VI SEMESTER DICE

INDUSTRIAL AUTOMATION AND DRIVES

EBOOK

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on

INDUSTRIAL AUTOMATION AND DRIVES

for

VI Semester DICE

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UNIT I INDUSTRIAL DRIVES

1.1 ELECTRIC DRIVE:

A drive consists of various systems combined together for the purpose of motion control.A drive uses diesel or petrol engines, gas or steam turbines, hydraulic motors and electric motors for supplying mechanical energy for motion control

Electric Drive: The drives that employ electric motors for motion control are known as electric drives.

Parts of an electric drive: The electric drive consists of the major components

1. Electrical motor and mechanical load
2. Power modulator
3. Source
4. Control Unit
5. Sensing unit

1.2 TYPES OF ELECTRIC DRIVES:

The electric drives are classified into three types. They are

1. Individual drive
2. Group drive
3. Multimotor drive

1.3 Individual drive:

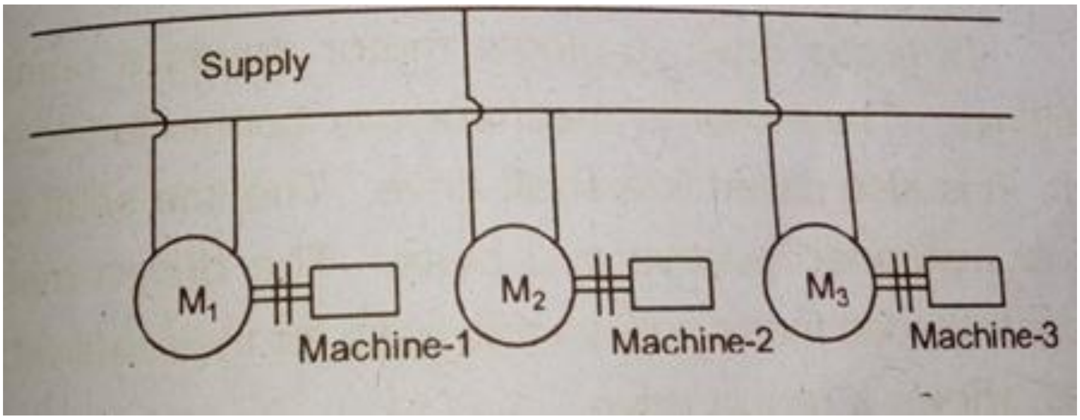


Fig 1.1 Individual drive

In individual drive single electric motor is used to drive one individual machine. Most of the industries use this type of drive. The above fig 1.1 shows the individual drive.

1.3.1 ADVANTAGES:

1. The machines can be installed at any desired position.
2. If there is a fault in one motor other machines will not be affected since they are working independently
3. Continuity in the production of the industry is achieved
4. Efficiency of the system is high

1.3.2 DISADVANTAGES:

1. The initial cost is high

1.4. Group drive:

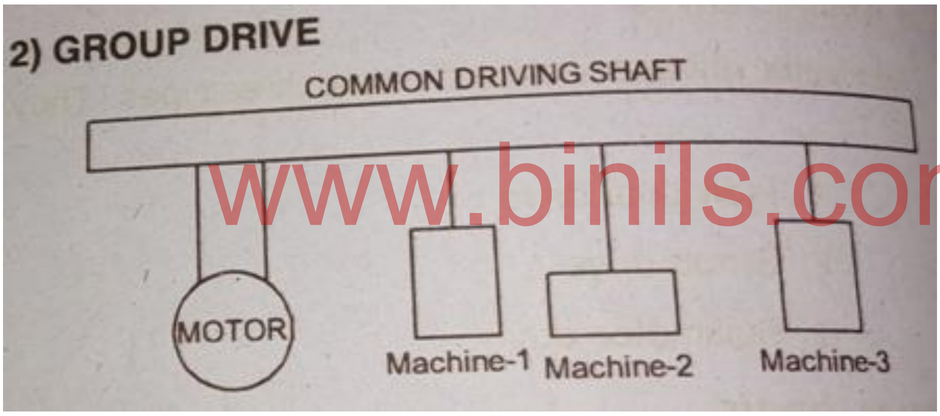


Fig 1.2 Group Drive

In group drive, a single motor drives a number of machines. The motor is mechanically connected to a long shaft. It is also called line shaft drive. The line shaft is fitted with multistepped pulleys and belts. The driven machines are connected to these pulleys and belts for their required speed the above figure 1.2 shows a group drive.

1.4.1 ADVANTAGES:

1. Initial cost is less compared to individual drive.
2. In group drive system all the operations can be stopped simultaneously
3. Only less space is required as compared to individual drive.
4. It requires little maintenance as compared to individual drive.

1.4.2 DISADVANTAGES:

1. If the motor fails all the operations will be stopped.
2. If most of the machines are idle the main motor will operate on load with less efficiency
3. The noise level at the work site is quite high
4. Group drive has low power factor
5. Speed control of individual machine is not possible

1.5 MULTIMOTOR DRIVE:

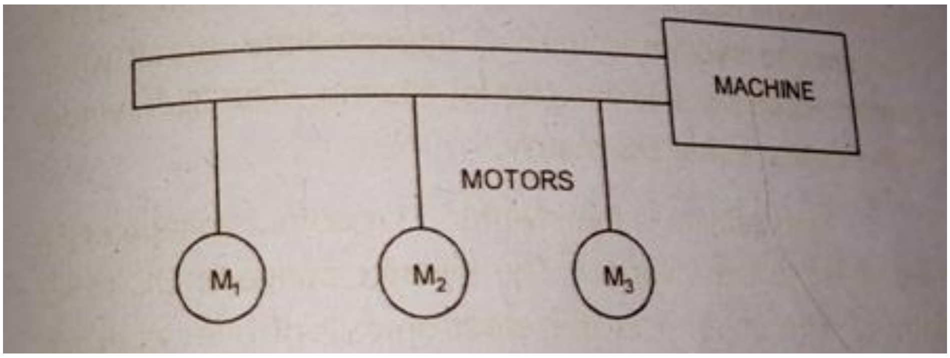


Fig 1.3 Multimotor drive

In multimotor drives separate motors are used for operating different parts of the same mechanism E.g., in case of an overhead crane, different motors are used for hoisting, long travel motion and cross travel motion. Such drive is also essential in complicated metal-cutting machine tools, paper making machines, rolling mils. The above fig 1.3 shows a multimotor drive.

1.6 STEPPER MOTOR:

A stepper motor is a digital electromechanical device which rotates through a fixed angular step for each input current pulse received by its controller. Rotation occurs because of the magnetic interaction between rotor poles and stator poles of the sequentially energized stator windings.

. When a given number of pulses are applied to the motor the shaft would have been rotated through a given angle. The motor can be used to control position by keeping count of the number of pulses. The average motor speed is proportional to the rate at which the pulse command is delivered. The motor is ideally suited for open loop speed and position control.

There are three modes of operation when using a stepper motor. The mode of operation is determined by the type of step switching sequence applied. The three types of step switching sequences are:

1. Wave switching sequence
2. Full stepping sequence
3. Half Stepping sequence

1.7 STEP ANGLE:

It is the angular displacement of the rotor of a stepper motor for every pulse of excitation given to the stator windings of the motor. It is determined by the number of teeth on the rotor and number of phases.

Step angle (β) = 360°/ (m Nr)

m - Number of phases

Nr - Number of teeth on the rotor

1.8 SLEWING RATE:

When the stepping rate of the motor is increased the rotor has less time available to drive the load from one position to the other. Beyond a certain pulsing rate the rotor cannot follow the command and begins to miss the pulses. The load torque and the pulsing rate is such that if the point of operation lies to the left of curve I, the motor can start and synchronise without missing a pulse.

For a constant load toque T_L for a stepping rate ' s' of the stepper motor

$s < s_1$ ---the motor starts and synchronises

s increases to s_1 ----the motor rotates without losing a step

$s = s_2$ ----The motor starts losing synchronism

Areas between curves I and II represent the various torques for which the range of stepping rate which the motor can follow without losing synchronism. The range between s_1 and s_2 is the slewing range and the motor is in the slewing mode. The slew range is useful for speed control.

At stepping rate corresponding to the slew range the motor cannot be started or reversed without losing the steps. The motor should be accelerated at low speed rates. Similarly to stop or reverse the motor it should be decelerated to less speed. Such acceleration and deceleration without losing a step is called ramping.

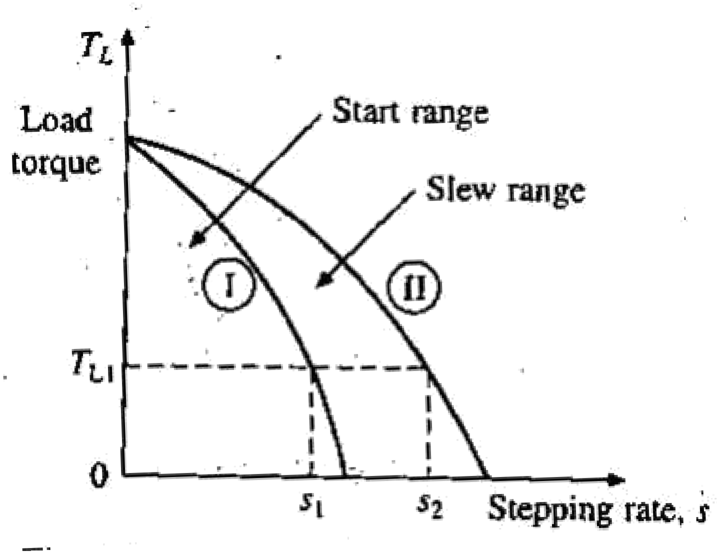


Fig 1.4 Torque vs stepping rate characteristics

1.9 TYPES OF STEPPER MOTOR:

Stepper motors are classified into three types

1. Variable reluctance (VR) Stepper motor
2. Permanent magnet (PM) Stepper motor
3. Hybrid stepper motor

1.10 VARIABLE RELUCTANCE STEPPER MOTOR (VR Stepper Motor):

In variable reluctance stepper motor, the reluctance of the magnetic circuit is formed by the rotor and stator teeth vary with the angular position of the rotor. The VR stepper motor can be classified into two types. They are

1. Single stack type
2. Multi stack type

1.10.1 SINGLE-STACK VARIABLE RELUCTANCE STEPPER MOTOR:

The single stack variable reluctance motor has no permanent magnet either on the rotor or the stator. The rotor carries no windings. It has salient pole stator and rotor. Fig 1.5 shows the single stack variable reluctance motor.

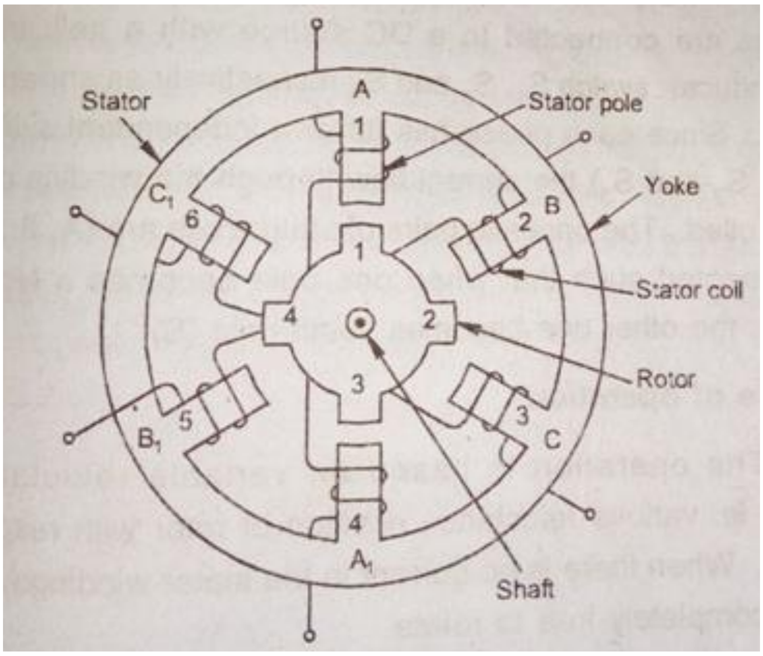


Fig 1.5 Variable reluctance stepper motor

The stator and rotor are different. Usually the number of poles of stator is an even number. When the stator has six salient poles, the rotor has four poles. If the stator has four poles then the rotor has two poles. Every stator pole carries a field coil or exciting coil. The exciting coils of opposite poles are connected in series. The two coils are connected such that their mmf gets added. The combination of two coils is known as the phase winding. Phase A consists of two terminals A1 and A2. Similarly phase B has B1 and B2 and Phase C has C1 and C2. The A,B,C phase windings are connected to a DC Source with a help of a semiconductor switch S1,S2 and S3 respectively as shown in fig1.6. Since each phase has its own independent switch (like S1, S2 and S3) the current flow through the winding can be controlled. The opposite pairs of stator coils are (A1& A2) are connected such that when one pole becomes a North pole (N), the other one becomes the South pole (S).

1.10.2 Principle of operation:

The operation is based on variable reluctance principle i.e. variable reluctance position of rotor with respect to stator. When there is no current in the stator windings, the rotor is completely free to rotate. When any one phase of the stator is excited, a magnetic field is produced in that phase winding. This magnetic field axis lies along the excited windings poles. Then the rotor rotates in such a direction so as to achieve minimum reluctance position.

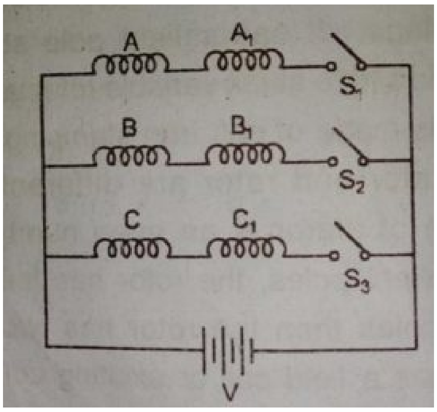


Fig 1.6 Connection of stator coils in VR stepper motor

Fig 1.6 shows phase winding connection and switching connection of VR stepper motor. When switch S1 is closed, the phase winding A is energized. A magnetic field with its axis along with the stator poles of phase A is created. Now the rotor moves to the position such that rotor teeth align themselves with stator teeth of phase A. That is the rotor teeth 1 (pole) and 3 move and lining up with the stator teeth (poles) 1 and 4. This is the position in which the reluctance of magnetic circuit is minimum. Here θ=0°, it is shown in Fig.1.7 (i).

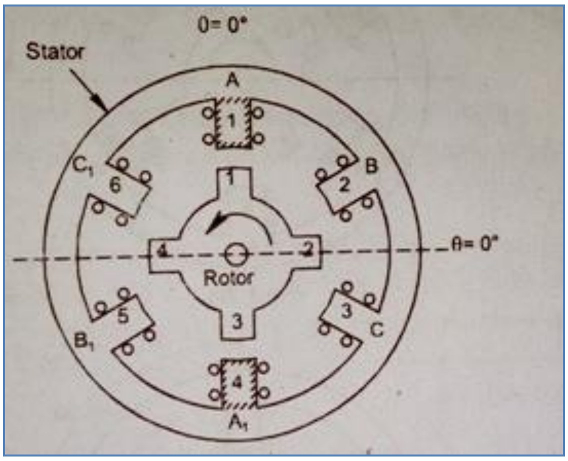


Fig 1.7 (i) VR Stepper motor operation for θ =0 degrees

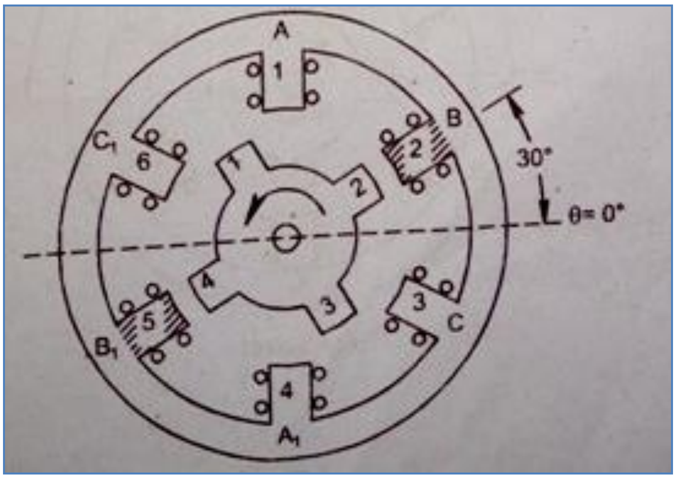


Fig 1.7 (ii) VR Stepper motor operation for θ =30 degrees

Next, phase winding A is de-energized by opening the switch S1 and phase winding B is energized by closing the switch S2. Now the rotor teeth 2 and 4 move and align with the stator teeth 2 and 5. It is shown in Fig 1.7(ii). Here the rotor rotates through full step of 30° in the anti-clockwise direction.

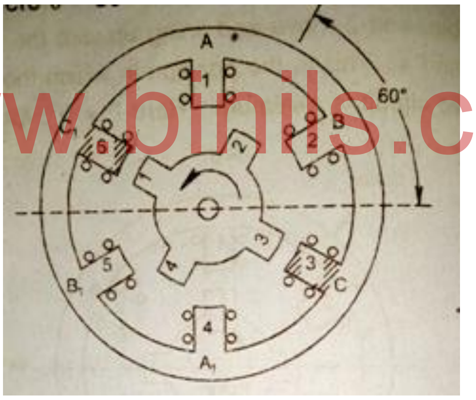


Fig 1.7 (iii) VR Stepper motor operation for θ= 60 degrees

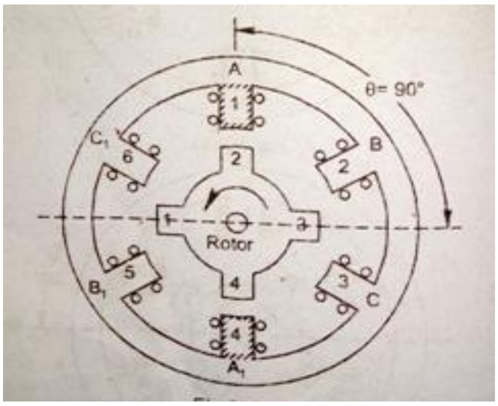


Fig 1.7 (iv) VR Stepper motor operation for θ= 90 degrees

Next, phase winding B is de-energised by opening the switch S2 and phase winding C is energized by closing the switch S3. Now the rotor teeth 1 and 3 move and align with stator teeth 3 and 6. It is shown in fig 1.7(iii). Here the rotor rotates another 30° in the anti-clockwise direction. Here θ =60°.

Again phase winding A is energized and phase winding C is de-energized. Now the rotor teeth 2 and 4 align with the stator teeth 1 and 4 as shown in Fig 1.7(iv). Here the rotor rotates another 30° in anticlockwise direction. Here θ =90°.

The stator windings are energized in the sequence of ABCA, the rotor rotates each time through an angle of 30° in anti-clockwise direction.

Phase A	Phase B	Phase C	θ
✓	–	–	0°
–	✓	–	30°
–	–	✓	60°
✓	–	–	90°

Fig 1.8 Table of the VR stepper motor - anticlockwise rotation

If the stator windings are energised in the sequence ACBA the rotor will rotate in clockwise direction. It is shown in the truth table given below

Phase A	Phase B	Phase C	θ
✓	–	–	0°
–	–	✓	30°
–	✓	–	60°
✓	–	–	90°

Fig 1.9 Table of the VR stepper motor - clockwise rotation

1.10.2 MULTI-STACK VARIABLE RELUCTANCE STEPPER MOTOR:

Multi stack variable reluctance stepper motors are used to obtain smaller step angle in the range of 2 to 15° Multi stack motor may employ as many as seven stacks but three stacks are commonly used.

The multi stack variable reluctance stepper motor consists of 'm' identical single stack variable reluctance motors. Their rotors are mounted on a common shaft. The stators and rotors have the same number of poles or teeth and therefore, same pole pitch

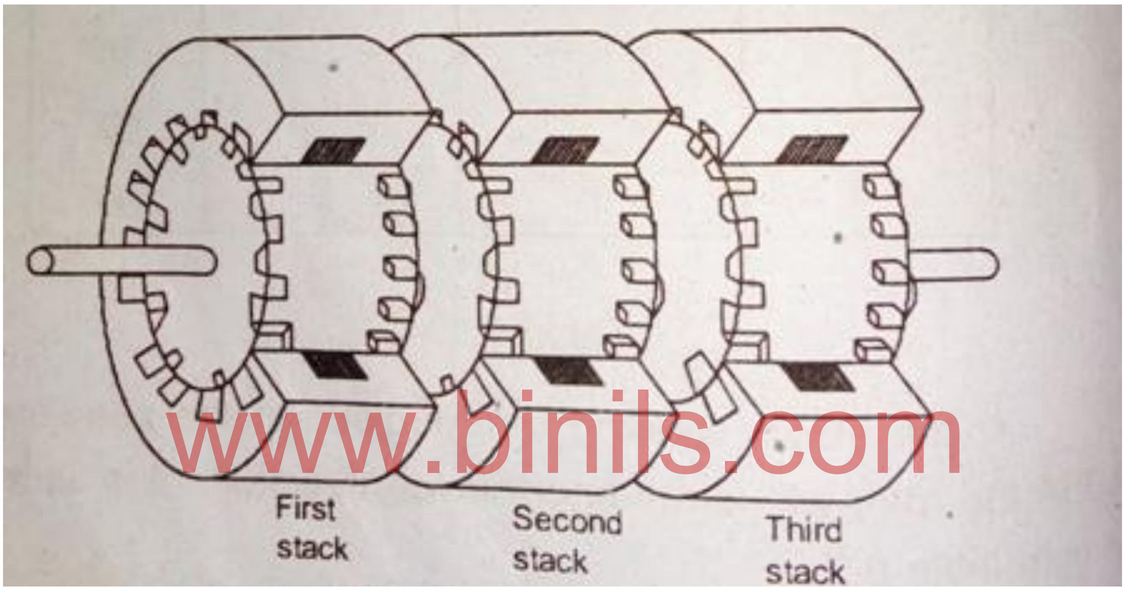


Fig 1.10 Multi stack variable reluctance stepper motor

For a 'm'- stack motor the stator poles in all m-stacks are aligned, but the rotor poles are displaced by 1/m of pole pitch from one another. All the stator pole windings in a given stack are energised simultaneously. Hence the stator winding of each stack forms one phase. Hence the number of phases of motor is equal to the number of stacks.

The Fig 1.11 shows the cross section of a three stack (three-phase) variable reluctance stepper motor. In each stack, stator and rotors have 12 poles. For a 12 pole rotor, pole pitch is 30° (360°/12=30°). Hence the rotor poles are displaced from each other by one third of pole pitch (1/3 * 30°=10°). The stator teeth in each stack are aligned.

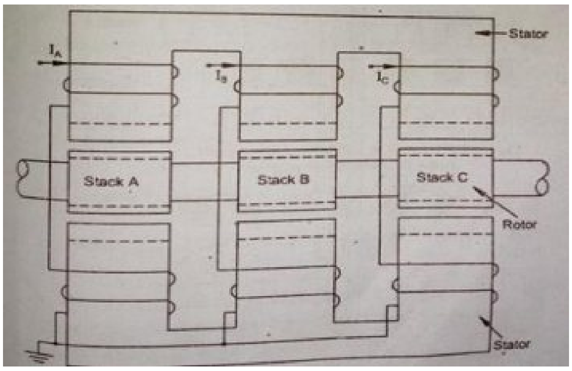


Fig 1.11 Three stack variable reluctance stepper motor

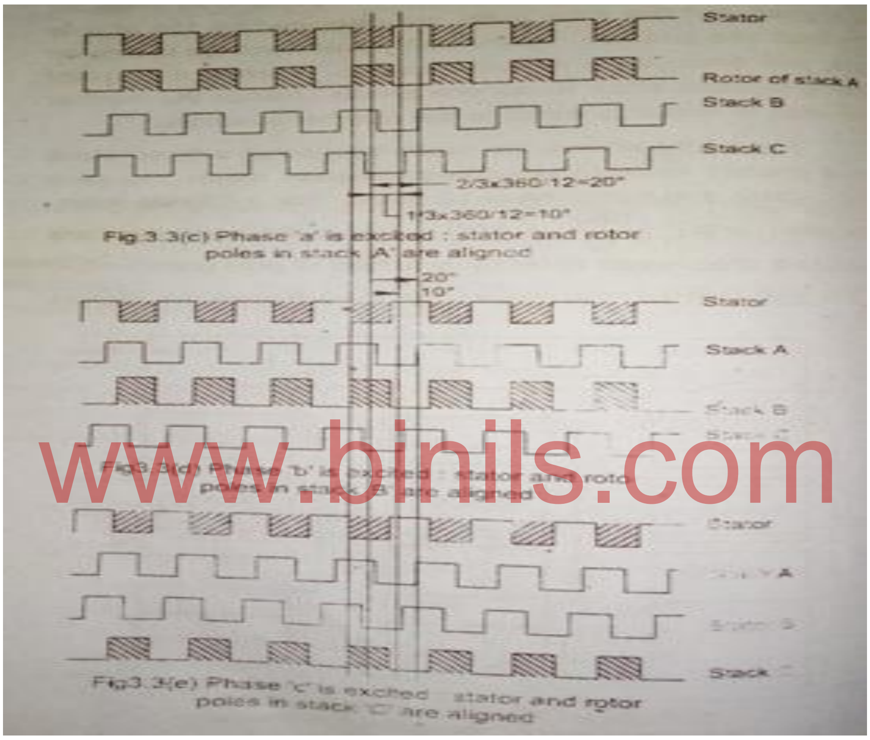


Fig 1.12 Multi stack stepper motor operation

When phase A is energised (stator of stack-A), the relative positions of stator and rotor poles are shown in fig 1.12 when phase A is energised the rotor poles of stack A get aligned with the stator poles. But the rotor poles of stack B and C do not get aligned.

