obvious sensor to use is a compass, which echoes the bearing of the mobile robot in realtime.
- Proximity sensors are used to sense the presence of an object close to a mechatronicsdevice.

Knowledge Representation:

- In the mobile robot applications, the robots are expected to communicate to humans the location of victims andhazards.
- They would be providing a map of the environment they have explored, with the simulated victim and hazard location clearlyidentified.
- The environment that the robots operate in is three-dimensions, hence they should be able to map inthree-dimensions.
- The area may change dynamically during operationtime

Planning:

- The planning or behaviour generation elements of the robots build on the knowledge representation and the sensingelements.
- The robots mustbe able to navigate around obstacles, make progress in their mission take into account time as a limiting resource, and make time critical decisions.
- The planner should make use of an internal map generated by the robot and find alternative routes to exit the arenas that may be quicker or avoid arm that have become no longertraversable

Autonomy:

- The robots are designed to operate withhumans.
- The level of interaction may vary significantly, depending on the robot's design and capabilities, or on thecircumstances.
- Robots may communicate back to humans to request decisions, but should provide the human with meaningful communication of thesituation.
- The human should provide the robot with high level commands, such as "go to the room on the left" rather that joystick the robot in thatdirection.

Collaboration:

- The final element to be evaluated in the robot's overall capabilities is collaboration among teams of robots.Multiple robots, either homogeneous or heterogeneous in design and capabilities, should be able to more quickly explore thearea.
- The issues to be examined are how effectively they maximize coverage given multiple robots, whether redundancy is an advantage, and whether or how they communicate among themselves to assignresponsibilities.
- The human may make the decisions about assignments for each robot a priority, but that would not be as desirable as seeing the robots jointly decide how to attack the problem when confronted in thefield.

5.7. CASE STUDY 5 - AUTOMATIC CAMERA

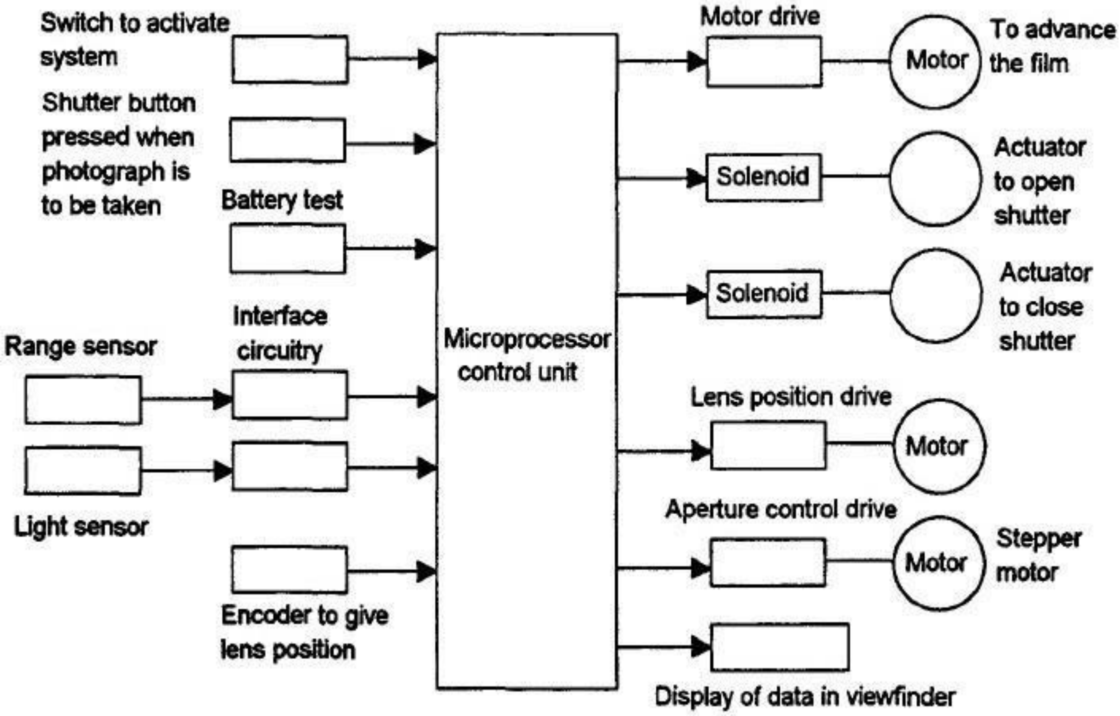

Fig 8: Automatic camera

The modern camera is likely to have automatic focusing and exposure. The basic aspects of a microprocessor-based system that cannot be used to control the focusing and exposure. When the switch is operated to activate the system and the camera pointed at the object being photographed, the microprocessor takes the input from the range sensor and sends an output to the lens position drive to move the lens to achieve focusing. The lens positionis fedbacktothemicroprocessorsothatthefeedbacksignalcan'tbeusedtomodify the lens position according to the inputs from the rangesensor.

The light sensor gives an input to the microprocessor which then gives an output to determine, if the photographer has selected the shutter controlled rather than aperture controlled mode, the time for which the shutter will be opened. When the photograph has been taken, the microprocessor gives an output to the motor drive to advance the film ready for the nextphotograph.

The program for the microprocessor is a number of steps where the microprocessor is making simple decisions of the form: is there an input signal of a particular input line or notandifthereisoutputasignalonaparticularoutput line.Thedecisionsarelogicdecisions with the input and output signals either being low or high to give on-offstates.

A few steps of the program for the automatic camera might be of the form: begin:

if battery check input OK
then continue
otherwise stop
loop
read input from range sensor calculate lens
movement output signal to lens position drive
input data from lens position
encoder

compare calculated output with actual output stop output when lens in
correct
position

send in-focus signal to viewfinder
display
etc.