Now, if the phase A is de-energised and B is energised, the rotor poles of stack B align with the stator poles. Hence the rotor will move by one third of the pole pitch (10°) in anticlockwise direction as shown in Fig 1.12. During this period the rotor poles of A and C do not get aligned with the stator poles.

Then if phase B is de-energised and C is energised, the rotor will move one third of pole pitch(10°) in anti-clockwise direction as shown in Fig 1.12. During this period the rotor poles of A and B do not get aligned with the stator poles.

1.11 HYBRID STEPPER MOTOR:

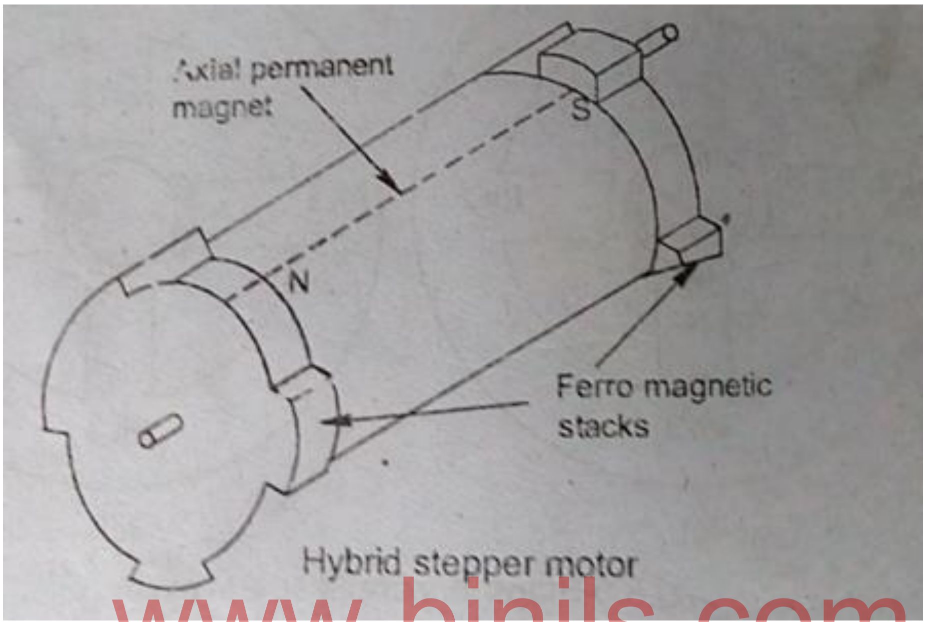


Fig 1.13 Hybrid stepper motor

Hybrid stepper motor combines the features of both PM and VR stepping motors.

The rotor construction of hybrid stepper motor is shown in fig 1.13. It consists of an axial permanent magnet. The two ends of the axial permanent magnet are attached by two identical ferromagnetic stacks as shown in fig 1.13. These two stacks consist of equal number of teeth. In this figure there are three teeth on each stack

At one end, the stack attains north (N) magnetic polarity and the other end the stack gets south (S) magnetic polarity. The two stacks have an angular displacement of one half of the rotor teeth pitch. The stator has salient pole structure. The stator poles carry concentrated windings like other type of stepper motors.

WORKING:

For understanding the operation of hybrid stepper motor (HSM). In this figure the rotor of north poles at the front end of fig 1.14 are shown with full lines, whereas the south pole at the far end are shown with dotted lines.

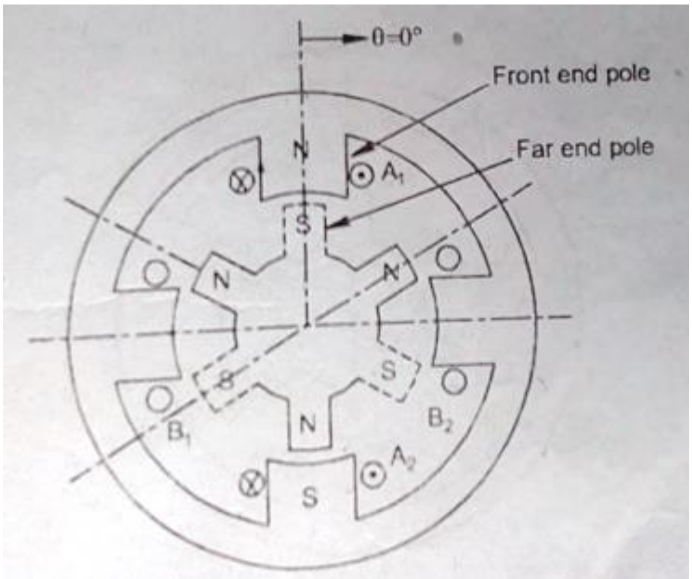


Fig 1.14 Cross section of a hybrid stepper motor

When phase winding A is energized with current I, N pole at A1 and S pole at A2 are created on the stator. Pole at A1 attracts S pole of the rotor at far end and pole at A2 attracts N pole of the rotor at the front end as shown in Fig 1.14. This equilibrium position of rotor structure results in maximizing the flux linkages with the phase winding A. Hence rotation θ =0°

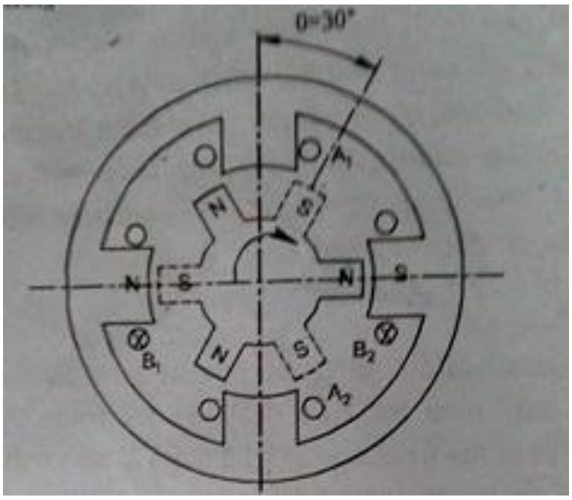


Fig 1.15(i) Hybrid stepper motor rotation for θ= 30 degrees

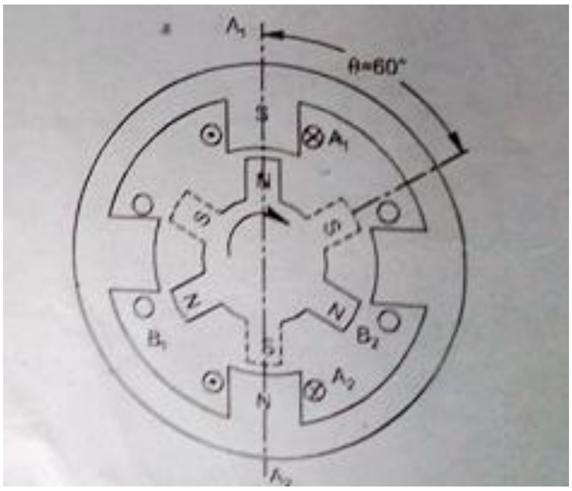


Fig 1.15 (ii)Hybrid stepper motor rotation for θ= 60 degrees

For turning the rotor clockwise through a step, de-energise the phase winding A and excite phase winding B so that N pole at B1 and S pole at B2 act on the rotor. Pole at B1 attracts S pole of far end of the rotor and pole at B2 attracts N pole of front end of the rotor So a step angular rotation of 30° clockwise is achieved as shown in Fig1.15(i). In this equilibrium position, maximum flux linkages are now linked with phase winding B.

If excitation is removed from the phase winding B and reversed excitation (by reverse current) is applied to phase winding A, stator pole on A1 attracts the front N pole of the rotor and stator pole at A2 attracts the rotor far end S pole. This gives rise to further step angle movement of 30° clock wise as shown in fig 1.15(ii). In this manner 12 steps will be completed in one revolution.

Sequence of exciting the phase winding for clockwise rotation is A1B1A2B2A1 and for anti-clockwise rotation the sequence will be A1B2A2B1A1.

1.11.1 ADVANTAGES:

1. High stepping rate capacity.
2. High efficiency at lower speeds and lower stepping rates.
3. Higher holding torque capability.
4. Better damping due to presence of rotor magnet.

1.11.2 DISADVANTAGES:

1. Higher inertia and weight due to presence of rotor magnet.
2. Performance affected by changes in magnetic strength.

1.12 CLOSED LOOP CONTROL OF STEPPER MOTOR:

In the drive systems explained earlier, the step command pulses were given from an external source. This type of operation of stepper motor is referred to open loop drive system. The open loop drive is attractive and widely accepted in applications of speed and position controls. However the performance of stepper motor driver in open loop mode may fail to follow a pulse command, when the frequency of pulse train is too high or the initial load is too heavy. The performance of stepper motor can be improved by employing position feedback or speed feedback to determine the proper phase winding to be switched at proper timing. This type of control is called as closed-loop drive.

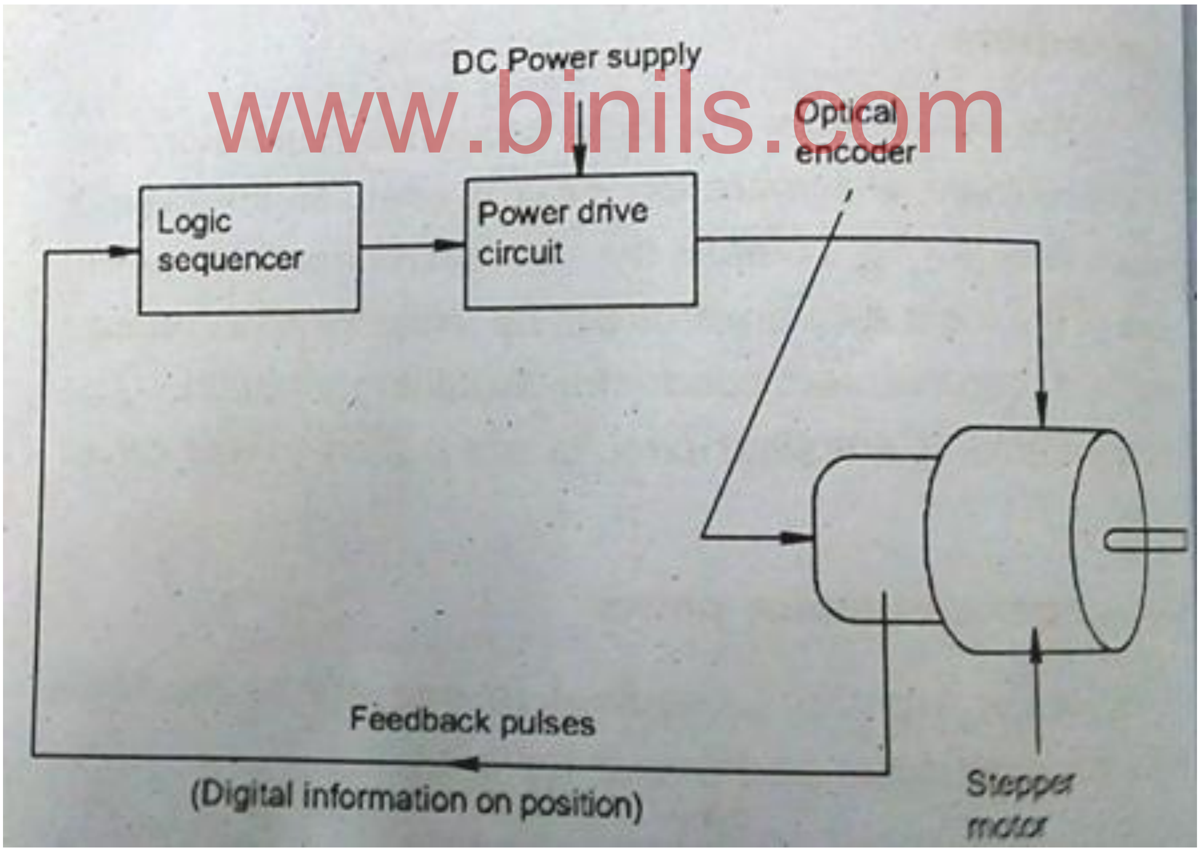


Fig 1.16 Block diagram of closed loop drive.

It consists of logic sequencer power drive circuit, optical encoder and stepper motor. In a closed loop control, a position sensor is needed for detecting the rotor position. For this purpose optical encoder is used. This optical encoder is coupled with motor shaft.

The pulses from the optical encoder are the digital information of the rotor position. These pulses are fed to the logic sequencer. Now the logic sequencer determines the excitation of the proper phase windings of the stepper motor through power drive circuit. Now the stepper motor rotates. The relation between the rotor's present position and the phases to be excited is called the lead angle.

1.12.1 APLLICATIONS OF STEPPER MOTOR:

1. Computer controlled systems
2. Driving the paper feed mechanism in line printers.
3. Tape drives.
4. Driving magnetic heads in floppy disc drivers.
5. Driving pens of X-Y plotters.
6. Robotics
7. Numerical control of machine tools.
8. Textile industry
9. Electrical watches.
10. Typewriters.
11. Integrated circuit fabrications.
12. Space craft launched for scientific applications.

1.13 OPEN LOOP CONTROLOF THE STEPPER MOTOR

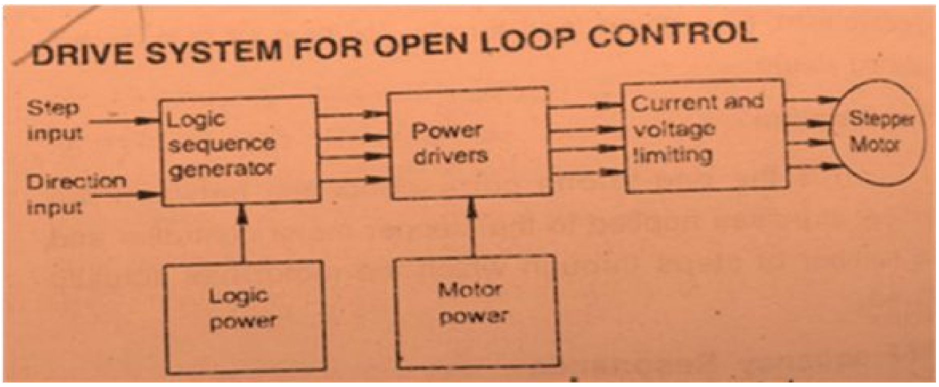


Fig 1.17 Block diagram of drive for open loop control

The block diagram of a open loop drive system for a stepper motor is shown in Fig 1.17. The stepper motor is a digital device that needs binary (digital) signals for its operation. Depending on the stator construction two or more phases have to be sequentially switched using a master clock pulse input. The clock frequency determines the stepping rate and hence the speed of the rotor.

It consists of following blocks.

1. Logic sequence generator
2. Power drivers
3. Logic power and motor power
4. Current and voltage limiting
5. Stepper motor

Logic sequence generator:

It is a logic circuit, which controls the excitation of the winding sequentially depending upon the step command pulse. Logic sequencer is a combination of JK flip-flop IC chips and logic gates.

Power drivers:

The outputs from the logic sequence generator are low level signals which are too weak to energise the stepper motor windings. To increase the voltage, current and power levels of the logic sequence generator output switching power amplifiers are used. (Power semiconductor switching circuits). The power switching amplifier circuits are called power driver circuits.

Logic power and motor power supplies:

Power supplies are required to operate the logic sequence generators and then power drive circuits.

Current and voltage limiting:

This circuit provides fast decay of current in the phase winding of a stepper motor when it is turned off during a particular step in the logic sequence.

1.14 Optical encoder:

Optical encoders are using optical and photoelectric sensing system. The linear and angular encoders have a pattern of transparent and opaque areas corresponding to the conducting and non-conducting areas respectively of the contacting brush type. The sensing system consists of light sources, each provided with a focusing lens and equal number of photo electric devices, and receiving the light beam from its corresponding light source. The light source is kept on one side and the photo sensors on the other sides of the encoders.

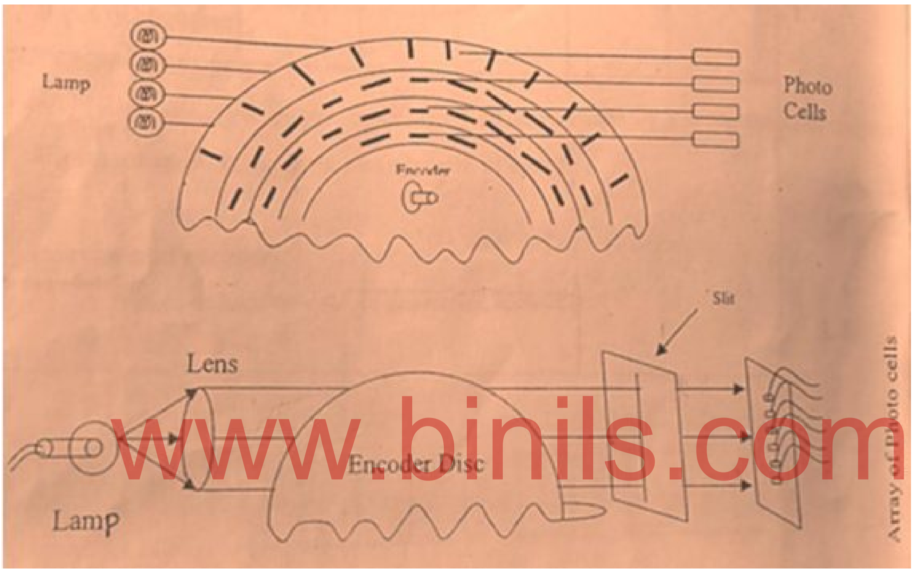


Fig 1.18 (a) Optical Encoder

The sharpness of focusing and special technique adopted in the manufacture of the encoders enable the achievement of an accuracy of better than 1 in 10^8. The transition between a transparent and an opaque area must be sharp and well defined so that there is less noise in the sensors during the transition between the logic ‘0’ and ‘1’ and the correct logic decisions. In this respect, optical encoders are specially favoured for application in high-frequency system.

Instead of having a large number of light sources, a single lamp and a lens is used as shown in the Fig1.18 (b), to flood the encoder on one side while the sensors receive the light through a narrow slit located accurately with respect to the reference line

A cylindrical lens produces a single line beam, which is so projected on to the reference line of the disc as to be incident on the sensors after passing through the disc.

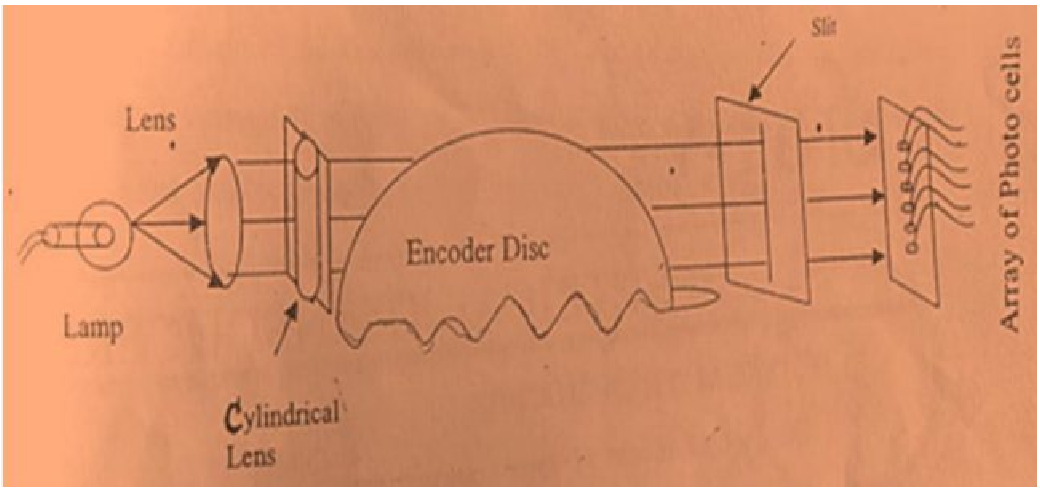


Fig 1.18(b) Array of photo cells

1.15 SERVO MOTOR:

For applications that requires special performance characteristics such as precise speed or position control in both directions, special motors are often more suitable than conventional motors. These non conventional motors often used are the servo motors. The servomotors are also called as the control motors and have high torque capabilities. The power ratings vary from a watt to upto a few hundred watts. They have low inertia and have a high speed of response. They are smaller in diameter and longer in length. They are operated at low speeds to zero speed.

1.15.1 ADVANTAGES:

1. They produce high torque at all speeds.
2. They are capable of holding a static position.
3. They do not overheat.
4. Due to low inertia, they can reverse directions easily.
5. They are able to return to a given position without any drift.
6. They can be accelerated and decelerated quickly.

1.15.2 APPLICATIONS:

1. Radar Tracking and Guidance systems.
2. Process controllers
3. Computers
4. Machine tools.

1.16 TYPES OF SERVO MOTORS:

The motors that are used in automatic control systems are called servomotors. When the objective of the system is to position an object or a load using a servomotor then the system is called servomechanism. Depending on the supply required to run the motor, they are broadly classified as DC servomotors and AC servomotors. The DC motors are expensive than AC motors. But the DC servomotors have linear characteristics and so it is easier to control

1.16.1 A.C SERVO MOTOR:

The AC servo motors are of the two-phase squirrel cage induction type and the three phase induction motor modified for high power servo system. They run at a frequency of 60 Hz or 400 Hz

A. Drag-Cup rotor AC servo motor:

Drag-cup construction is used for very low inertia applications. In this type of motor, the rotor construction is usually of squirrel cage or drag-cup type, here only a light cup rotates while the rotor core is stationary (thus inertia is quite small).

The servo motor contains two windings namely, main winding (sometimes called fixed or reference winding) and the control winding. The voltages applied to the windings are at right angles to one another. Usually one winding is excited with a fixed voltage while the other one is excited by the control voltage (which is the output from a servo-amplifier).While in operation, the output torque of the motor is roughly proportional to the applied control voltage and the direction of torque is determined by the polarity of the control voltage.

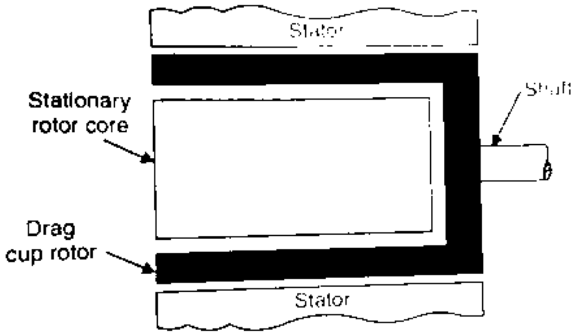


Fig 1.19 Drag cup servo motor

B. Shaded-pole type servo motor:

This type of motor employs a phase-sensitive relay to actuate those contacts which produce a short-circuit of the shaded pole winding to produce rotation in the desired direction.

The main shortcoming of this motor is that it responds only when the amplifier error signal is of adequate magnitude to cause the relay to operate.

1.16.2 DC SERVO MOTORS:

The dc servomotors are either separately excited dc motors or permanent magnet dc motors. The separately excited dc motor consists of the armature and the field windings. The speed of the dc servo motor is controlled by varying the armature voltage.

The armature winding resistance is large such that the torque speed characteristics are linear. A step change in the armature voltage or current produces a quick change in the position or speed of the rotor.

A. **PERMANENT MAGNET D.C. MOTOR:**

Permanent magnet D.C. motors are same as that of D.C. shunt motor with the difference that there is a permanent magnet instead of the stationary field windings for producing the required magnetic flux.

The construction of PMDC motor as shown in the figure consists of the cylindrical steel stator supporting the permanent magnet. The stator also provides return path for magnetic flux. The rotor consists of the armature windings, commutator and the brushes same as those in a conventional D.C. motor. The material used for permanent magnet has high residual flux density and high coercivity. For the motors having the rating up to 150KW, ALINICO permanent magnets may be used. Ferrite magnets are used in fractional KW motors. For small and large motors rare earth magnets are used.

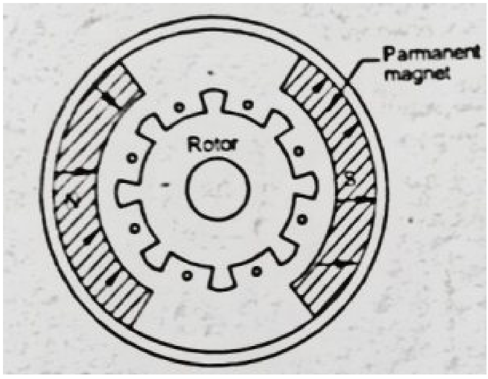


Fig 1.20 Permanent magnet DC motor

Working:

These motors normally run on 6V, 12V or 24V D.C. supply. This D.C supply can be obtained from batteries or rectified A.C. Because of the interaction between the flux produced by the permanent magnet and the current carried by the armature, a torque is produced and the motor rotates.

Advantages:

1. These motors do not require external excitation for producing magnetic field.
2. As the field windings are absent, the size of such motor is small.
3. The cost of this motor is low.
4. The efficiency of the motors are high, since field losses are absent.
5. These motors produce less noise.

B. BRUSHLESS DC MOTOR:

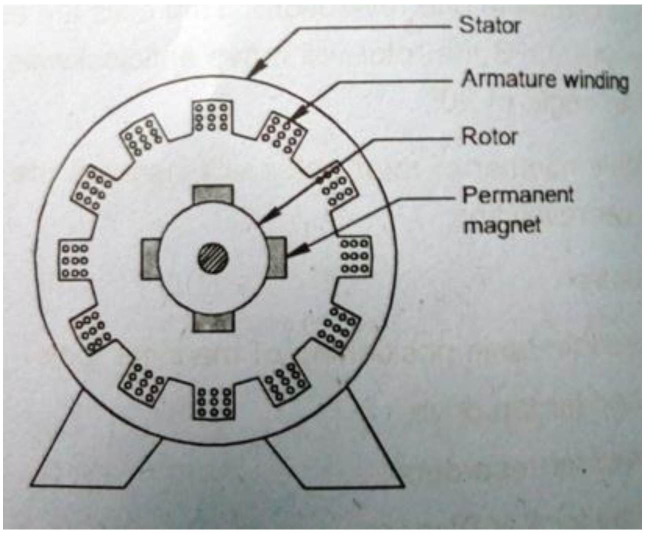


Fig 1.21 Brushless DC motor

The above figure1.21 shows the structure of a brushless dc servomotor The stator consists of an armature core and armature windings. The armature core is made of laminating punched silicon steel sheet of 0.35 to 0.5 mm thickness. The armature core is slotted and is skewed to reduce the armature torque ripples. The armature windings are similar to an A.C. motor and are usually of distributed three phase type. The rotor carries the permanent magnet and is fixed on the motor shaft. The shape of the magnet is either cylindrical or salient pole. Rare earth magnets are used to improve the performance of the motor.

An inverter fed trapezoidal PMAC motor drive operating in self controlled mode is called a brushless dc motor. Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall effect sensors embedded into the stator windings Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.

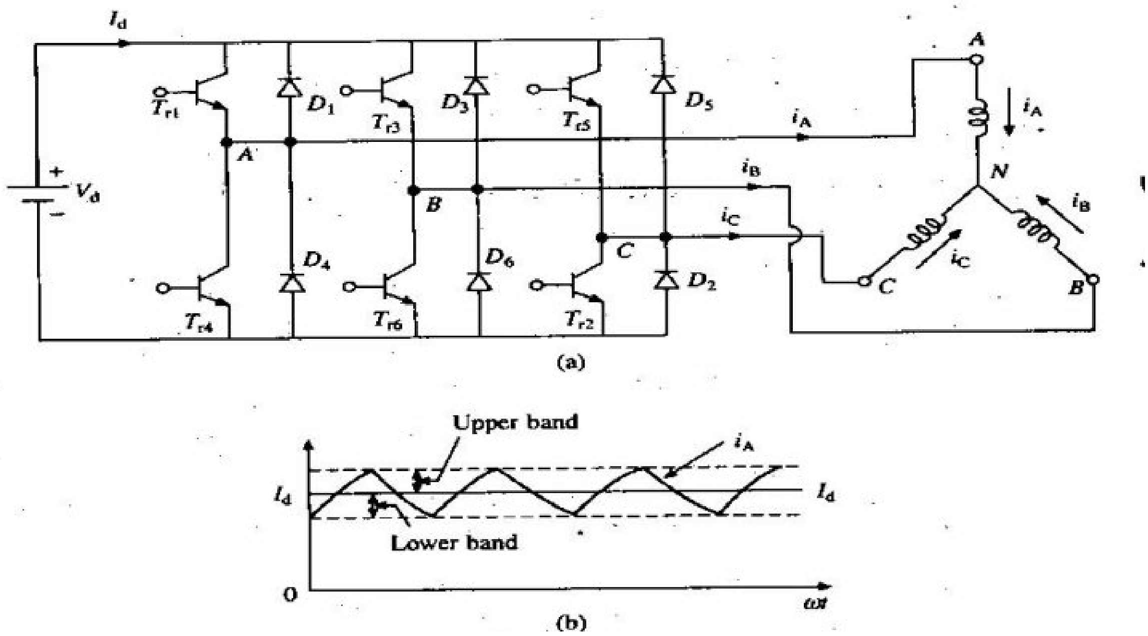


Fig 1.22 Working of BLDC motor

They can be operated up to the boundary of high speed rotation without decreasing the maximum torque. The heat dissipated in the shaft diffuses into the air through the frame. It is therefore easy to cool .

Applications:

These servo motors are best suited for low power applications.These motors are widely used in aircraft control systems, electromechanical actuators, process controllers, robotics, machine tools, in instrument servos, computers etc.

1.17 SERVO MECHANISM:

It consists of three parts

1. Controlled device, 2. Output sensor and 3. Feedback system

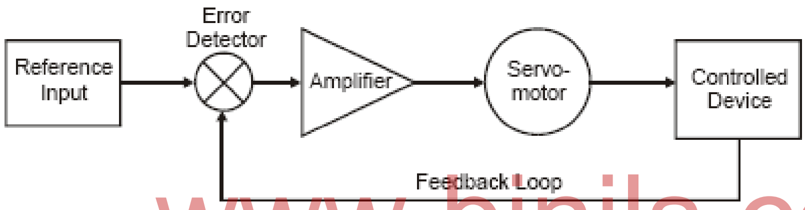


Fig 1.23 Block diagram of servo mechanism

It is a closed loop system where it uses positive feedback system to control motion and the final position of the shaft. Here the device is controlled by a feedback signal generated. The reference input and the feedback output signal are compared and produce the difference signal called the error signal.

The error signal or the control voltage acts as the input signal to the servomotor. The shaft of the servomotor makes an angular displacement proportional to the applied control voltage. This signal is present as long as the feedback signal is generated or there is a difference between reference input signal and reference output signal. So the main task of servomechanism is to maintain the output of a system at a desired value

1.18 INDUCTION MOTOR

Induction motors are used in variety of applications at home, factory, office and business establishments. Single phase induction motor is not self-starting. Additional arrangement has to be made to make it self-starting.

1.18.1 Eddy current drives:

An eddy current drive consists of an eddy current clutch placed between an induction motor running at a fixed speed and the variable speed load. Speed is controlled by controlling D.C. excitation to magnetic circuit of the clutch. Since motor itself runs at a fixed speed it can be fed directly from A.C. mains.
The principle of an eddy current clutch is identical to an induction motor in which both stator and rotor are allowed to rotate. Stator which is coupled to driving induction motor, has D.C. winding which produces magnetic field rotating at the speed of the rotor. Rotor has a metal drum coupled to the load. Eddy currents are induced in rotor drum by stator magnetic field. Interaction between the stator field and eddy currents produce a torque which causes rotor to move with a slip. Slip, and therefore, the load speed, can be controlled by controlling D.C. current through rotor winding. Speed torque characteristics are identical to an induction motor.

Speed reduction is obtained by wasting a power equal to sP_{in} (where 's' is the slip and Pin is the input power)in the rotor drum. Minimum speed is usually restricted to 30 % below the synchronous speed because efficiency becomes too low and cooling of the rotor drum becomes difficult below this speed.

Load can be decoupled from induction motor by setting D.C. winding current to zero. Motor can now be started on no load. Load can be smoothly started by slowly increasing D.C. winding excitation. Eddy current clutch is available in different constructions and sizes ranging from fraction of kW to MW.

1.18.2 Advantages:

The advantages of eddy current drives are

1.Rugged in construction.
2.Easy to maintain.
3.Reliable in operation.
4.Step less speed control with good speed regulation.
5.Controlled acceleration and soft start.
6.High starting torque.
7.High overload capacity
8.Ability to handle in impact loads.

REVIEW QUESTIONS

	UNIT I INDUSTRIAL DRIVES
	PART A-Two marks questions
1.	What is an electric drive?
2.	What are the parts of electric drive?
3.	What are the types of an electric drive?
4.	What is a stepper motor?
5.	What is an individual motor drive?
6.	What is a group drive?
7.	What is a multimotor drive?
8.	What are the types of a stepper motor?
9.	What are the advantages of a stepper motor?
10.	What is a brushless dc motor?
11.	What are the advantages of a brushless dc motor?
12.	What is a servo motor?
13.	Mention the applications of an eddy current drive.
14.	What is an eddy current drive?
	PART B-Three marks questions
15.	Write short notes on the types of electric drives.
16.	What are the selection factors for the electric drives?
17.	Draw the block diagram of an electric drive.
18.	How is the stepper motor used for industrial automation?
19.	Discuss in brief the types of servo motors.

	PART C-Ten marks questions
20.	Explain the parts of an electric drive with a block diagram.
21.	Explain the construction and working of a variable reluctance stepper motor
22.	Explain the construction and working of a hybrid stepper motor
23.	Explain the construction and working of a permanent magnet DC motor?
24.	Explain the construction and working of a brushless dc motor?
25.	Explain the eddy current drive control of an induction motor.
26.	Explain the closed loop control of stepper motor.
27.	Explain the drive circuits for the stepper motors.

UNIT-II PNEUMATIC AND HYDRAULIC SYSTEMS

2.0 INTRODUCTION

In the industry, we use three methods for transmitting power from one point to another. Mechanical transmission is through shafts, gears, chains, belts, etc. Electrical transmission is through wires, transformers, etc. Fluid power is through liquids or gas in a confined space. In this chapter, we shall discuss a structure of the hydraulic systems and pneumatic systems, i.e, the fluid power systems

FLUID POWER:

Fluid power is the technology that deals with the generation, control and transmission of forces and movement of mechanical element or system with the use of pressurized fluids in a confined system. Both liquids and gases are considered as fluids. Fluid power system includes a **hydraulic system** (*hydra* meaning water in Greek) and a **pneumatic system** (*pneuma* meaning air in Greek). Oil hydraulic employs pressurized liquid petroleum oils and synthetic oils, and pneumatic employs compressed air that is released to the atmosphere after performing the work. The technology of generating, controlling and transmitting power using pressurised fluids is termed as fluid power. Fluid power systems are classified into

i) Hydraulic system
ii) Pneumatic system.

2.1 HYDRAULIC SYSTEM:

2.1.0 INTRODUCTION:

A hydraulic system uses force which is applied at one point and transmitted to another point using an incompressible fluid, plant equipment and machinery. In this type of machine, high-pressure liquid called hydraulic fluid is transmitted through the machine to various hydraulic motors and hydraulic cylinders.

The fluid is controlled manually or automatically by control valves and distributed through hoses and tubes. The popularity of hydraulic machinery is due to large amount of power that can be transferred through small tubes and flexible hoses, and the high power density and wide array of actuators that can make use of this power.

2.1.1 DEFINITION OF A HYDRAULIC SYSTEM:

A system which transmits power from one place to another place by using pressurised oil or water is called a **hydraulic system.**

Hydraulic system is used to perform useful work in various fields such as machine tool industries, agriculture, space, defense, automobile etc.

The branch of science which deals with the hydraulic systems with oil as working medium is called **oil hydraulics.**

2.2 ELEMENTS OF HYDRAULIC SYSTEM (HYDRAULIC POWER SUPPLY):

Hydraulic system consists of six basic components as shown in Fig.2.1.

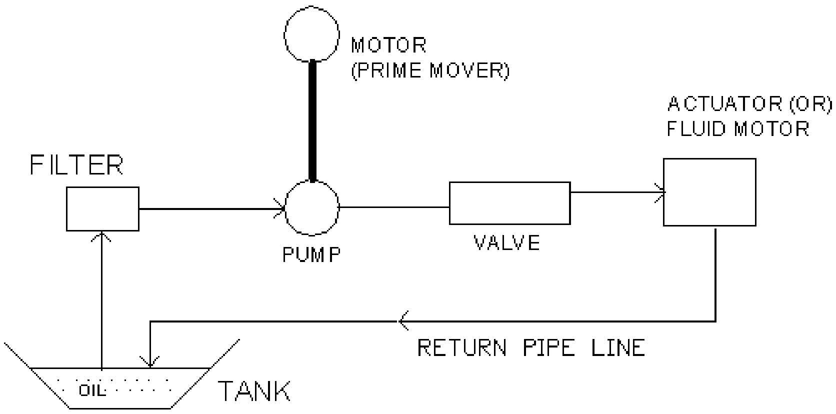


Fig: 2.1 Hydraulic system

They are,

- Tank or reservoir to store the oil (hydraulic liquid)
- Pump to force oil into the system
- Prime mover (electric motor) to drive the pump
- Valves to control pressure, flow rate and direction of the oil.
- Actuator (cylinder or hydraulic motor) to convert oil energy into useful work.
- Pipe line to carry liquid to all the hydraulic components.

WORKING:

When pump is driven by a prime mover, it draws oil from the tank and then increases the pressure of the oil.

High pressure oil flows through the control valves. They control the pressure, flow rate and direction of the oil.

Oil enters the actuator. When actuator is a hydraulic cylinder, it converts oil energy into linear motion. But when actuator is a hydraulic motor, it converts oil energy into rotary motion. Finally, oil coming out of actuator is returned to the tank through pipe line. Cycle is repeated.

MERITS

- Does not require complicated mechanical links such as gears, cams, pulleys, levers etc.
- Lubricated by itself
- Speed control is accurate.
- Force multiplication is provided easily.
- Silent in operation.

DEMERITS:

- Leakage of oil reduces the force
- Cost of oil is high
- Hydraulic line may burst, causing human injury.
- Periodic replacement of pipes is necessary.

2.3 HYDRAULIC ACCUMULATORS:

2.3.0 DEFINITION:

Hydraulic accumulator is a device for accumulating and storing liquid under pressure by using an external source. This source may be weight or spring or compressed gas.

A hydraulic accumulator in its simplest form consists of a liquid chamber and a gas chamber separated by a piston or bladder. Symbol of accumulator is shown in Fig 2.2

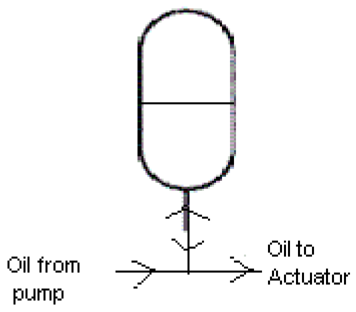


Fig.2.2 Accumulator

Accumulator serves many functions. They are given below.

1. Leakage compensator
2. Shock absorber
3. Secondary power source
4. Emergency power source
5. Thermal expansion compensator
6. Temporary storage receiver etc.

2.3.1 TYPES OF ACCUMULATORS:

The types of accumulators are

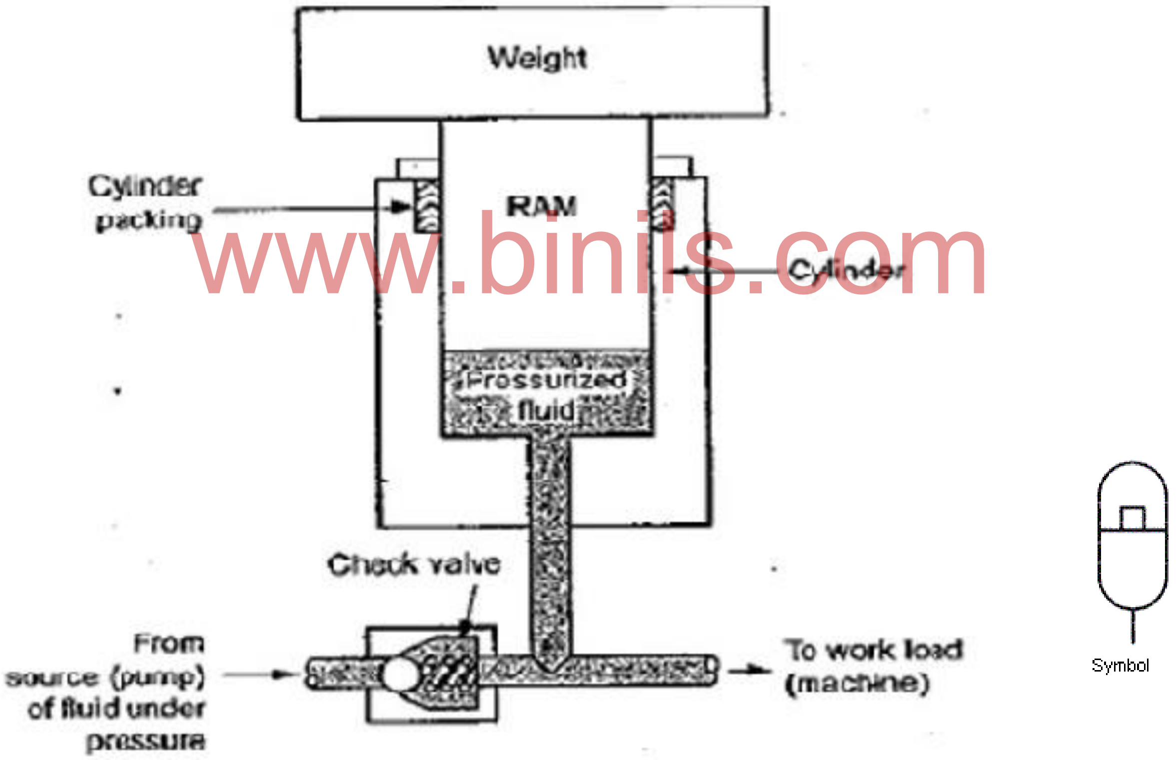
1. Weight loaded or gravity type accumulator
2. Spring loaded type accumulator
3. Gas filled bladder type accumulator

2.3.2 WEIGHT LOADED OR GRAVITY TYPE ACCUMULATOR:

This is the oldest type of accumulator.

CONSTRUCTION

It consists of a strong vertical cylinder in which ram is sliding as shown in fig.2.3. Oil seal is used to prevent leakage of oil. Dead weight is placed on the top of the ram. The gravity force of the dead weight provides the potential energy in the accumulator



Fg.2.3 Weight loaded or gravity type accumulator

WORKING

When the pump supply is not required for the system, oil enters into the accumulator. Ram and dead weight move up against the gravity force and oil is stored under pressure.

When the system pressure falls, ram moves down due to gravity force. Oil is pushed back into the system.

MERITS

- Constant liquid pressure is always maintained.
- Simple in construction

DEMERITS:

- Large in size
- Heavy in weight
- Cannot be held in inclined and horizontal positions
- Not used in mobile applications.

2.3.3 SPRING LOADED TYPE ACCUMULATOR

This is similar to the weight loaded type, except that the ram is preloaded with springs.

CONSTRUCTION

It consists of a cylinder in which ram is sliding as shown in fig.2.4

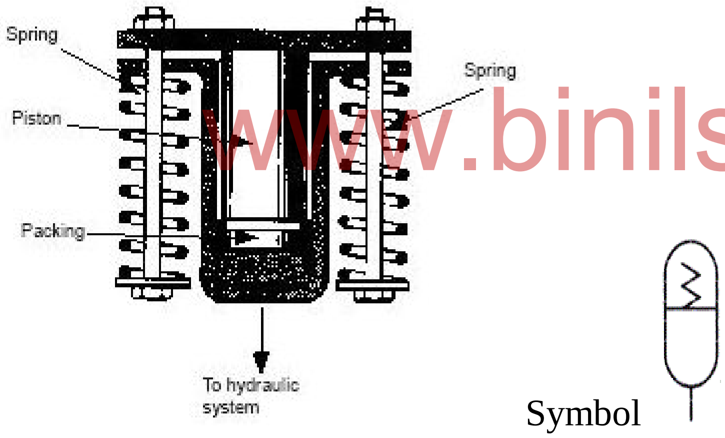


Fig 2.4 Spring loaded type accumulator

Oil seal is used to prevent the leakage of oil. Depending upon the amounts of system pressure, the spring compression is adjusted by means of a screw.

WORKING

When the pump supply is not required for the system. Oil enters into the accumulator. By compressing the spring, ram moves up and oil is stored under pressure.

When system pressure fails, spring expands. Ram moves down. Oil is pushed back into the system.

MERITS

- Can be held in any position
- Suitable for small volume output of oil at low pressures.

DEMERITS

- Constant liquid pressure cannot be maintained
- Not suitable for high pressure
- Not suitable for cyclic load applications as spring may lose its elasticity due to fatigue.

2.3.4 GAS FILLED BLADDER TYPE ACCUMULATOR

This is the mostly used accumulator in hydraulic systems

CONSTRUCTION

It consists of a cylindrical shell with semi-circular ends to better withstand system pressure. An elastic rubber bladder filled with compressed gas (Nitrogen) is fitted inside the shell as shown in Fig 2.5.

There is a gas charging valve at the top and a spring operated poppet valve at the bottom. This poppet valve closes the inlet when the bladder is fully expanded. This prevents the bladder from entering into the inlet port. So, the bladder is not damaged.

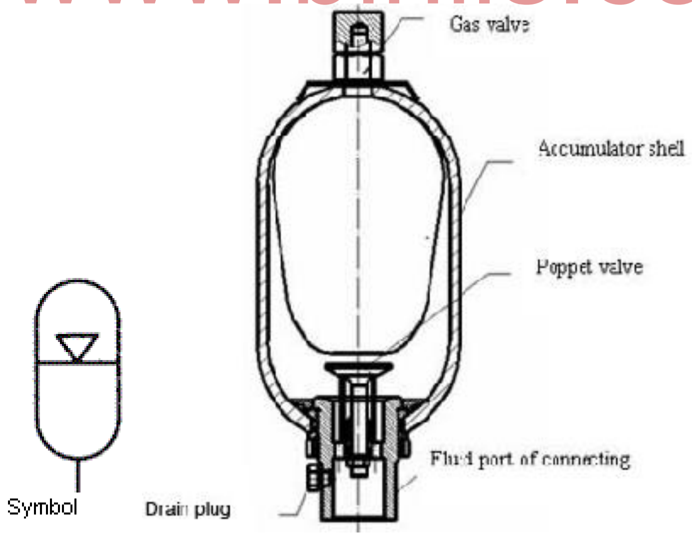


Fig 2.5 Gas filled bladder type accumulator

WORKING

When pump supply is not required for the system, oil enters into the accumulator. Elastic bladder shrinks. Oil is stored under pressure.

When system pressure falls, elastic bladder expands. Oil is pushed back into the system.

MERITS

- Positive sealing is attained between the gas and oil chambers. Thus the leakage of oil between the chambers is impossible.
- As light-weight bladder provides quick response to pressure variations, this accumulator is mainly used as pressure regulator and shock absorber.

DEMERITS

- To prevent the damage of bladder, poppet valve is required.
- Costlier than other accumulators

2.4 PNEUMATIC SYSTEM:

2.4.1 INTRODUCTION

A system which transmits power from one place to another place by using compressed air is called pneumatic system. Air is used instead of a gas, because air is safe and is readily available.

Pneumatic system is used to perform useful work in various fields such as industries, automobile, railway, space, construction, etc.

Pneumatic power is used in the operation of pneumatic tools such as pneumatic hammers, pneumatic drills, pneumatic cranes, pneumatic hoists, pneumatic grinders, etc.

Pneumatic systems are best suited for material handling operations in mines where electrical and hydraulic systems cannot be used because of the danger of firing.

2.4.2 ELEMENTS OF PNEUMATIC SYSTEM:

The main components of pneumatic system are shown in figure 2.6

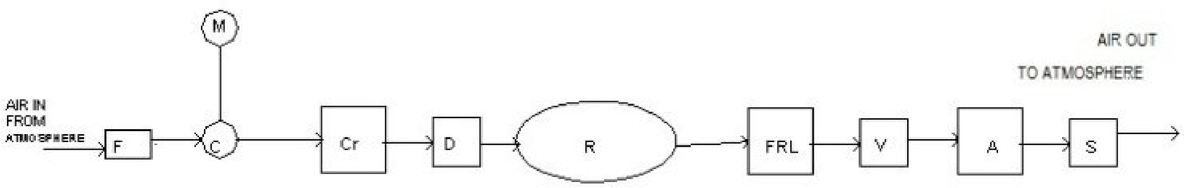


Fig 2.6 Elements of Pneumatic System

Where,	F	– Filter	R	- Receiver
	C	– Compressor	FRL	- Filter, Regulator, Lubricator
	M	– Electric motor	V	- Pneumatic valve
	Cr	– Cooler	A	- Actuator
	D	– Dryer	S	- Silencer

They are,

1. **Filter** to remove impurities and water droplets from air entering into the system.
2. **Compressor** to compress the air that enters from the atmosphere.
3. **Prime mover** (electric motor) to drive the compressor.
4. **Cooler** to remove the heat of compression from the air.
5. **Dryer** to remove the condensed water droplets from the cooled air.
6. **Receiver** to store the compressed air.
7. **FRL unit** to remove the remaining impurities, to regulate the Pressure and to mix the lubricant with air.
8. **Valves** to control pressure, flow rate and direction of air.
9. **Actuator** (cylinder or pneumatic motor) to convert air energy into useful work.
10. **Silencer** to reduce the noise of exhausting air.
11. **Pipe line** to carry air to all the pneumatic components.

WORKING

When compressor is driven by prime mover, it draws air from the atmosphere and then increases the pressure of air. Then it is stored in the receiver.

After passing through the FRL unit and valves, air enters the actuator. When actuator is a pneumatic cylinder, it converts air energy into linear motion.

But when actuator is a pneumatic motor, it converts air energy into rotary motion.

Finally, air coming out of actuator is exhausted to the atmosphere through silencer. Return pipe line is not required.

2.5 FRL UNIT:

It is a combined unit of filter, regulator and lubricator. Its ISO symbol is shown in fig.2.7 Each element is described as follows.

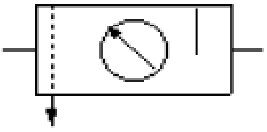


Fig.2.7 FRL UNIT

2.5.1 FILTER

NECESSITY

Water droplets, impurities present in the incoming air may cause wear of the moving parts. To prevent this, filter is included in the pneumatic system. It removes the contaminants from the air.

CONSTRUCTION

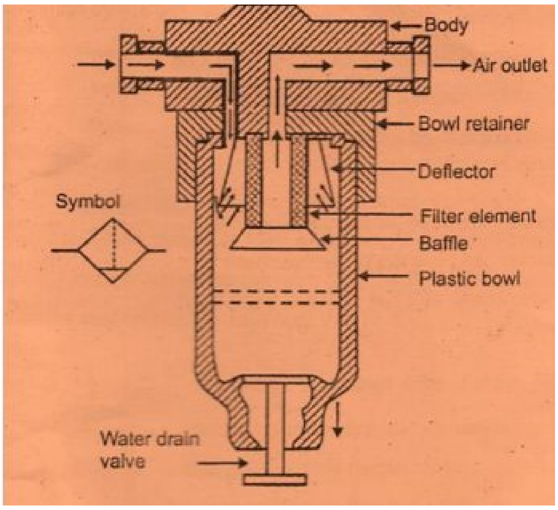


Fig 2.8 Filter

It consist of a plastic bowl, inlet and outlet ports, a deflector that deflects the inlet air to enter the filter element, which is made of sintered brass or bronze and a drain plug at the bottom of the bowl.

WORKING

Air enters into the filter through the inlet port. The deflector causes the air to rotate. Due to centrifugal force, water droplets and heavy impurities are separated and get collected at bottom of the bowl. The remaining filter impurities (in the range of 5 to 50 microns) move along with the air and pass through the filter elements where they are arrested. Drain plug is opened to drain the accumulated water and solid particles.

2.5.2 REGULATOR

NECESSITY

The pressure of compressed air delivered by the compressor is varying. This variation may affect the performance of the valves and the actuators. To prevent this, regulator is included in the pneumatic system. It regulates the system pressure at constant limit.

CONSTRUCTION

It has a metallic body with inlet and outlet ports, poppet valve, diaphragm, springs and adjustment screen. The pressure is regulated by a diaphragm. The output pressure acts on one side of the diaphragm and spring acts on the other side. The spring force can be adjusted by means of an adjustment screw.

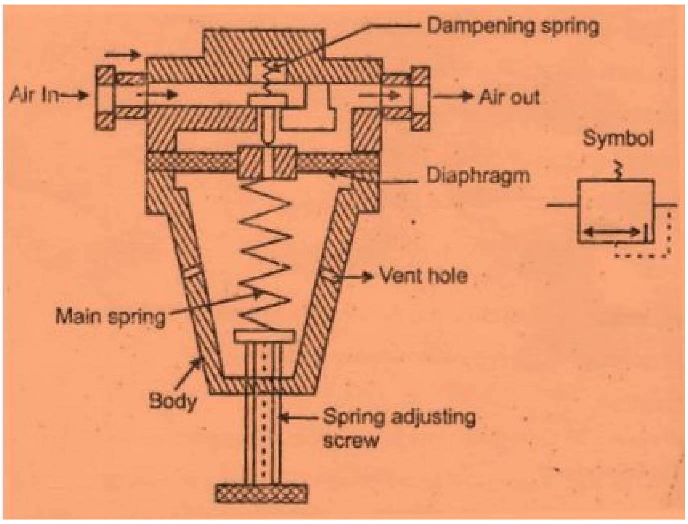


Fig 2.9 Air Regulator

WORKING

When outlet pressure increases above the constant limit, diaphragm moves up by compressing the spring. So the poppet valve moves up and reduces the area of flow at the valve seat. Air flow rate at inlet reduces and hence outlet pressure rises back to the constant limit.

When outlet pressure decreases below the constant limit, spring expands and moves down the diaphragm, so the poppet valve moves down and increases the area of air flow at the valve seat. Air flow rate at inlet increases and hence outlet pressure rises back to the constant limit.

2.5.3 LUBRICATOR

Air is not a good lubricant. To prevent the wear of the moving parts in the pneumatic system, lubricant oil is mixed with air in fine mist form by lubricator. It is connected next to the regulator in pneumatic system.

CONSTRUCTION

It consists of a glass bowl which stores lubricant oil at its bottom. It has a feed tube, a ball check valve to maintain a column of oil in the tube, venturi and a needle valve to adjust the oil flow rate

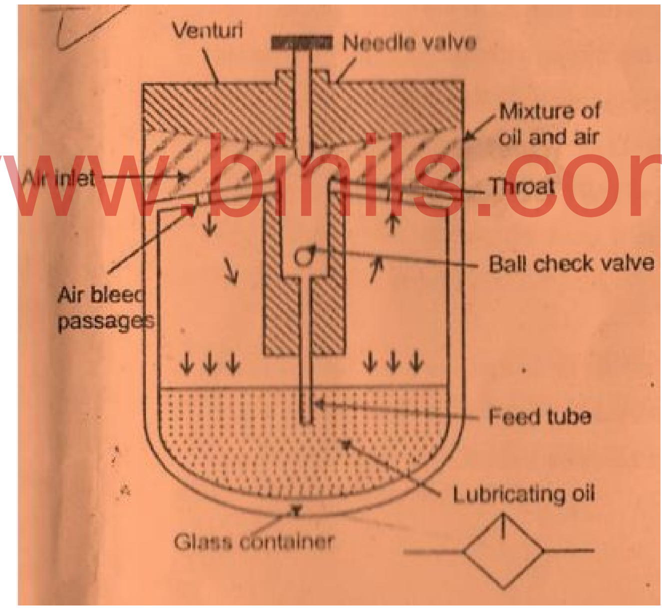


Fig. 2.10 Lubricator

WORKING

Lubrication follows the principle of venturimeter .i.e., when air passes through the venturi its velocity is increased and pressure is reduced. Due to this the pressure drops and the oil from the reservoir rises through the feed tube. It sprays out in fine mist form and mixes with air. This oil carried by the compressed air is used to lubricate the pneumatic components.

2.6 PRESSURE CONTROL VALVES

These valves maintain the desired pressure levels in various components of the pneumatic circuits; thereby they protect the components from damage due to over-pressurisation.

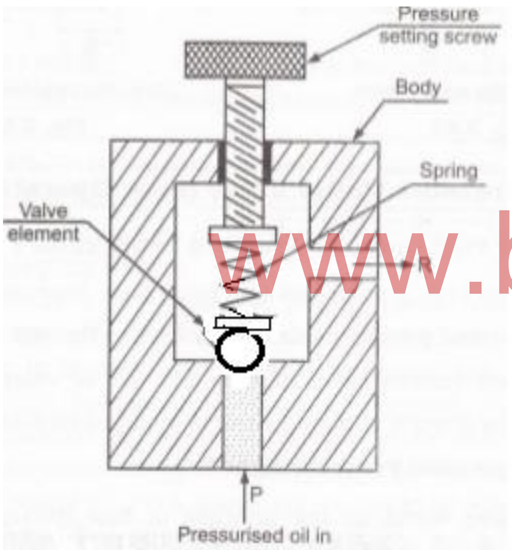
Pressure control valves are classified into

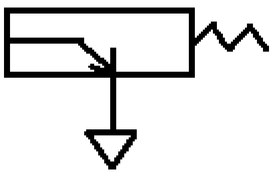
1. Pressure relief valves
2. Pressure regulation valves

2.6.1 PRESSURE RELIEF VALVES

This is the most commonly used pressure control valves in pneumatic system. It provides overload protection for system components.

CONSTRUCTION





Symbol

Fig. 2.11 Pressure relief valve

Its main parts are

1) **Valve body** having inlet and outlet ports. The inlets ports is exposed to the system pressure and is blocked by the ball. Outlet ports are vented to the atmosphere.
2) **Ball** is the valves elements. It lies in the intersectional passage between inlet and outlet ports.
3) **Heavy spring** by its force, hold the ball on valve seat.
4) **Adjustment screw** is used to adjust the spring tension.

WORKING

A relief valve is normally closed.

When system pressure (inlet pressure) exceeds the normal operating pressure, the ball is forced of its seat and the valve is opened. The compressed air flows from the pressure line through the valve to the outlet port and is exhausted into the atmosphere.

This diversion of flow reduces the system pressure back to the normal level. As soon as the pressure is reduced below the valve's setting, the spring reseats the ball and the valve is again closed. The pressure at which the valve begins to open is called the cracking pressure of the valve. Thus, relief valve acts as overload protection device and is generally located near the compressor.

Relief valve has certain drawbacks. They are

1. Owing to pressure pulsations, valve opens and closes rapidly. This results in vibrations and noise.
2. Valve seal is rapidly damaged. This allows excessive leakage, causing the loss of power.
3. Valve should be cleaned regularly to remove the dust deposits.

2.6.2 PRESSURE REGULATION VALVE (OR PRESSURE REDUCING VALVE):

Generally, many components of pneumatic system require high pressure, high volume compressed air. But, few components of pneumatic system may require low pressure, low volume compressed air. To meet this demand, pressure reduction valve is used. It supplies the small volume of air at the reduced pressure.

CONSTRUCTION:

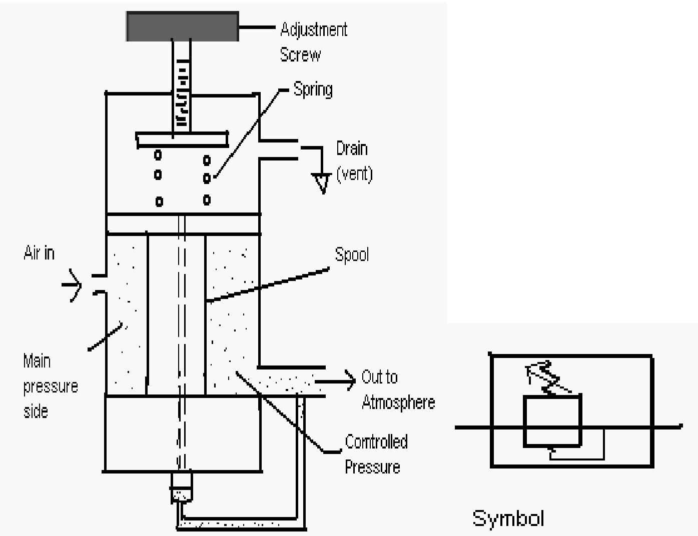


Fig.2.12 Pressure regulation valve

Its main parts are,

1. Valve body having inlet and outlet ports. The inlet port is exposed to the system pressure and outlet port is exposed to the reduced pressure.
2. Accurately machined valve spool is tightly fitted inside the valve body. The sliding action of the spool opens and closes the outlet port.
3. A pilot line is taken from the bottom of the spool.
4. Spring by its force, keeps the spool in lower position and thereby maintains the valve in open position.

WORKING

A pressure reduction valves is normally open. When pressure at the outlet port is at normal level, the spring holds the spool in open position.

Air from pressure line enters the valves at the inlet port, flows past the valve spool and enters the outlet port. Pressure at the outlet port acts through the pilot line to the bottom of the spool. If the pressure is insufficient to overcome the spring force, the valves remains open.

When the pressure at the outlet port and under the spool exceeds the spring force, the spool rises and partially blocks the outlet port. As flow rate through outlet port is decreased, outlet pressure is reduced back to normal level.

When the valve is closed completely by the spool, back flow at the outlet port would increase the pressure above the valve setting. To avoid this, drain line is provided to exhaust the air into atmosphere. So, a pressure reducing valve supplies air through its outlet port at constant reduced pressure irrespective of the system pressure at its inlet port.

2.7 DIRECTIONAL CONTROL VALVES

The directional control valves [DCV] are used to control the direction of flow in a pneumatic circuit. They are used to start, stop and regulate the direction of air and help the distribution of air in the desired line. They contain ports (external openings) through which air can enter and leave. These ports are termed as ways. Based on ways, directional control valves are classified as one, two, three, four, five ways. The ways are designated by alphabets

C (P)= Compressor line port or Pressure line port

E (T)= Exhaust Port or the return line port

A, B = Working Ports to cylinders or pneumatic motors.

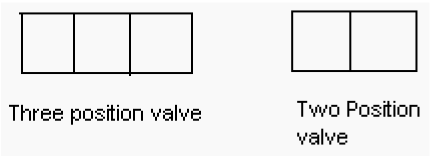
Based on the construction of the internal moving parts, these valves are classified as

1) Sliding spool type
2) Rotary spool type

Based on the actuating devices these valves are classified into

1) Manually operated
2) Mechanically operated
3) Electrically operated

Based on the number of positions of valve elements, directional control valves are classified into two positions and three positions. For representing valves in circuit diagram, symbols are used. Each position of the symbol is denoted by squares.



Symbols show only the functional aspect of the valve and do not show the constructional details.

For symbols the following terminology is used.

1. A valve position is represented by square.
2.The number of adjacent squares is equal to the number of valve positions.
3. Inside the square the arrow lines indicate the direction of flow.
4. Cut offs of air flow are shown by short traverse lines inside the square.
a. Connection to inlet and outlet ports are drawn only to neutral position
b. Working line connections are indicated by A, B.
c. Compressor line is indicated by C (P) and Return line by E (T).

For example the symbol of 4/3 DCV is shown in fig.2.13

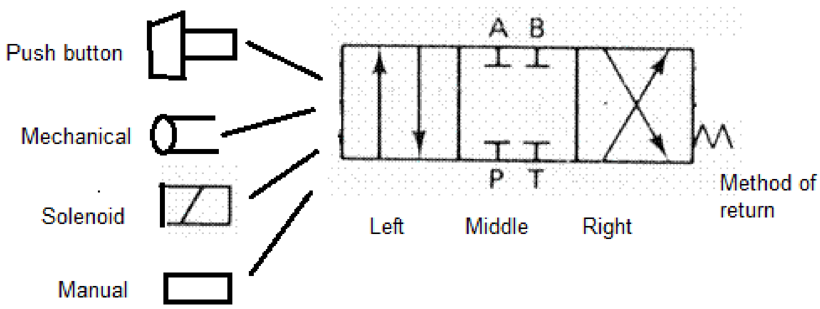


Fig.2.13 Directional Control Valve

4/3 means 4 ways [A, B, C (P) and E (T)] and 3 positions [Left, Middle, Right]

Left Position (Working **Position)**

Flow is straight. C (P) port is connected to A and B port is connected to E (T).

Middle Position [Neutral Position]

All the ports are blocked. No flow takes place through the valve.

Right position (Working position)

Flow is crossed. C(P) port is connected to B and A port is connected to E(T).

2.7.1 ROTARY SPOOL TYPE:

Four way three positional rotary spool type valves are shown in fig.

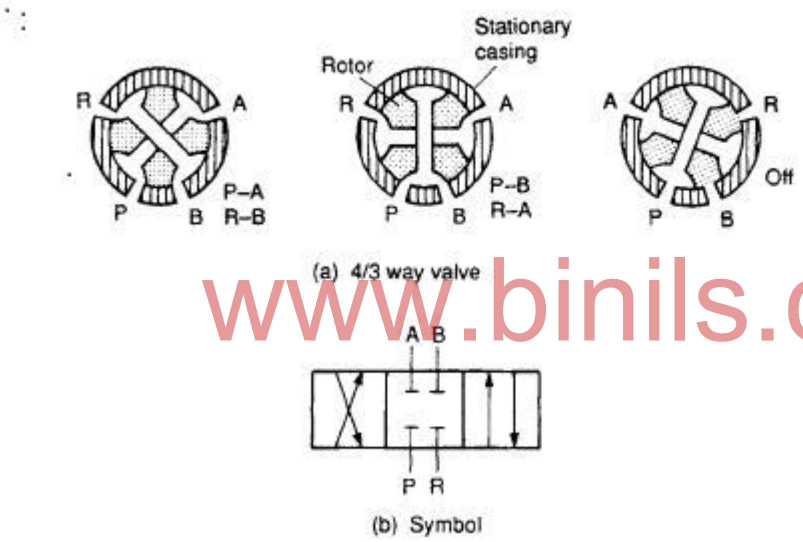


Fig.2.14 Spool valve

It consists of a rotating spool (rotor) closely fitted and rotated inside a cylindrical bore of a valve body (stationary casing). The casing is having four ports (P, R, A and B). Passages are drilled within the rotor. They connect or block off the ports in the casing to provide the four paths. The valve is actuated manually or mechanically.

The graphic symbol shows the flow path configuration through the valve for each of the three positions.

MERITS

- Compact
- Simple construction

DEMERITS

- Low operating pressure

2.7.2 SLIDING SPOOL TYPE DCV:

It is mostly used in pneumatic circuits.

The valve element is a spool. It is a circular shaft containing lands of large diameter machined to slide inside a finely finished bore in the valve body. The grooves between the lands provide the flow paths between ports. These valves are designed to operate with two or three unique positions of the spool.

The spool can be positioned manually, mechanically or electrically.

For example, two way spool type DCV with the symbol is shown in Fig 2.16

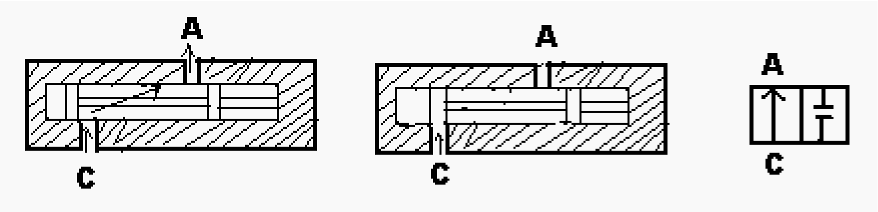


Fig.2.15 Sliding spool DCV

In a two way spool type DCV, a spool moves back and forth in the machined bore of the valve body. In one position, flow is permitted from C port to A port. In the other position, C port is blocked by the spool land.

Merits:

- Simple construction
- Valve bore and spool finishing is simple and easier.
- Valve bore and spool get uniform wear and tear.
- All types of actuators are possible.

2.7.3 3/2 DIRECTIONAL CONTROL VALVE

Three way-two position DCV is a sliding spool type valve. The spool moves back and forth in the machined bore of the valve body to control the flow. It has the following three ports.

C (P)– Compressor port connected to pressure line

E (T)– Exhaust port vented to atmosphere

A – Working port connected by line to cylinder or pneumatic motor. The symbol of valve is shown in Fig.2.16.

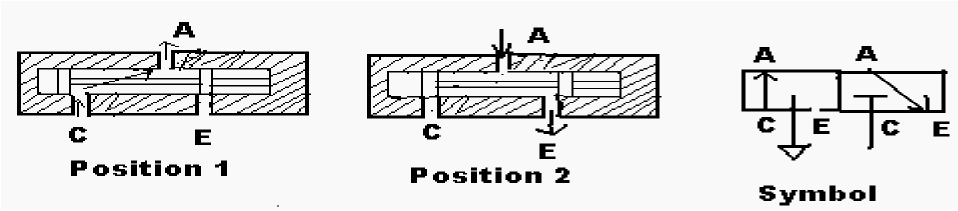


Fig 2.16 3/2 DCV

It alternatively pressurises and exhausts one working port.

In spool position 1, flow is permitted from C port to A port. E port is blocked by the spool land. In spool position 2, flow is returned from A port to E port. C port is blocked by the spool land. The valve is actuated manually, mechanically or electrically.

APPLICATION

This valve is used to operate single acting pneumatic cylinder as shown in figure.

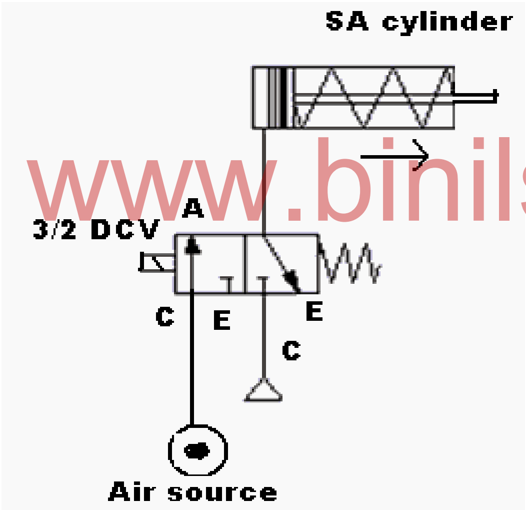


Fig.2.17 Single acting cylinder

Spool position 1

Compressed air flows through C-A ports as indicated by straight arrow line in the left square of the symbol. It enters the cylinder and forces the piston forward (extension). The movement of piston is transmitted further for doing the required work.

Spool position 2

At the end of the forward stroke, spring expands and moves the piston backward (retraction). Air from cylinder flows through A –E ports as indicated by the inclined arrow line in the right square of the symbol. From E port, air is exhausted to the atmosphere.

2.7.5 4/3 DIRECTIONAL COTROL VALVE

Four way- three position DCV is a sliding spool type valve. The spool moves back and forth in the machined bore of the valve body to control the flow. It has the following four ports.

C – Compressor port connected to pressure line

E – Exhaust port vented to atmosphere

A and B – Working port connected by line to cylinder or pneumatic motor.

The symbol of valve is shown in Fig 2.18.

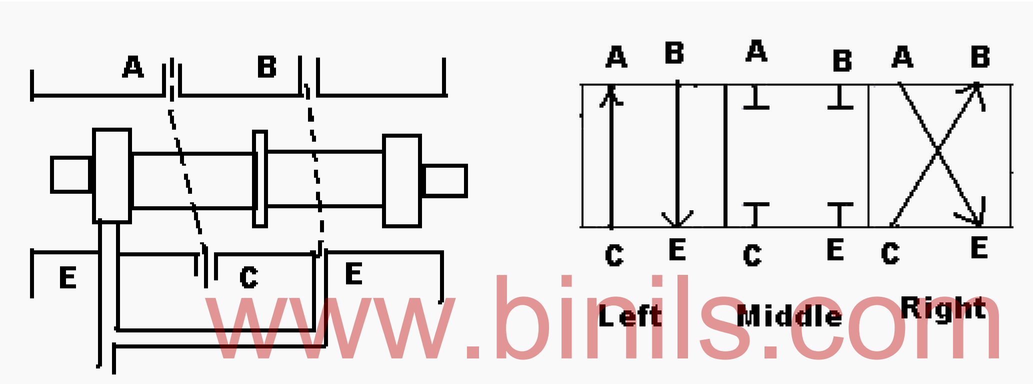


Fig 2.18 4/3 DCV

It alternatively pressurises and exhausts two working ports.

In the left position of spool, flow is permitted from C port to A port. At the same time, return flow is permitted from B port to E port.

In the right position of spool, flow is permitted from C port to B port. At the same time, return flow is permitted from A port to E port.

The valve is actuated manually, mechanically or electrically.

In the middle position of spool, all the ports are blocked by the lands of the spool. No flow is permitted through the valve. This position is used when it is necessary to stop or hold the cylinder at some intermediate point.

APPLICATION

This valve is used to operate double acting pneumatic cylinder or pneumatic motor as shown in Fig 2.19.

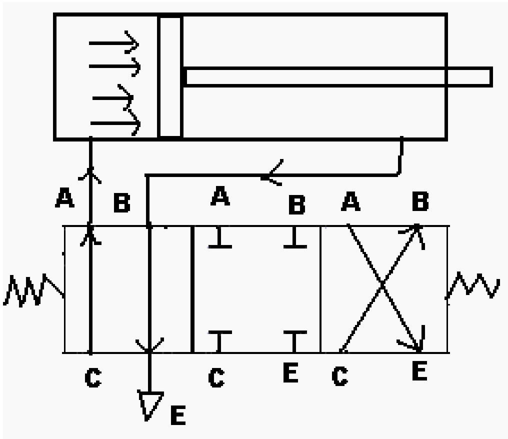


Fig.2.19 4/3 DCV operating a DAC

2.7.6 5/2 DIRECTIONAL CONTROL VALVE

Five way-two position DCV is a sliding spool type valve. The spool moves back and forth in the machined bore of the valve body to control the flow. It has the following five ports.

P (C)– Compressor port connected to pressure line

R (E)– Exhaust port vented to atmosphere

S (E)– Another exhaust port vented to atmosphere.

A and B – Working port connected by line to cylinder or pneumatic motor.

The diagram and the symbol of the 5/2 direction control valve is shown in the Fig 2.20.

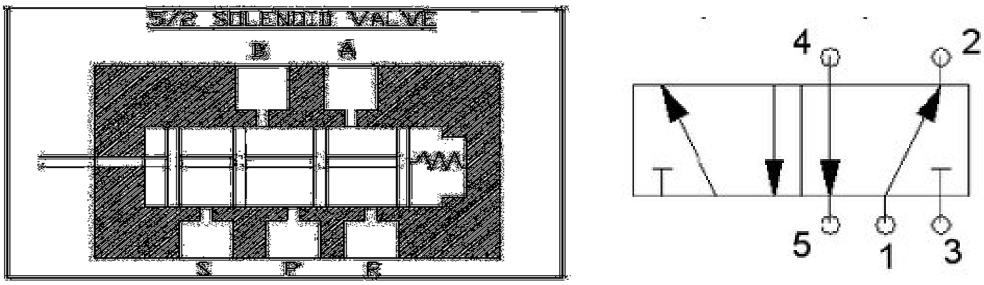


Fig 2.20 5/2 DCV

It alternatively pressurises and exhausts two working ports. It provides the same basic control of flow paths as a four port type.

In spool position 1, flow is permitted from P port to A port. At the same time, return flow is permitted from B port to R port. Another exhaust port which is Port S is blocked by the spool land.

In spool position 2, flow is permitted from P port to B port. At the same time, return flow is permitted from A port to S port which is another exhaust port. Port R is blocked by the spool land. The valve is actuated manually, mechanically or electrically.

APPLICATION

This valve is used to operate double acting pneumatic cylinder or pneumatic motor.

2.8 POPPET VALVE

The directional control valves so far studied are all of the type that uses a sliding piston or spool. Other designs use flat plates and poppets but the functions are the same although they may not be as robust and are more suited to pneumatics. Poppets make take the form of a ball, a disc or a cone. This valve is normally in closed condition. They are used in conjunction with valve seats to control the air flow.

When the pushbutton is depressed, the ball is pushed out of its seat and flow occurs as a result of port 1 being connected to port 2.When the button is released, the spring forces the ball back up against its seat and so closes off the flow.

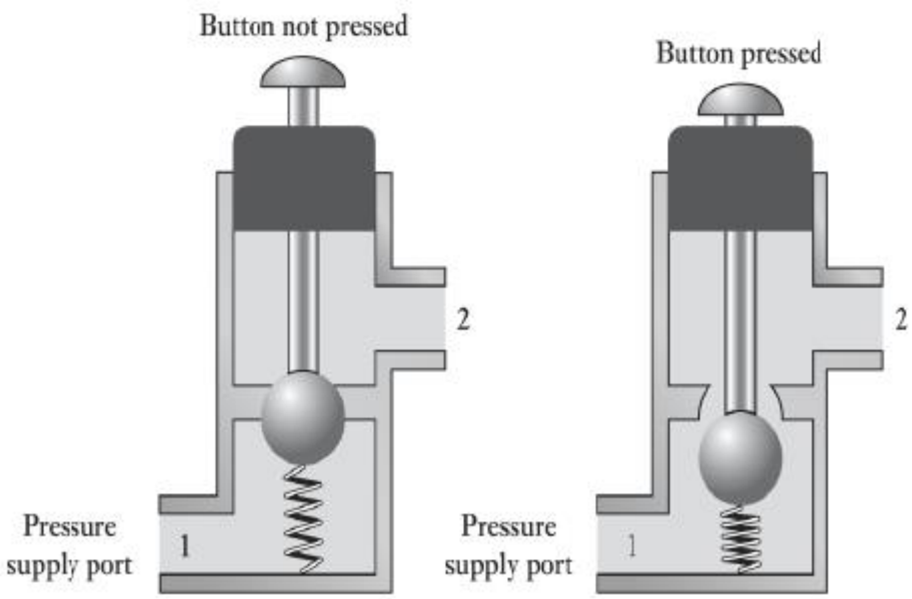
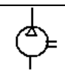
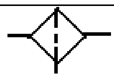
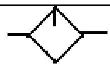
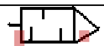
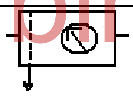
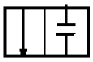
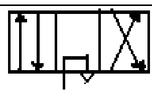
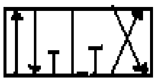
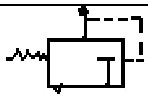
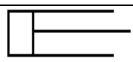
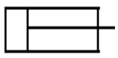
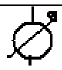
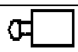
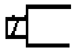
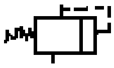
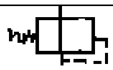
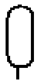
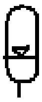
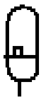


Fig 2.21 Poppet valve

2.9 VALVE SYMBOLS:

Pneumatic and hydraulic systems are having many components. Bureau of Indian standards (BIS) follow the symbols adopted for various pneumatic and hydraulic components by International standard Organization (ISO). Some of these symbols are tabulated below.

S.No	Components	Symbol
1.	Compressor	
2.	Pneumatic motor	
3.	Pressure Source	
4.	Air reservoir	
5.	Filter	
6.	Lubricator	
7.	Silencer	
8.	FRL Unit	
9.	3/2 DCV	
10.	4/3 DCV	
11.	5/2 DCV	
12.	Regulator	
13	Single acting cylinder	
14.	Double acting cylinder	
15.	Fluid motor	
16.	Push button	

17.	Solenoid	
18.	Pressure relief valve	
19.	Pressure reducing valve	
20.	Accumulator	
21.	Spring loaded accumulator	
22.	Gas charged accumulator	
23.	Weighted accumulator	
24.	Pressure gauge	

2.10 PNEUMATIC CIRCUITS:

They are similar to hydraulic circuits. The only difference is that in a pneumatic circuit, no return line is used because of release of return air directly into the atmosphere. This is indicated by a small triangle leading from the exhaust port of DCV. As centralised compressor supplies pressurised air for various pneumatic circuits, no input device is shown separately for each circuit. The input device is indicated by a small circle with dot at centre. It directly feeds pressurised air into FRL unit.

2.10.1Pneumatic circuit for the direct control of a Single Acting Cylinder:

In a single acting cylinder, air pressure is applied to one side of the piston only. A built in spring is used to provide the opposition to the movement of the piston.

A pneumatic circuit for the direct control of a single acting cylinder is shown in figure

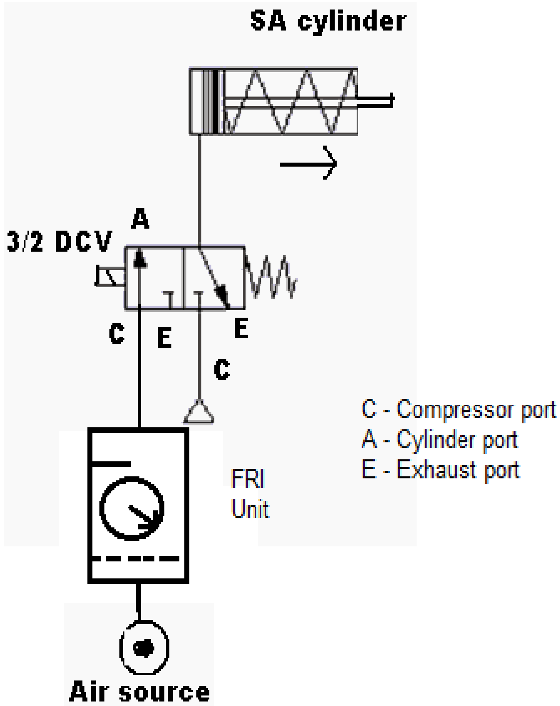


Fig 2.22 Control of Single Acting cylinder

Air source - Supplies pressurised air

1. FRL - Purifies the air, regulates air pressure and mixes lubricant oil with air.
2. 3/2 DCV - Controls the direction of flow of air to SA cylinder.
3. SA cylinder – Produces piston movement by using pressurised air.

WORKING:

When DCV is actuated by passing the current through solenoid, air flow path will be in the direction as indicated by the straight arrow line. i.e., air flows through C.A ports and enters the piston side of the cylinder. It moves the piston forward by compressing the spring. This motion is transmitted further for doing the required work.

When DCV is not actuated by stopping the current through solenoid, piston is moved back by the spring tension. Return air from cylinder will flow through the DCV in the direction as indicated by the inclined arrow line. i.e., return air flows through A port to E port and is directly exhausted into the atmosphere.

2.10.2Pneumatic circuit for the direct control of a Double Acting Cylinder:

In a double acting cylinder, no return spring is used. Air pressure is applied to each side of the piston. The pressure difference between the two sides results in the movement of the piston.

A pneumatic circuit for the direct control of a double acting cylinder is shown in fig.

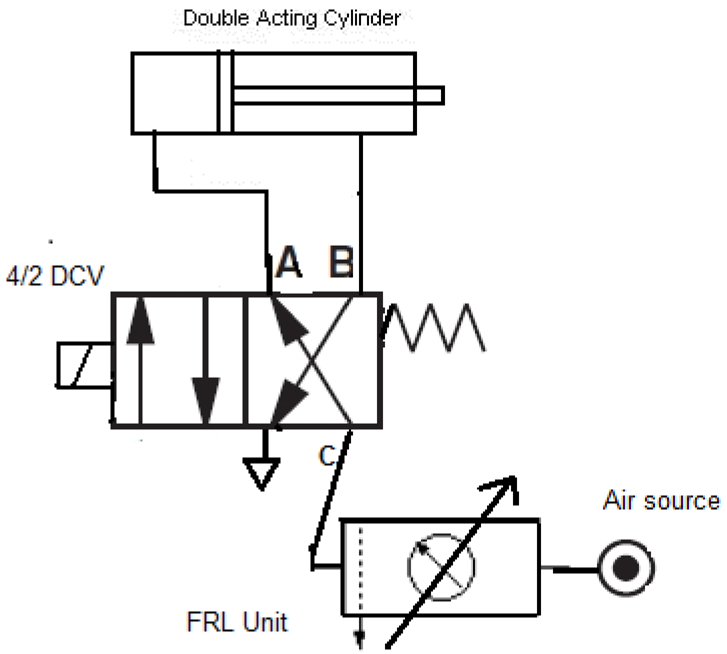


Fig 2..23 Control of Double acting cylinder

This circuit consists of the following parts.

1. Air source - Supplies pressurised air
2. FRL - Purifies the air, regulates air pressure and mixes lubricant oil with air.
3. 4/2 DCV - Controls the direction of flow of air to DA cylinder.
4. DA cylinder – Produces piston movement by using pressurised air.

WORKING:

When DCV is actuated by passing the current through solenoid, air flow path will be in the direction as indicated by the straight arrow lines in the left square. i.e., air flows through C-A ports and enters the piston side of the cylinder. It moves the piston forward. This motion is transmitted further for doing the required work. At the same time, return air from the rod side of cylinder (entered in the previous cycle) flows through B-E ports and is directly exhausted into the atmosphere. E is the exhaust port.

When DCV is not actuated by stopping the current through solenoid, air flow path will be in the direction as indicated by the crossed arrow in the right square. i.e., air flows through C-B ports and enters the rod side of the cylinder. It moves the piston backward. At the same time, return air from the piston side of cylinder flows through A-E ports and is directly exhausted into the atmosphere.

APPLICATION:

It is used in the shifting of simple jigs, clamps, etc.

2.12 COMPARISON BETWEEN HYDRAULIC AND PNEUMATIC SYSTEMS

Usually hydraulic and pneumatic systems and equipments do not compete. They are so dissimilar that there are few problems in selecting any of them that cannot be readily resolved. Certainly, availability is one of the important factors of selection but this may be outweighed by other factors.

Table shows the comparison of hydraulic and pneumatic systems.

Comparison between a hydraulic and a pneumatic system

S.No	Hydraulic System	Pneumatic System
1.	It employs a pressurized liquid as a fluid	It employs a compressed gas, usually air, as a fluid
2.	An oil hydraulic system operates at pressures up to 700 bar	A pneumatic system usually operates at 5–10 bar
3	Generally designed as closed system	Usually designed as open system
4	The system slows down when leakage occurs.	Leakage does not affect the system much
5	Valve operations are difficult	Valve operations are easy
6	Heavier in weight	Lighter in weight
7	Pumps are used to provide pressurized liquids	Compressors are used to provide compressed gases.
8	The system is unsafe to fire hazards	The system is free from fire hazards.
9	As oil is incompressible, speed control is accurate.	As air is compressible, speed control is not accurate.
10	Automatic lubrication is provided	Special arrangements for lubrication are needed.
11	Suitable for heavy load	Suitable for medium load
12	High cost	Low cost

REVIEW QUESTIONS

	UNIT II PNEUMATICS AND HYDRAULICS SYSTEMS
	PART A-Two marks questions
1.	What is pneumatics?
2.	What is hydraulics?
3.	What are the types of pressure control valves?
4.	What is a pressure control valve?
5.	What is a directional control valve?
6.	What is a hydraulic accumulator?
7.	What is air preparation?
8.	What are the types of DCVs?
9.	What are the advantages of hydraulics?
10.	What are the advantages of pneumatics?
11.	What is FRL unit?
12.	Draw the symbol of (4/2, 4/3, 5/2) DCV.
13.	What is a double acting cylinder?
14.	List the applications of systems using pneumatic power .
15.	List the applications of systems using hydraulic power .
	PART B-Three marks questions
16.	Write short notes on the types of hydraulic accumulators/
17.	Differentiate between hydraulics and pneumatics?
18.	Discuss in brief the elements of pneumatic system.
19.	How is the single acting cylinder controlled?
20.	Write short notes on the types DCVs.

	PART C-Ten marks questions
21.	Explain the elements of a hydraulic system with a block diagram.
22.	Explain the construction and working of a pressure relief valve
23.	Explain the construction and working of a DCV.
24.	Explain the construction and working of FRL unit.
25.	Explain the construction and working of hydraulic accumulators?
26.	Explain the control of a double acting cylinder.
27.	Explain the construction and working of a pressure reducing valve.

UNIT III PROGRAMMABLE LOGIC CONTROLLER

3.1DEFINITION:

A programmable logic controller (PLC) can be defined as a digital electronic device that uses a programmable memory to store the instructions and to implement functions such as logic, sequencing timing, counting and arithmetic, in order to control the machine and the process.

3.2 Conventional Hard wired Logic:

- Relays have to be hardwired to perform a specific function. So modification is difficult
- Power consumption is high
- Non-reliable one
- Speed of operation is low
- Installation is difficult

3.3 RELAYS:

A relay is an electrically operated device. The relay is an important part of many control systems because it is useful for remote control and for controlling high voltage and current devices with a low voltage and current control signal relays and may have NO contacts or NC contacts or combinations of both. The various types of relays are explained below.

a) Electromechanical relay:

Electromechanical relay is a magnetic switch. It turns the load circuit ON or OFF by energizing an electromagnet, which opens or closes the contacts in the circuit. This relay can be used to control a high voltage load circuit with a low voltage control circuit. The construction of the relay is as shown in the figure

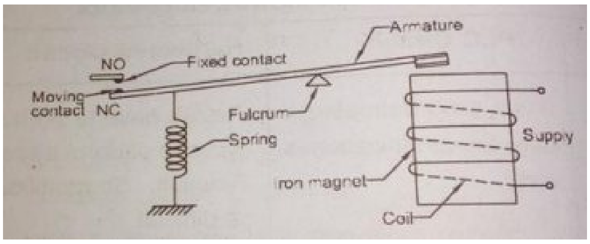


Fig 3.1 Electromechanical relay

Coils are wound on separate bobbins made of plastic or bakelite with suitable enameled copper wire. Then it is impregnated in varnish to protect from room moisture. The lead wire terminal is soldered to terminal tags.

When current flows through the coil, a magnetic field is developed that attracts the iron arm of the armature to the iron magnet set up. As a result, the contacts on the armature and relay frame are switched. i.e. the NC contacts are opened and NO contacts are closed.

b) Solid state relays:

The solid state relays do not have actual coils and contacts. Instead they are semiconductor switching devices such as bipolar transistors, MOSFETs, SCRs or TRIACS. The solid state relay has no moving parts, it is resistant to shock and vibration and it is sealed against dirt and moisture.

The block diagram and symbol of optically coupled solid state relay are shown in below figure. A LED incorporated in the input circuit glows when proper DC signal is applied to its input. The LED shines on the phototransistor, which then conducts, causing the trigger current to be applied to the Triac. It will actuate the load connected at the output terminals.

The output is isolated from the input by the simple LED and phototransistor arrangement. In this circuit a light beam is used as the control medium, so voltage spikes or electrical noise could not be produced. Solid state relays can be used to control AC and DC loads. It is more reliable and has a longer life compared to electromagnetic relays.

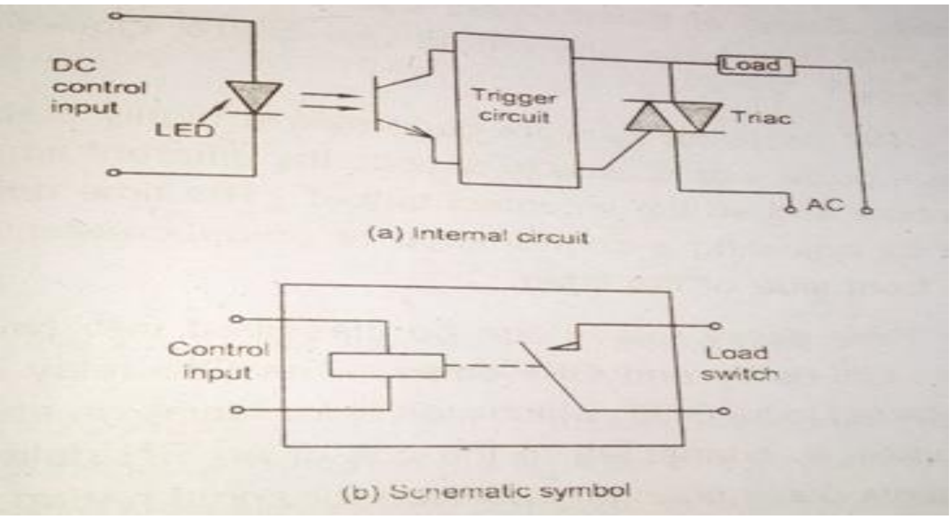


Fig 3.2 Solid state relay

c) Timing relays:

Timing relays are conventional relays that are equipped with an additional hardware mechanism or circuitry to delay the opening or closing of load contacts. Timing relays are similar to other control relays. Some circuits require both timing contacts as well as instantaneous contacts operated by the same energized relay coil. The instantaneous contacts operate when the coil is energized or de-energized, independent of the timing mechanism. The timing contacts can be arranged to delay after energizing or de-energizing the coil. Some of these timers use a RC circuit to obtain the time base and others use quartz clocks as the time base.

RC oscillator network generates a highly stable and accurate pulse that is used to provide the different time delay increments and switch a contact output. The time delay can be set by adjusting a control knob or potentiometer located on the front side of the timer.

Time delay relays can be classified into two basic groups: On-delay and OFF delay. The ON-delay relay is often referred to as DOE, which stands for “delay on energize”. When power is connected to the coil of an ON delay timer, the contacts delay changing position for some period of time. The OFF-delay relay is often referred to as DODE which stands for ‘delay on deenergize’. The operation of the OFF-delay timer is the opposite to the coil of the ON-delay timer. When voltage is applied to the coil of the OFF-delay timer, the contacts will change position immediately and the contacts change to their normal positions after a time delay.

d) Latched relay:

Electromechanical latching relays are designed to hold the relay closed after power has been removed from the coil. Latching relays are used where it is necessary for contacts to stay open and/or closed even though the coil is energized only momentarily.

The mechanically held latching relay uses two types of coils. The latch coil momentarily energized to set the latch and hold the relay in the latched position. The unlatch or release coil is momentarily energized to disengage the mechanical

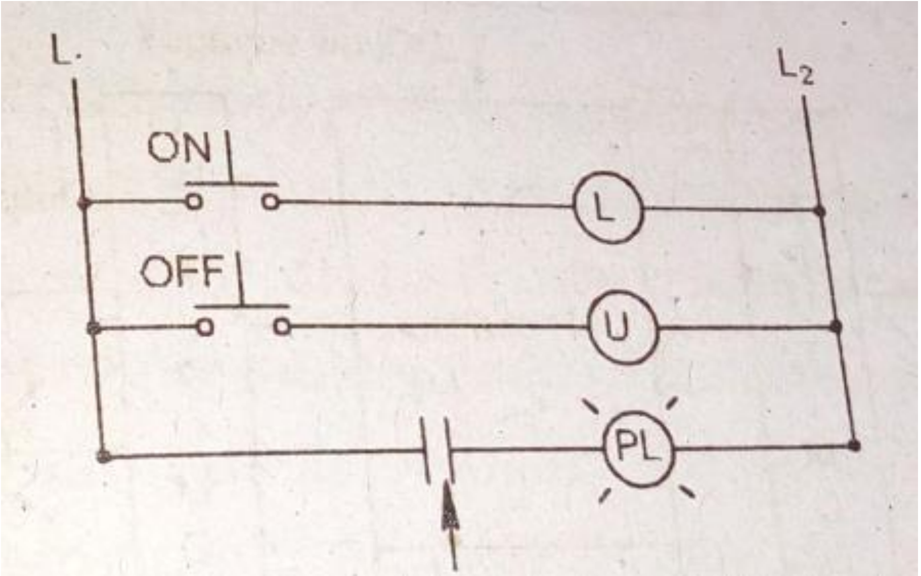


Fig 3.3 Latching Relays

latch and return the relay to the unlatched position. The schematic diagram for an electromagnetic latching type relay circuit is shown in the figure. The contact is shown with the relay in the unlatched position. In this state the circuit to the pilot light is open, so the light is OFF.

When the ON button is momentarily actuated, the latch coil is energized to set the relay to its latched position. The contacts close, completing the circuit to the pilot light, so the light is switched ON. Note that the relay coil does not have to be continuously energized to hold the contacts closed and keep the light ON. The only way to switch the lamp OFF is to actuate the OFF button, which will energize the unlatch coil and return the contacts to their open, unlatched state. In case of power loss the relay will remain in its original latched or unlatched state till the power is restored. This arrangement is often referred to as a memory relay.

3.4 FEATURES OF PLC:

1. The input and output status are individually indicated.
2. Separate display comments are available.
3. It provides isolation between input and output.
4. Output by zero cross type solid state relays.
5. Compact size
6. Economical cost
7. Easily mountable
8. Choice of operating voltages

9. Multi digit alpha numeric displays
10. High speed counter outputs.
11. Powerful instruction set
12. Relay outputs
13. More flexibility.
14. Separate in built supply for sensing the switch contacts for the inputs
15. It is used for wide variety of functions
16. It consists of a large number of timers, counters, contacts, auxiliary relays
17. Programmed using ladder diagrams or computer based software.

3.5 ADVANTAGES OF PLC:

1. The wiring is reduced by 80% compared to a conventional relay control system.
2. The power consumption is reduced.
3. Self diagnostics functions for easy and fast troubleshooting.
4. A single panel can be used in multiple applications merely changing the program.
5. Spare parts are reduced.
6. Speed of operation is in milliseconds range.
7. Cost is less as there are many I/O devices and complex control functions.
8. Very reliable operation.
9. Printout of the PLC program for the purpose of documentation.
10. PLC can be connected easily to external devices such as instruments, controllers or automation equipment.

3.6 BLOCK DIAGRAM OF PLC:

PLC is a solid state system, with a programmable memory for storing instructions and implements specific functions such as logic, sequencing, timing, counting and arithmetic to control machines and processes.

The block diagram of a typical PLC is shown in the figure. It consists of five parts, namely processor unit, memory, power supply, input/output section (interface) and the programming device. Some manufactures refer to the processor as a CPU or a central processing unit.

i) Power supply:

The power supply is required to convert 230V AC voltage to low voltage DC desired for the logic circuits of the processor and the internal circuits of the input and output modules

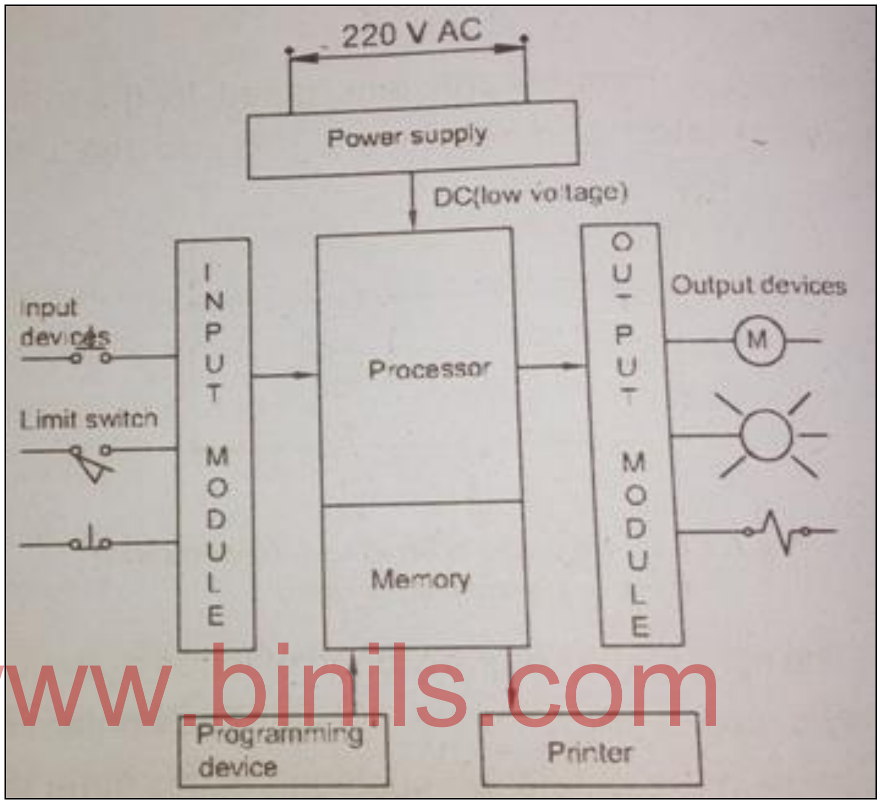


Fig 3.4 Block diagram of PLC

ii) Input/output section:

The input modules and output modules are referred to as I/O section. The real world input devices like push buttons, limit switches, analog sensors are wired to input module. The real world output devices like contractors, solenoid valves, indicator lights, positioning valves etc are wired to the output modules.

Real world input and output devices are of two types: discrete (digital) and analog. Discrete I/O devices are either ON or OFF (open or closed), while analog switches have infinite number of possible values. Examples of discrete input devices are the push button and the limit switch, while analog input devices are the temperature probes, pressure transducers etc., which give varying voltage and current.

The input from the analog input device is converted into its proportional binary by using analog to digital converter (ADC). The converted input is stored in memory of PLC or further use by the processor.

Discrete output devices like contactors, solenoid valves, indicator lamps are either energized or deenergized. The analog output devices require varying current or voltage to control the output. Example of output device is positioning valve. A Digital to Analog converter (DAC) is usually used at the output module for controlling analog output devices.

Iii) Processor:

The processor unit operates on low DC voltage of +5 volts. Input modules thus contain circuitry that converts input voltages of 120-240V AC or 0-24V DC from discrete input devices to low level DC voltage typically 0- 5V DC

Analog input module converts the 4-20mA signals from sensors to low level DC voltages for the processor unit. Similarly the output modules change low level DC signals from the processor to 120-240 AC or high level DC voltages or give output currents in range of 4-20mA.

iv) Programming device:

The programming device for a PLC can be a hand held programmer, dedicated programmer or personal computer. The program is entered using relay ladder logic, statement lists or control system flow carts. The most popular method of programming is the Relay Ladder Logic.

The hand held programmer uses either LED or LCD. The hand held programmers are small and light weight. They just look like a small calculator. Dedicated programmers use a standard video display terminal and keyboard for entering and displaying the program.

Personal computers have become the most popular programming device. A personal computer can be used to program a PLC using a special software installed on it.

3.7 Programming basics of PLC:

PLC Programming uses Ladder diagrams which are similar to drawing of switching circuits. The ladder diagram consists of two vertical lines representing the power rails. These two vertical lines are connected by means of horizontal lines and are known as rungs of the ladder.

Basic Standard symbols of Ladder Diagram:

<u>(1) Normally Open (NO) Contact:</u>

A Normally Open contact acts as a switch that passes the power flow when the reference is ON.

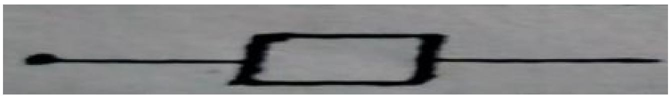
<u>(2) Normally Closed (NC) Contact:</u>

A Normally Closed contact acts as a switch that passes the power flow when the reference is OFF

<u>(3) Coil:</u>

A coil sets the reference ON when it receives the power flow.

<u>(4) Special Instructions:</u>



The special instructions are timer instruction, Counter instruction, arithmetic instruction, PID instruction etc..,

The ladder diagram language is basically a symbolic set of instructions used to create the controller program. Representations of contacts and coils are the basic symbols of the logic ladder diagram instruction set. In a rung, inputs must always precede the outputs. And each rung must start with an input or a series of inputs or a parallel of inputs and each with an output. The Inputs and Outputs are addressed and varies from manufacturer to manufacturer.

For eg GE FANUC Micro PLC

I/P element is addressed as I 00001, O/P element is addressed as Q00001

<u>Example of a simple Ladder Program:</u>

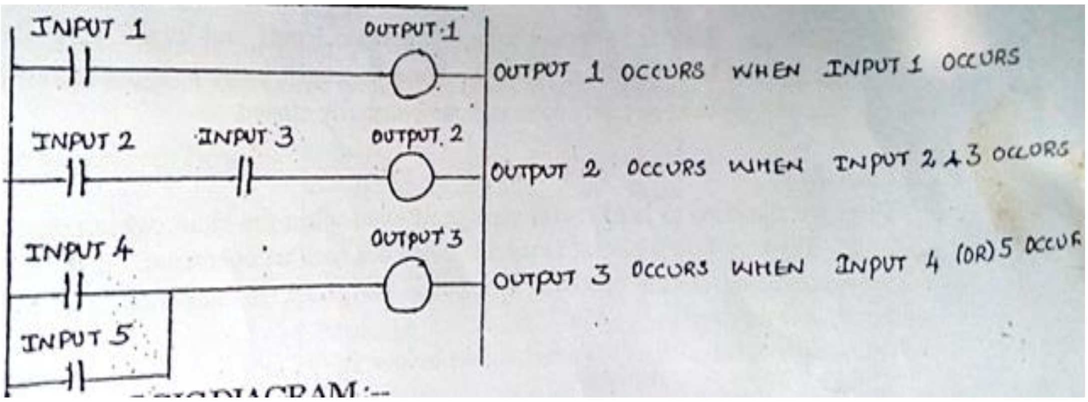
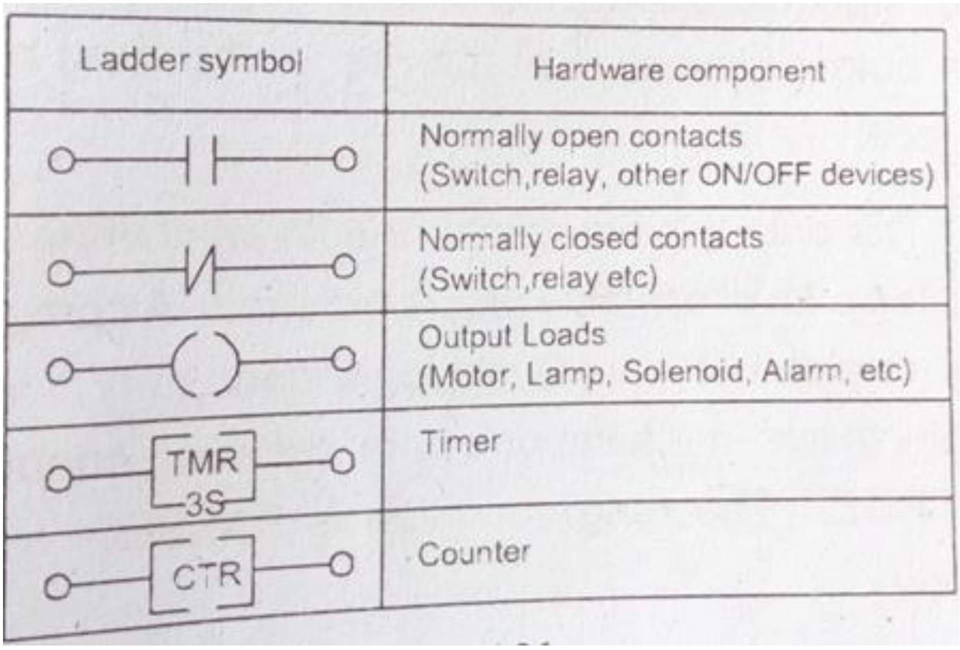


Fig 3. 5 Ladder Logic diagram

3.9 Symbols used in Ladder Logic:

Ladder diagrams are drawn using standard symbols that represent relay coils, contacts, counters, timers, switches, etc. some of the basic symbols used are shown in Fig 3.6 and Fig 3.7.



Ladder symbol	Hardware component
	Normally open contacts (Switch,relay, other ON/OFF devices)
	Normally closed contacts (Switch,relay etc)
	Output Loads (Motor, Lamp, Solenoid, Alarm, etc)
TMR 3S	Timer
CTR	Counter

Fig 3.6 Symbols of ladder logic diagram - I

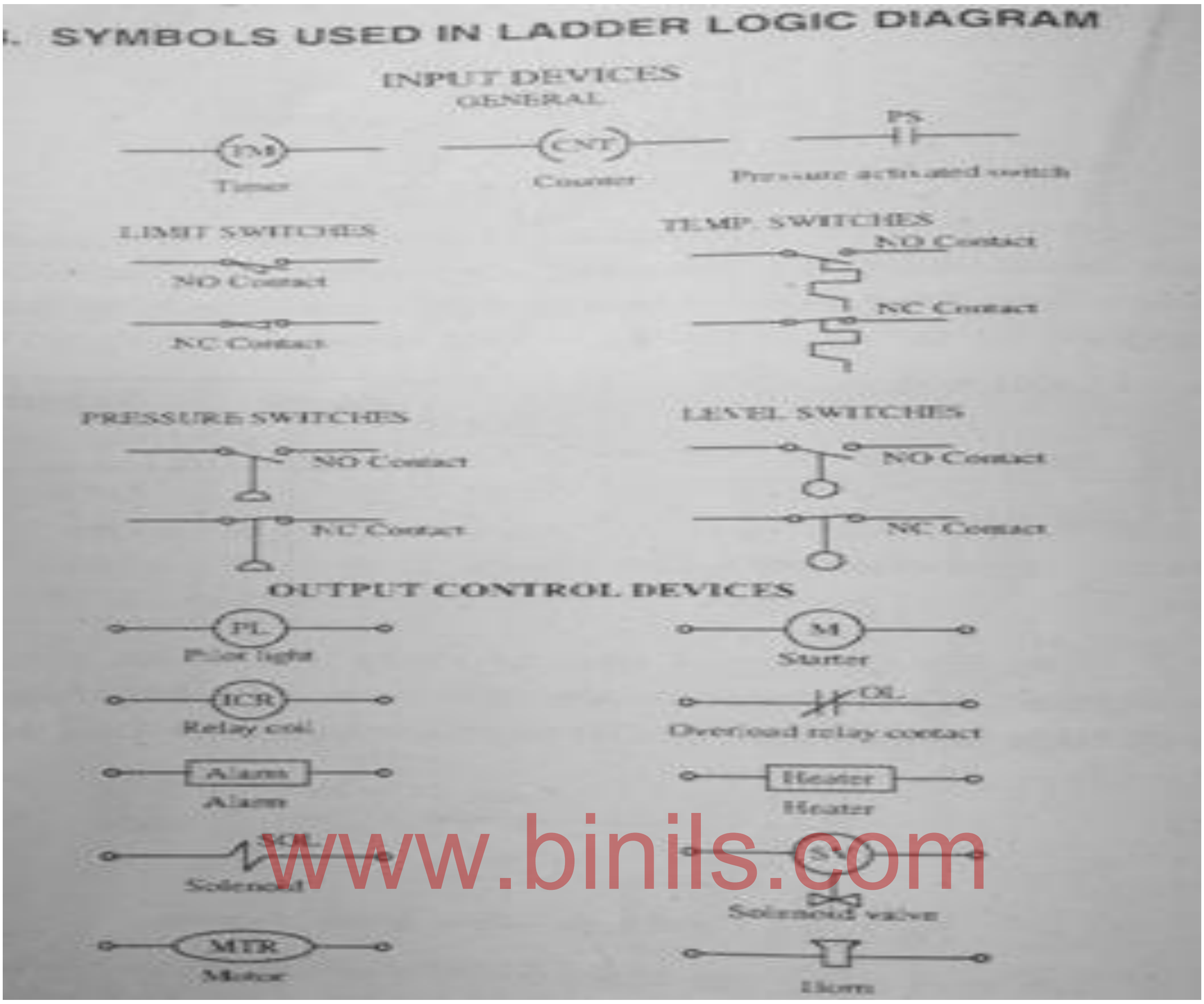
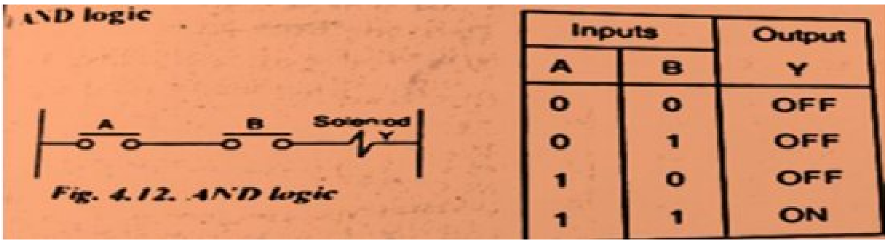


Fig 3.7 Symbols of ladder logic diagram- II

Using the above symbols, relay ladder diagram can be drawn from which logical ladder diagrams are derived.

3.10 LOGIC FUNCTIONS

The logic functions can be obtained by connecting switches in different manners. The ladder diagrams for different logic functions are shown below



Inputs		Output
A	B	Y
0	0	OFF
0	1	OFF
1	0	OFF
1	1	ON

Fig 3.8 AND logic

In AND logic two or more switches are connected in a serial manner. The switch assembly is used to control (ON or OFF) the load. The structure and truth table of two input AND logic are shown in the Fig 3.8.

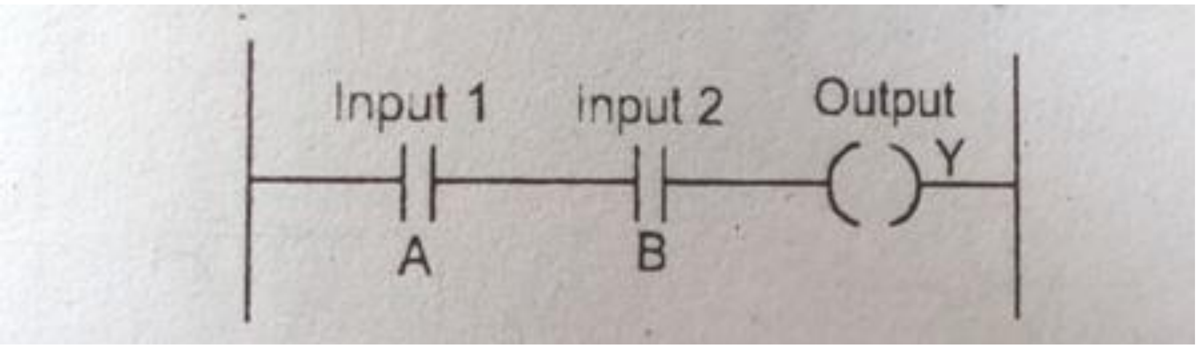


Fig 3.9 Ladder logic diagram of AND logic

In this logic, the load (solenoid) is ON only when both switches are in ON (close) level. Conversely the load is OFF, when minimum any one of the switch is in OFF (open) level. The relay ladder diagram of two input AND logic is as shown in Fig 3.9.

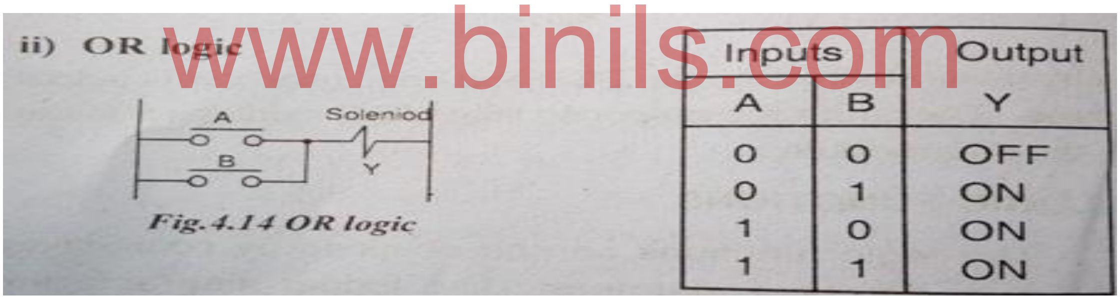


Fig 3.10 OR logic

In OR logic, two or more switches are connected in parallel manner. The switch assembly is used to control (ON or OFF) the load. The structure and truth table of two input OR logic are shown in Fig 3.10.

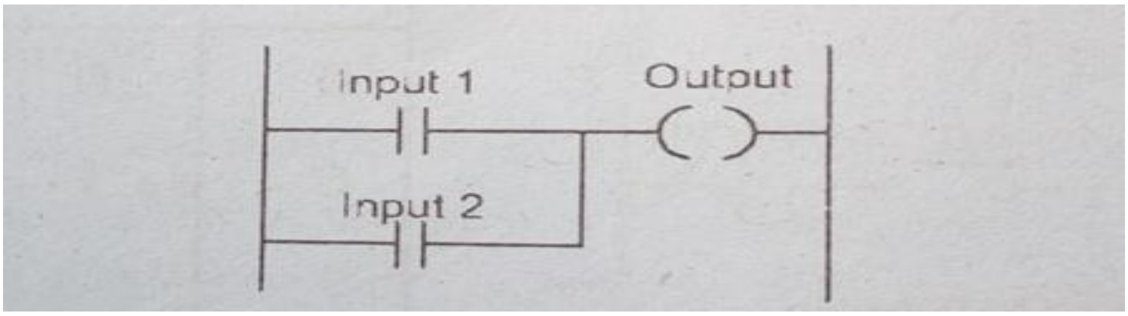
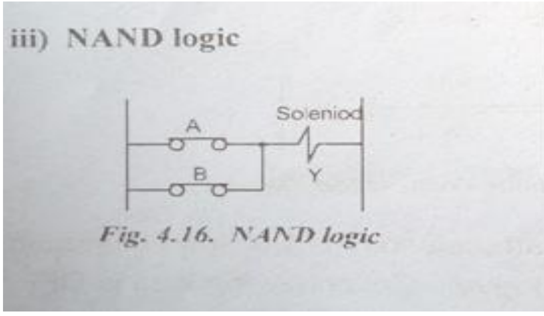


Fig 3.11 Ladder logic diagram of OR logic

In this logic ,the load is ON when minimum any one of the switches is in ON (close) level. Conversely the load is OFF when both switches are in OFF (open) level. The relay ladder diagram of two inputs OR logic shown in Fig 3.11.



Inputs		Output
A	B	Y
0	0	ON
0	1	ON
1	0	ON
1	1	OFF

Fig 3.12 NAND logic

In NAND logic two or more switches are connected in parallel manner. These switches are normally in ON (close) level. The structure and truth table of two input NAND logic are shown in Fig 3.12.

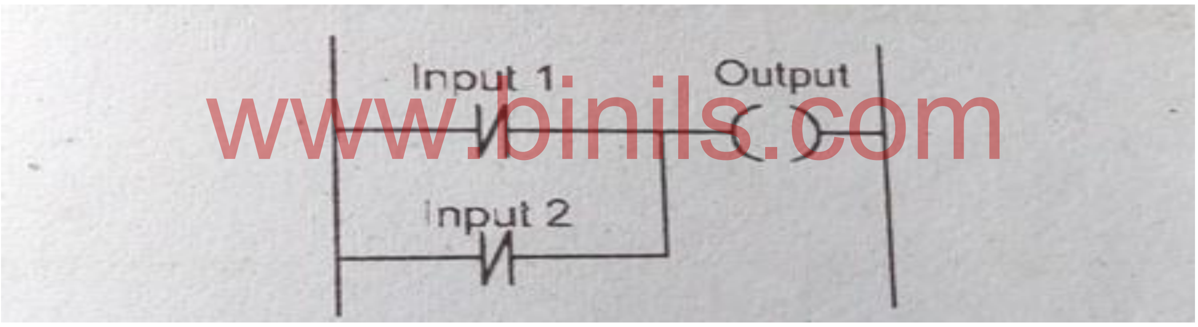
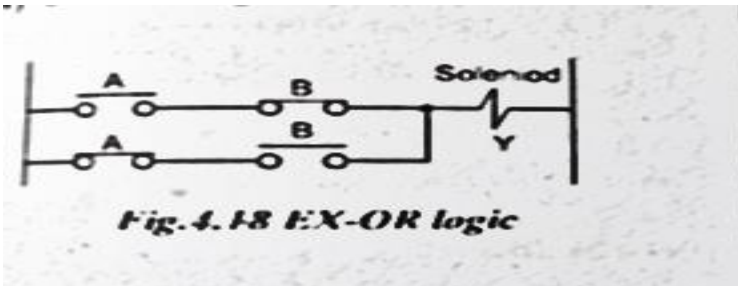


Fig 3.13   Ladder logic diagram of NAND logic

In this logic, the load is ON when minimum any one of the switch inputs is in low level. Conversely the load is OFF, when both input switches are in high level. The relay ladder diagram for two input NAND logic is shown in the Fig 3.13.



Inputs		Output
A	B	Y
0	0	OFF
0	1	ON
1	0	ON
1	1	OFF

.

Fig 3.14 EX-OR Logic

In Ex-OR logic, two inputs are connected as shown . The structure and truth table of two input Ex-OR logic are shown in the Fig 3.14.

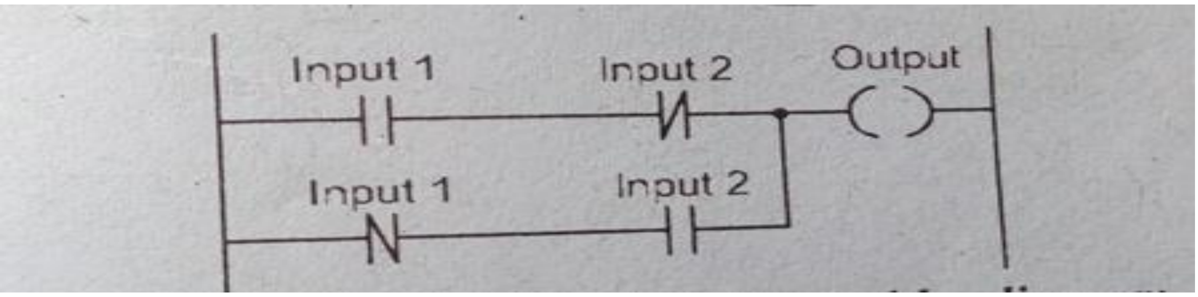


Fig 3.15 Ladder logic diagram of EX-OR logic

In this logic, the load is OFF when both inputs are either in low level. Conversely the load is ON when both inputs are in different levels (ie., one is low level and other is in high level). The relay ladder diagram of two inputs Ex-OR gate is shown in the Fig 3.15.

3.12 TIMERS:

A timer circuit is specified by stating the time interval to be set and the conditions or events that are to start and/or stop the timer. These are commonly referred as relays with coils and result in closing or opening of the input contacts after some preset time. The timer circuits are classified as follows.

i) Delay ON timer
ii) Cascaded Timer
iii) ON/OFF Cyclic timer
iv) Delay OFF Timer

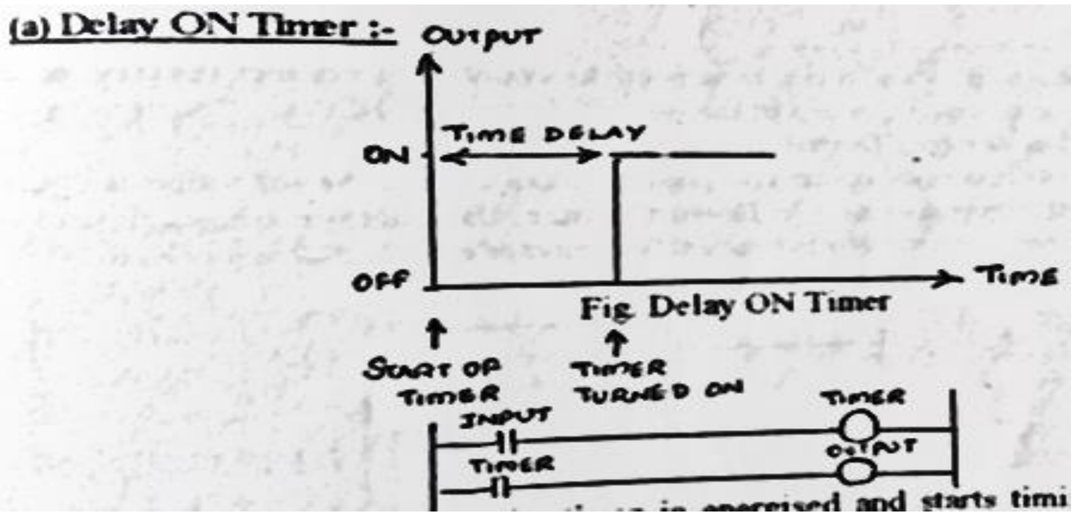


Fig 3.16 ON Delay Timer

When there is an input, the timer is energized and starts timing. After some preset time the contacts associated with the timer close and the output occurs.

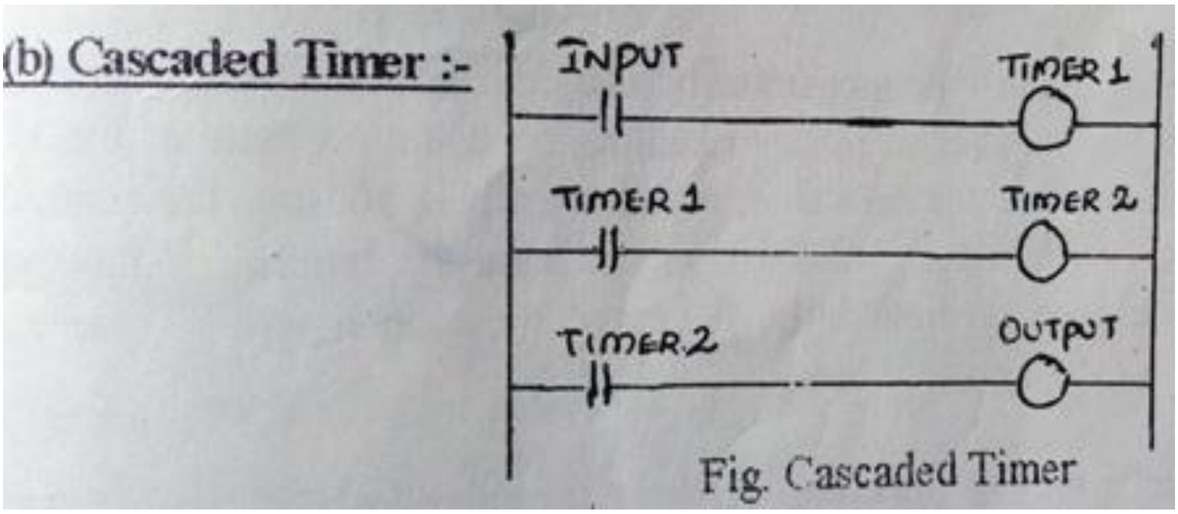


Fig 3.17 Cascaded Timer

Timers can be linked together to get a cascaded timer. So, larger delay time is possible with just one timer. When the input contacts close, Timer1 is started. After, its time delay, its contacts close and Timer2 is started. After its time delay, its contacts close and there is an output.

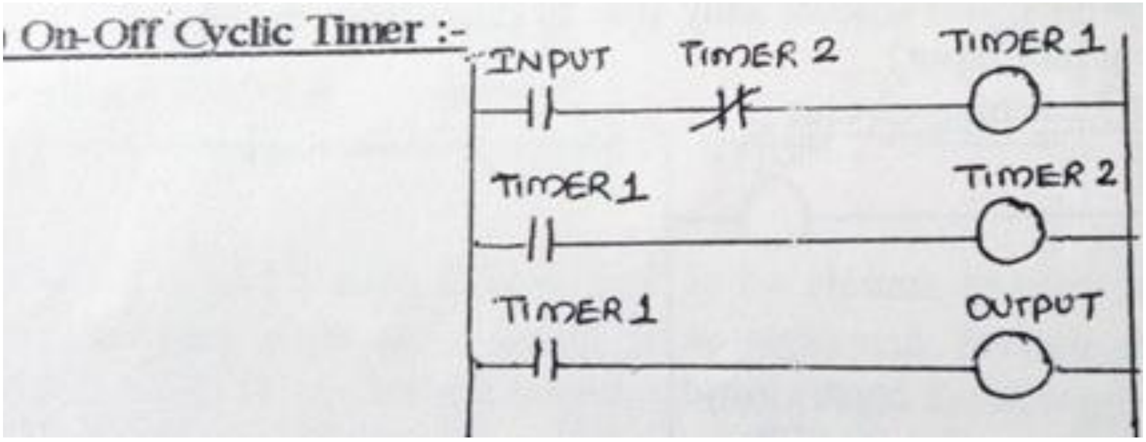


Fig 3.18 ON - OFF Cyclic timer

The above ladder diagram shows a program that can be used to cause an output to go ON for 0.5secs and then OFF for 0.5secs in a cyclic manner. When the input contacts close timer1 is started and comes ON after 0.5secs. After this time, the timer1 contacts close and start timer2. It comes ON after 0.5secs and opens its contacts. This result in switching OFF the Timer1. So the entire cycle restarts again.

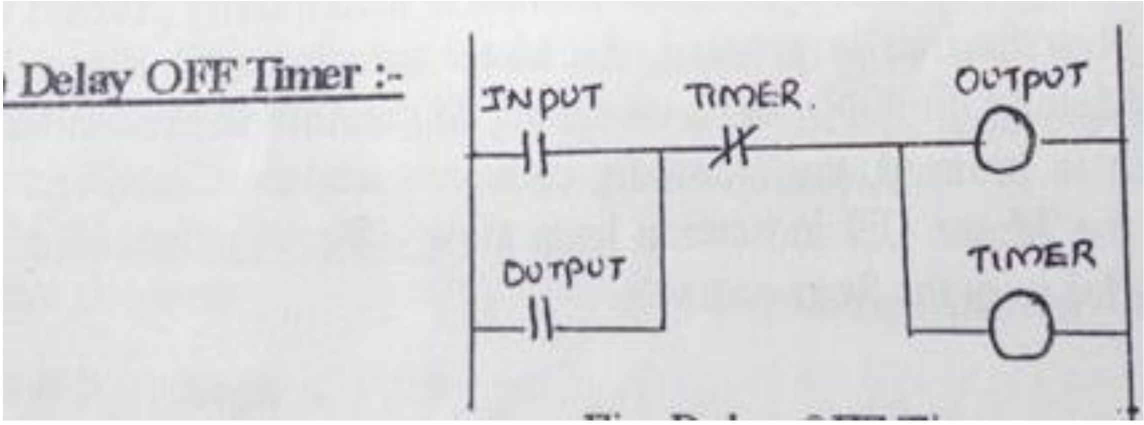


Fig 3.19 OFF Delay Timer

PLCs are generally provided with only Delay ON timers.(i.e.) a timer which comes ON after a time delay. A timer which switches off an output after a time delay is called as Delay OFF timer. When the input contacts are momentarily closed, the output is energized and the timer gets started. The output contacts latch the input and keep the output ON. After the preset time of the timer, the timer comes ON and breaks the latch circuit and switch of the output.

3.13 COUNTERS:

Counters are used when there is a need to count a specified number of contact operations. Counter circuit is one of the internal features of PLCs. Counters can be used either as a UP counter or a DOWN counter.

An Up counter counts up to the preset value. When the Set value is reached, the counters contact changes state. In Down Counter, the counter counts down from the preset value to zero, when zero is reached, the counter's contact changes state. The below figure shows a basic counting program

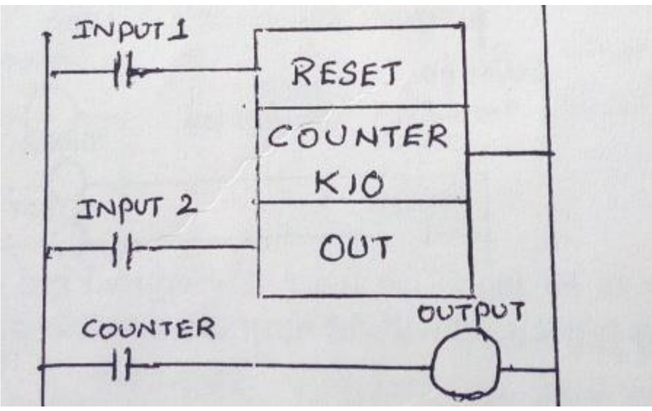


Fig 3.20 Counter

When the contact of Input1 is momentarily closed, the counter is reset. The counter will then count the number of pulses resulting from the contacts of Input2 closing and opening. When this reaches the set value, in this case it is 10, and then the counter contact closes. Thus output is switched on after 10 pulses from the input2. If the contacts of Input1 are momentarily closed any time during the count, the counter will be reset

3.14 PLC NETWORKING:

Today, automation is moving rapidly towards centralization from the central control room. It is necessary for system operators to have fingertip knowledge of the process from the central workstation. One application in which the computer is used to monitor and control a networked PLC system is shown below.

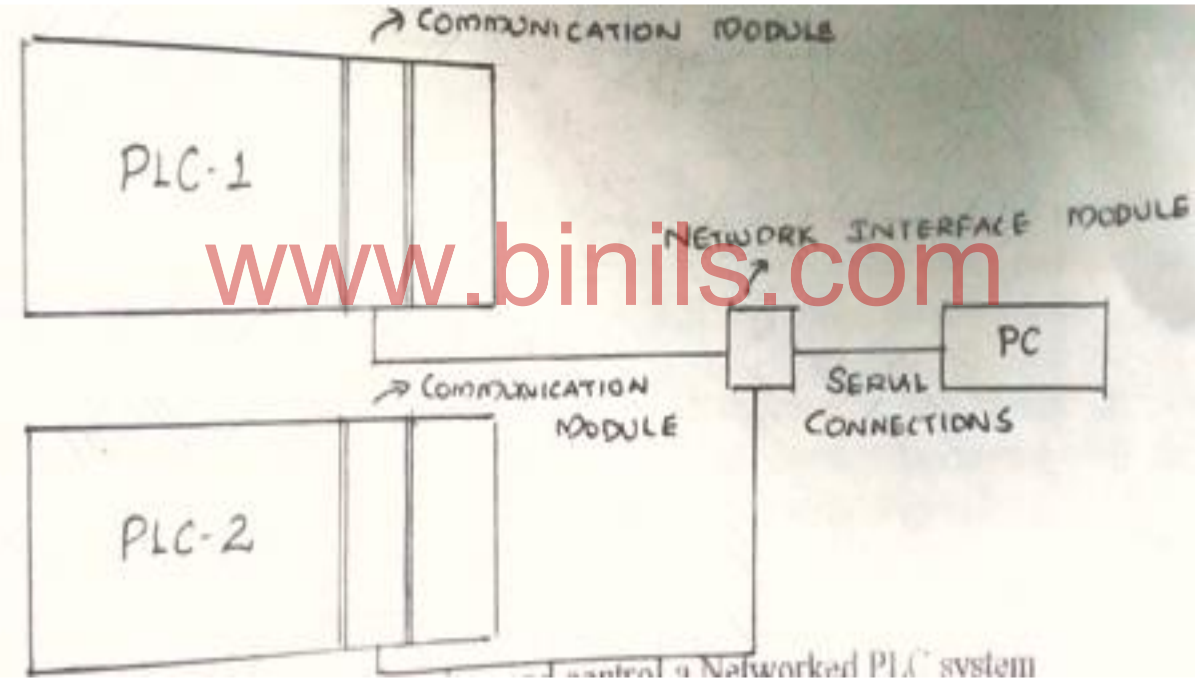


Fig 3.21 PLC NETWORK

Local Area Network (LAN) is to provide communication between the PLCs or between PLCs and Computers. In industry, the transmission medium most often used is Coaxial cable or Optical fibers because of the high noise immunity. LANs are configured in three basic topologies (Physical layout or configuration of the communication network)

- Star Network
- Bus Network

- Ring network

Protocol specifies the format and timing of message transmission between two or more communicating devices. All the devices, which are connected in the network, should have a common protocol. When the protocol is different, additional hardware and programming are required. MAP (Manufacturing Automation Protocol) is one of the common protocol, which can be accepted by most of the devices

The two basic network communication formats are:-

- Mater slave System
- Peer to Peer system

1)Master slave system:

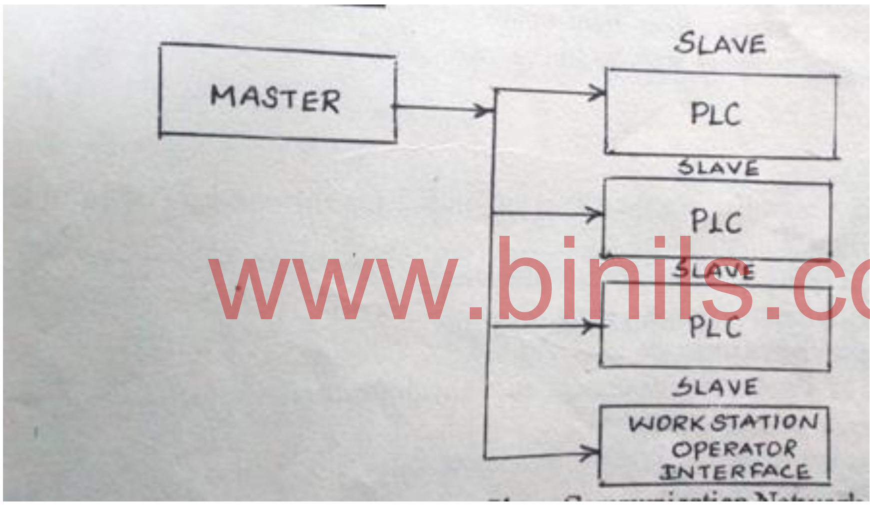


Fig 3.22 Master Slave system

A Master Slave system uses a host computer to manage all network communications between network devices. The Master network devices incorporate address to each slave devices individually. Direct communications between the slave devices are not possible. Information to be transferred between slaves must first be sent to the network master unit, which will in turn retransmit the message to the designated slave devices.

ii) Peer to peer system:-

In peer to peer system, each network device has the ability to take control of the network for the purpose of transmitting information or requesting information from other network devices. This type of communication is described as Token passing system because control of the network can be similar to the token that is passed from unit to unit.

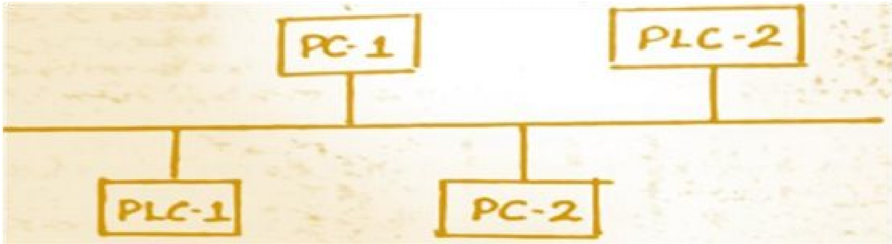


Fig 3.23 Peer to Peer system

The latest open architecture software, now allows PLCs and PCs to be integrated into fully networked systems that can be programmed under windows 95 or NT using the IEC 1131-3 programming standards.

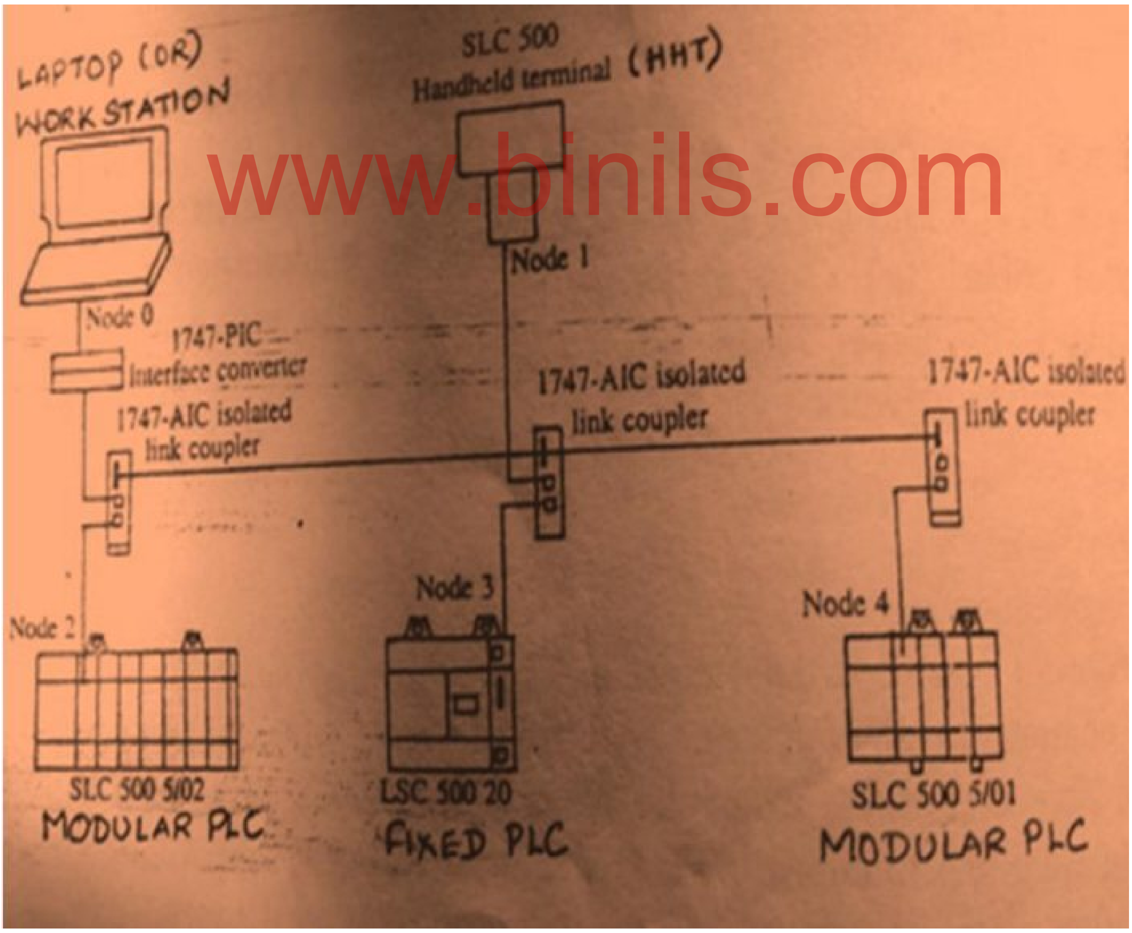


Fig 3.24 Fully Networked PLCs

The Primary objective of PLC communication is to exchange real time control data between the various PLCs and computers and/or other networks. Due to real time requirement, the suppliers maintain their own control over the access method, access mechanisms, package lengths, and network start-up and recovery mechanism.

3.15 STEPS INVOLVED IN THE DEVELOPMENT OF LADDER LOGIC PROGRAM:

Step-1 Input and Output listing:

A) Listing of inputs needed

i) START push button
ii) STOP push button
iii) Over Load Relay (OLR)

B) Listing of Output needed

i) START contactor coil (s)
ii) DELTA contactor coil (D)
iii) MAIN contactor coil (M)
iv) ON-DELAY Timer (TON)
v)

Step 2- Assignment of addresses to the I/O used

S.NO.	Component	Type	Address
i)	START push button	Input	I:0/0
ii)	STOP push button	Input	I:0/1
iii)	Over Load Relay	Input	I:0/2
iv)	STAR contactor coil	Output	O:0/1
v)	MAIN contactor coil	Output	O:0/2
vi)	DELTA contactor coil	Output	O:0/3
Vii)	ON-DELAY Timer	Timer	TON:0

3.16 PROGRAM EXECUTION AND RUN OPERATION BY PLC:

The PLC performs the following functions.

i. Store the status of inputs in controller's memory.(logic '1' for closed contact and logic '0' for open contact).

ii. Then the open and close conditions of internal contacts of ladder diagram also stored in controller's memory.

iii. When the START button is pressed, the motor contactor is energized and goes to run, because the other two contactors in the first rung (Delta O:0/2 and Timer T4:0/DN) are also placed in CLOSE positions.

iv. This condition will close the contact O:0/1 in the second rung. The two contacts of STOP (I:0/1) and OLR(I:0/2) are also in TRUE condition, so the main contactor (O:0/1) will be energized.

v. When main contactor O:0/1 is energized, it will energize the ON delay timer placed in rung3.

vi. After a particular time the timer contact placed in first rung (T4:0/DN) goes to FALSE, As soon as the supply applied to the star contactor goes to cut off and the star contactor placed in the fourth rung goes to reclosed. So the delta contactor placed in the fourth rung is energized, and also the delta contactor placed in the rung goes to FALSE.

vii. By this effect, the motor star connection is changed into delta connection and runs in full speed.

viii. When the STOP button is pressed, the contacts in second rung goes to FALSE, so the supply applied to the main contactor goes to cut off and the motor is stopped.

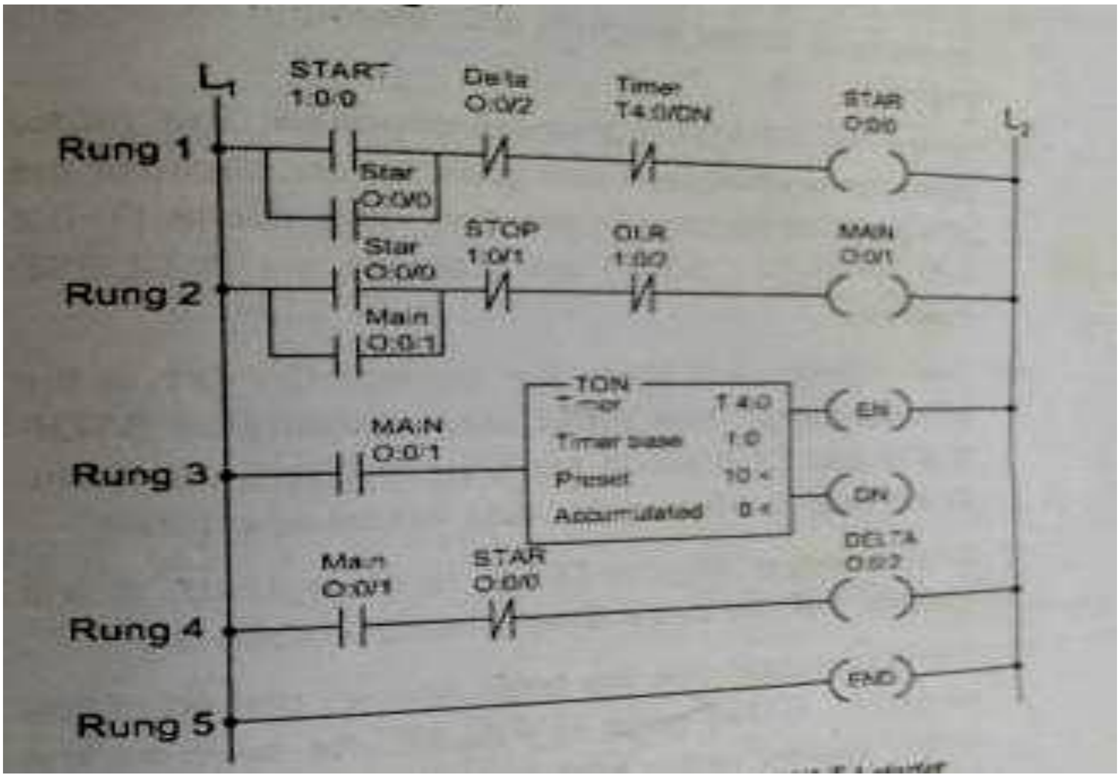


Fig 3.25 Ladder Logic diagram of the given program

3.17 Ladder logic diagram for liquid level controller

There is a water reservoir from which the water needs to be pumped out to the process tank. In the process tank there are two sensors connected around the edges of the tank according to the required heights i.e., one sensor is connected at the near bottom end of the tank called as lower level sensor and another one on the near top edge of the tank called as higher level tank. To let the water out of the tank there is a pipe connected at the bottom of the tank with a valve. This valve is to be used by user for the process application

The level sensor is a magnetic sensor and when the liquid level is above the high level sensor a HIGH (high level) signal is send to the PLC. When the liquid level goes down the low level sensor LOW (low level) signal is send to the PLC. The PLC checks the signals send by these sensors through its input port and give the proper signals through its output port as per the ladder logic program.

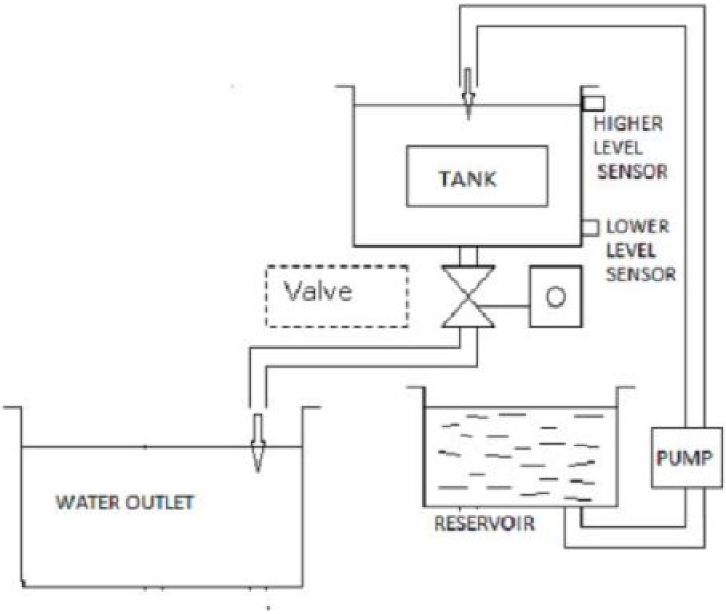


Fig 3.26 Liquid level controller

Sequence of process control actions done by the PLC:

1. When the water level in the tank is less than the lower level then the lower level sensor (LOW) senses and turns the motor of the pump ON to fill the tank.

2. Then the tank is filled up until it reaches the higher level where the higher level sensor (HIGH) senses and turns the motor of the pump OFF and filling of the water stops.

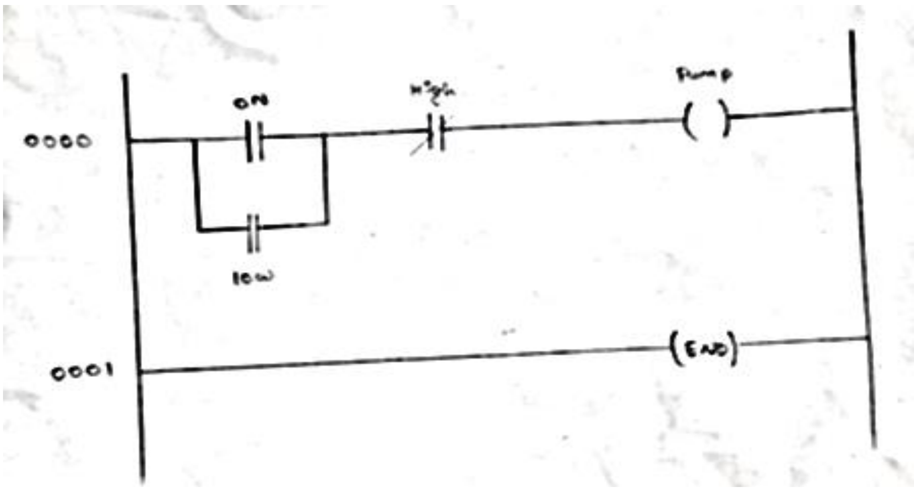


Fig 3.26 Ladder logic diagram of liquid level controller

3.18 PLC MANUFACTURERS

AMERICAN

1. Allen Bradley 2. Gould Modicon
3. Texas Instruments 4. General Electric 5. Westinghouse
6. Cutter Hammer 7. Square D

EUROPEAN

1. Siemens 2. Klockner&Mouller
3. Festo 4. Telemechanique

JAPANESE

1. Toshiba 2. Omron
3. Fanuc 4. Mitsubishi

REVIEW QUESTIONS

	UNIT III PROGRAMMABLE LOGIC CONTROLLER
	PART A -Two marks questions
1.	What is a programmable logic controller?
2.	What are the features of a PLC?
3.	What are the advantages of PLC?
4	What is ladder logic diagram?
5.	List the input or output devices of PLC.
6.	What is the function of input or output module in a P LC?
7.	What is PLC networking?
8.	List the manufacturers of PLC.
9.	What are the logic functions of PLC
10.	How is a TIMER or COUNTER instruction represented in a PLC?
	PART B-Three marks questions
11.	Write short notes on the logic functions of PLC
12.	What are the differences between hardwire relay logic and PLC?
13	Discuss the TIMER or COUNTER instructions in brief.
14	Discuss briefly the PLC networking.
	PART C -Ten marks questions
15.	Explain the PLC with a block diagram.
16.	Explain the ladder logic instructions
17.	Explain the steps for programming a PLC with ladder logic diagram.
18.	Explain the programming in ladder logic diagram for a liquid level system?

UNIT IV DISTRIBUTED CONTROL SYSTEMS

4.0 Definition

Distributed Control System is a specially designed control system used to control complex, large and geographically distributed applications in industrial processes. In this, controllers are distributed throughout the entire plant area. These distributed controllers are connected to both field devices and operating PCs through high speed communication networks Discrete Field devices such as sensors and actuators are directly connected to input and output controller modules through communication bus. These field devices or smart instruments are capable of communicating with PLCs or other controllers while interacting with real world parameters like temperature, pressure, etc.

The industrial process control using distributed processing for data and control is the characteristic of DCS. The controllers use PID control algorithms with numerous supporting regulatory algorithms for discrete and batch control applications.

DCS is a flexible and powerful integrated control system. The equipment is separated in functional areas and is installed in different work areas of a process plant. The plant operator monitors and manipulates the set points of the process parameters from the central control room. The operator views the process information transmitted from the processing area and displayed in the CRO .and also changes the control conditions from a keyboard.

The DCS typically performs the functions of data acquisition, signal conditioning, closed loop control, open loop control, alarm processing and annunciation, event recording, reporting, historical and real-time trend recording and communication with foreign devices/ systems.

4.1 Evolution of DCS

- The DCS was introduced in 1975.
- Both Honeywell and Japanese electrical engineering firm Yokogawa introduced their own independently produced DCSs at roughly the same time, with the TDC 2000 and CENTUM systems,

- US-based Bristol also introduced their UCS 3000 universal controller in 1975.
- In 1978 Metso(known as Valmet in 1978) introduced their own DCS system called Damatic (latest generation named Metso DNA).
- In 1980, Bailey (now part of ABB) introduced the NETWORK 90 system.
- Also in 1980, Fischer & Porter Company (now also part of ABB) introduced DCI-4000 (DCI stands for Distributed Control Instrumentation).

4.2 Functional elements of a DCS

DCS System consists minimum of the following components.

1. Field Control station (FCS): It consists of input/output modules, CPU and communication bus.
2. Operator station: It is basically human interface machine with monitor, the operator man can view the process in the plant and check if any alarm is present and he can change any setting, print reports.etc.
3. Engineering station: It is used to configure all input and output and drawing and any things required to be monitored on Operator station monitor.

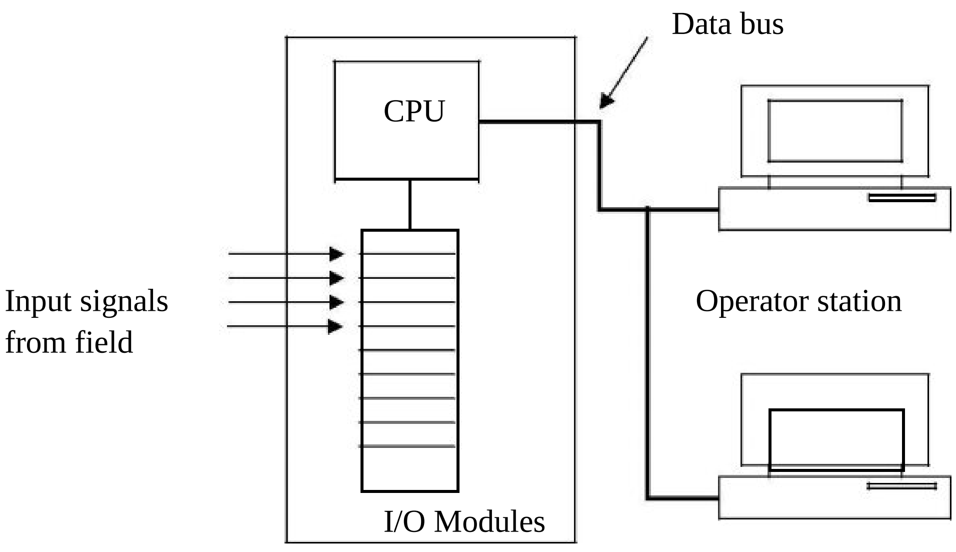


Fig 4.1 Basic configuration of a DCS System

4.3 Architecture of DCS

The architecture of DCS consists of

Local control unit (LCU)

The smallest collection of hardware in the system that can do closed loop control. The LCU interfaces directly to the process. This unit can handle 8 to16 individual PID loops, with 16 to 32 analog input lines, 8 to 16 analog output signals and a limited number of digital inputs and outputs.

Low level human interface (LLHI)

A device that allows the operator or instrument engineer to interact with the local control unit (e.g to change set points, control nodes, control configuration or tuning parameters) using a direct connection. LLHIs can also interface directly to the process. Operator oriented hardware at this level is called low level operator interface, instrument engineer oriented hardware is called the low level instrument engineering interface.

Data Input / output unit (DI/OU)

A device that interfaces to the process only for the purpose of acquiring or outputting data. It performs no control function.

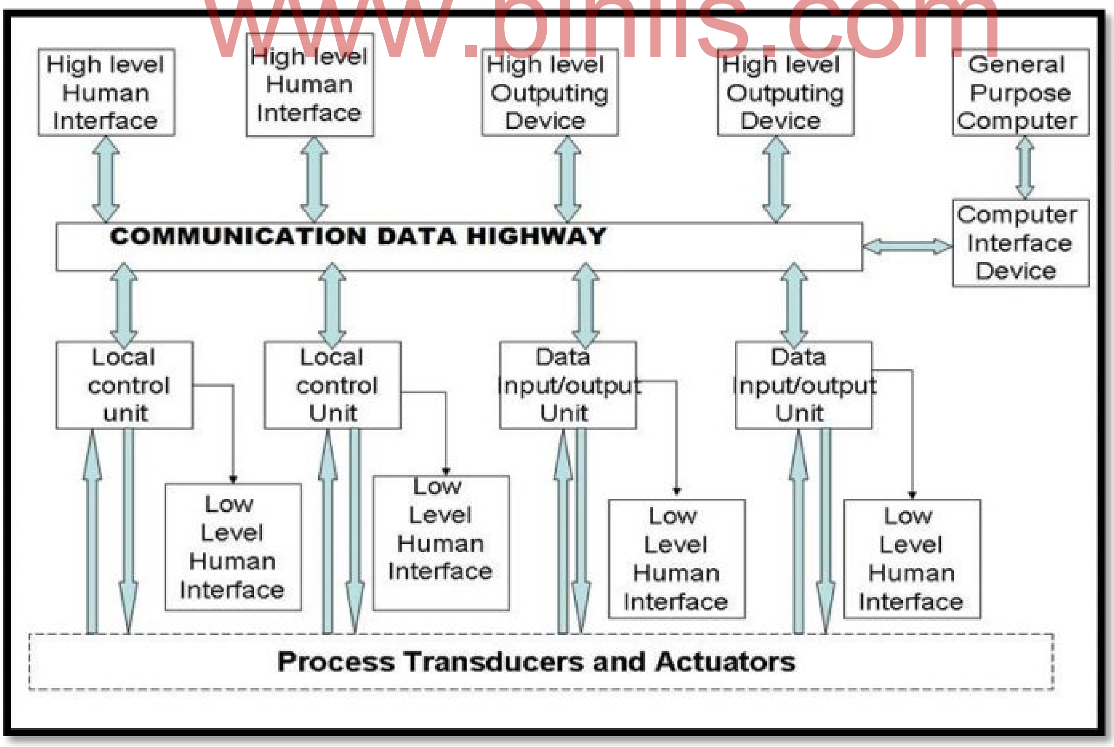


Fig 4.2 Block diagram of a generalized DCS

High level human interface (HLHI)

It is a collection of hardware that perform functions similar to the LLHI but with increased capability and user friendliness. It interfaces to other devices only over the shared communication facilities. Operator – oriented hardware at this level is called high level operator interface, instrument engineer oriented hardware is called high level engineering interface.

High level computing device (HLCD)

A collection of microprocessor based hardware that performs plant management functions performed by a plant computer. It interfaces to other devices through the shared communication facilities.

Computer interface devices (CID)

CID is a collection of hardware that allows an external general purpose computer to interact with other devices in the distributed control system using the shared communication facilities.

Shared communication facilities

One or more levels of communication hardware and associated software that allows the sharing of data among all devices in the distributed system. It is also known as the communication data highway.It is a serial digital data transmission link connecting all other components in the system and may consist of coaxial cables. Most commercial DCS allow for redundant data highway to reduce the risk of data loss.

4.4 Functional Levels in a DCS

Distributed Control System is divided into four different levels as follows ,performing the functions as described below;

Level 0: Field level

- This level comprises of the basic field instruments like sensors, transmitters etc. which are directly connected to the process.

Level 1: Direct process control

- This level handles various functions as
  - Data Acquisition
  - Data Check
  - Plant Monitoring
  - Open and Closed loop Control
  - Reporting

Level 2: Plant supervisory control

➢ This level handles various functions as:
- Plant Performance Monitoring
- Plant Coordination
- Optimal Process Control
- Adaptive Control
- Failure Detections

Level 3: Production scheduling and control

➢ This level handles various functions as:
- Production Dispatching
- Inventory Control
- Production Supervision
- Production Re-Scheduling
- Production Reporting

Level 4: Plant management

➢ This level handles various functions as:
- Market and Customer Analysis
- Orders And Sales Statistics
- Capacity and Order Balance
- Order Dispatching
- Production Planning
- Terms Supervision
- Financial Surveys

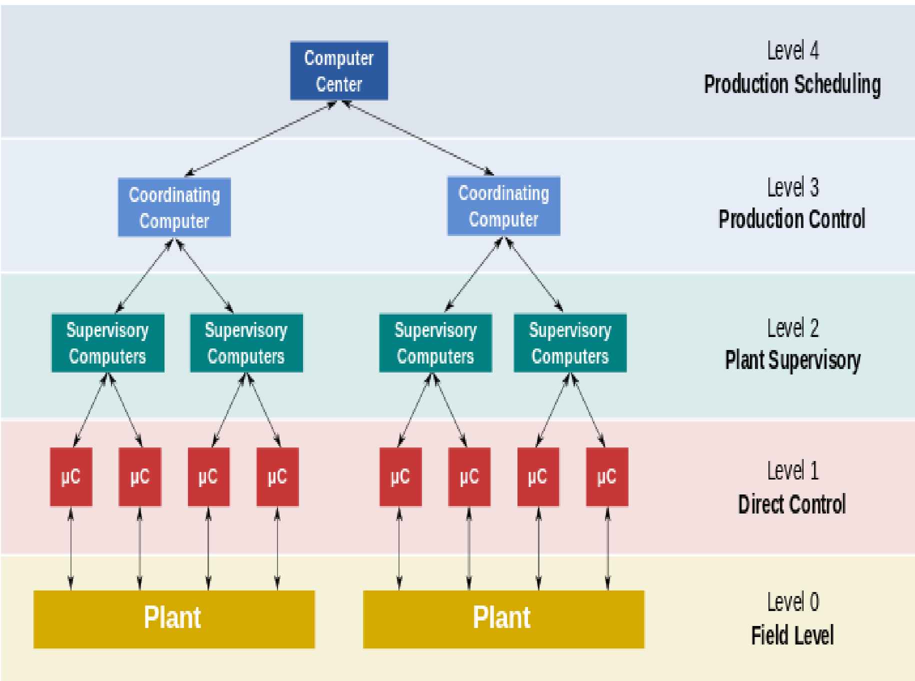


Fig 4.3 Different functional levels of operation in a DCS

4.5 Local Control Unit

- The Local control unit consists of the CPU, Memory and the Data I/O modules.
- **It** is a collection of hardware in the DCS that performs closed loop control operations. The control loops are mostly PID loops or continuous loop control.
- It takes the inputs from the process measuring devices and commands from the operator and computes the control outputs needed to make the process follow the commands.
- It also sends the control outputs to the actuators, driver valves and other mechanical devices that regulate the flows, temperatures, pressures and other variables to be controlled in the plant.
- It requires proper design for safe and efficient operation.
- The microprocessor and the clock form the CPU (the controller) of the LCU.
- The ROM and RAM are used for storage of the controller programs and temporary information.
- The LCU has I/O circuitry so that it can receive or read analog and digital data and send signals out.
- The CPU communicates with the other elements of the LCU over the internal shared data bus and transmits addressing, data control and status information in addition to data.

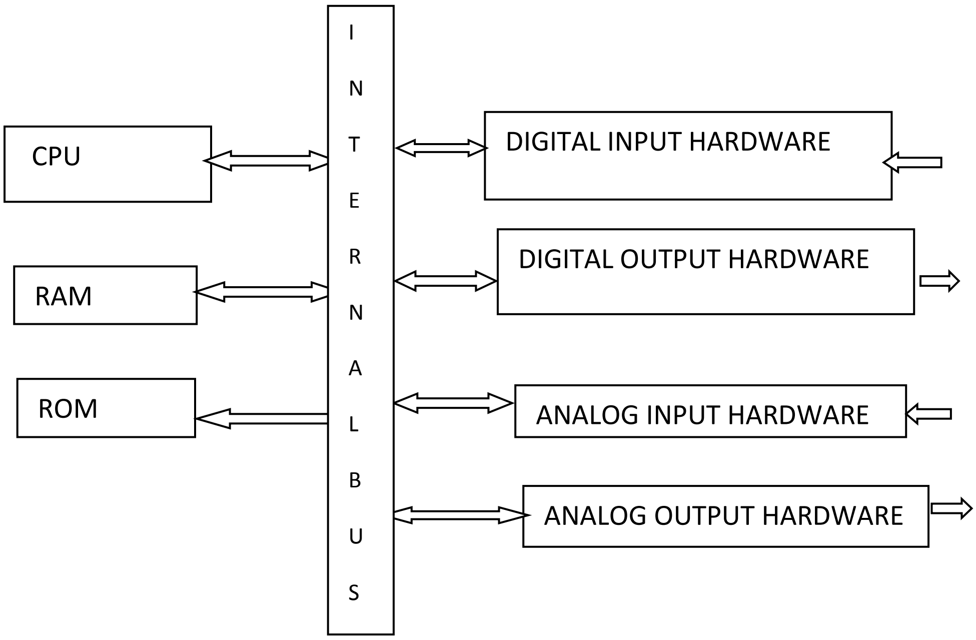


Fig 4.4 Elements of a LCU

- The control algorithms can be coded in assembly language and located in the ROM.
- A controller reads the input ,executes the control algorithms and generates control outputs in a fixed cycle indefinitely.
- The LCU is represented by function blocks. The LCU may have library functions blocks in ROM, like PID control, square root, logic functions for sequence control.
- To configure control loops the function blocks are selected and implemented as software modules within the LCU.
- The LCU architecture has the controllers different in size, I/O capability and range of functions provided depending on the application. They are of configuration A, configuration B and configuration C.

  The LCU should have the following features.

  a) Flexibility of changing the control configuration.
  b) Easy and simple operation to configure the LCU control algorithm.
  c) Controller to be bypassed in case of failure and manual operation to be done.
  d) Should have redundant controllers.
  e) Ability of the LCU to communicate with other LCUs and other elements in the system.
  f) The control language can be a high level language or a block oriented language with control functional blocks.

4.5.1 Evaluation of the controllers

1. Number of I/O channels.
2. Number of functional blocks and/or language statements that can be executed.
3. Range of functions provided-functionality of continuous control, logic control, arithmetic functions
4. Architectural parameters depending on application
5. Vendor who designed the equipment
6. Performance of the controller-rate at which the controller scans the inputs, process function blocks and generates the outputs.
7. The number, type and speed of communication channels to other operator devices, other controllers and devices in the system.
8. Controller output security

4.6 Human Machine Interface

For the automated equipment to be used in a safe and effective manner, well-engineered human interface system to permit error free interaction between the humans and the automated system

Personnel interacting with the control system

1. Instrumentation and control system engineers setting up the control system initially and adjusting and maintaining it.
2. Plant operators-responsible for monitoring, co-processing and running the process through the control system during start-up operation and shutdown

Human interface capability can be provided as

a) Low-level human interface (LLHI) connected directly to the LCU or data I/O unit using dedicated cables. The LLHI allows the operator to select controller set points and modes. It allows manual control of the process and allows the instrumentation engineer to configure the control system logic and the control parameters.

b) High level human interface (HLHI) connected to the LCU or data I/O through shared communication facility.

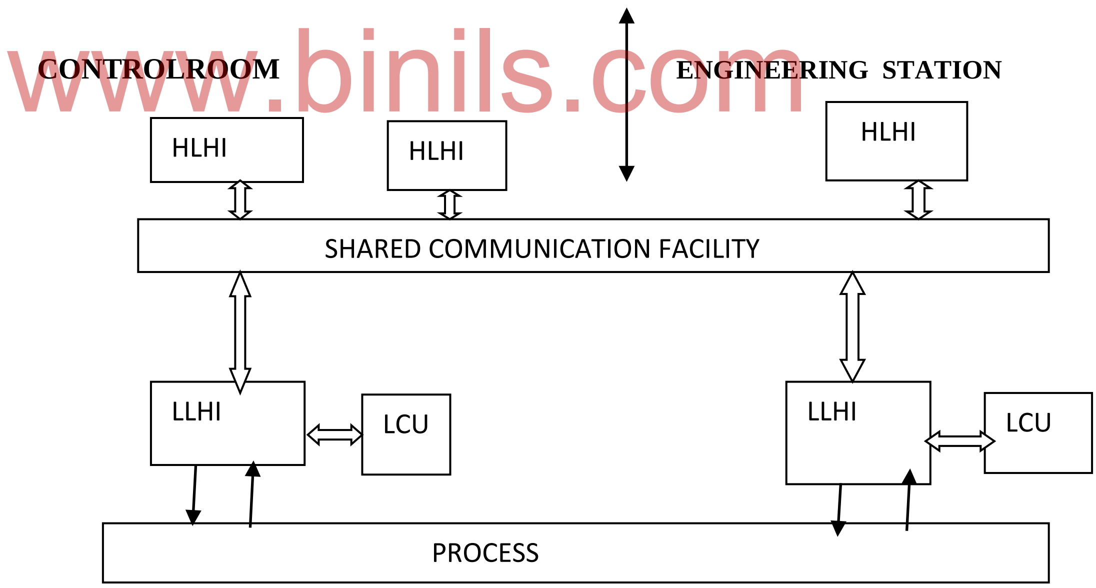


Fig 4.5 Human Machine Interface

4.6.1 Operator Interface

- The operator interface is a HMI which presents process data to a human operator and through which the human operator controls the process.
- It is usually linked to the system's databases and software programs, to provide trending, diagnostic data, and management information such as scheduled maintenance procedures, logistic information, detailed

schematics for a particular sensor or machine, and expert-system troubleshooting guides.

- The HMI system usually presents the information to the operating personnel graphically, in the form of a mimic diagrams.
- This means that the operator can see a schematic representation of the plant being controlled.
- For example, a picture of a pump connected to a pipe can show the operator that the pump is running and how much fluid it is pumping through the pipe at any moment. The operator can then switch the pump off. The operator HMI software will show the flow rate of the fluid in the pipe decrease in real time.
- Mimic diagrams may consist of line graphics and schematic symbols to represent process elements, or may consist of digital photographs of the process equipment overlaid with animated symbols.
- The system monitors whether certain alarm conditions are satisfied, to determine when an alarm event has occurred. Once an alarm event has been detected, one or more actions are taken (such as the activation of one or more alarm indicators, and perhaps the generation of email or text messages so that management of remote operators are done.

Fig 4.6 Human Machine Interface Console

1. **The Low Level Operator Interface LLOI consists** of panel board instrumentation stations, indicators, trend recorders, timing devices. It is located close to the LCU or data I/O. The LLOI is located near the process and provides manual backup controls if the HLOI fails.
2. **The High Level Operator Interface (HLOI)** has the latest digital technology, CRT or flat panel displays, peripheral devices like printers and magnetic storage. It is configured in a console arrangement that allows the engineers to be seated. HLOI results in reduction of control room size and field wiring .It is located anywhere in the plant.

   The control room and instrument engineering area contains HLOI which perform all the primary operational and engineering functions. It is used to monitor and control the operation of the process through all of the LCUs in the distributed system. Information passes between the LCUs and the HLHI by shared communication facility. The present version of HLHI is modular. It consists of communication controller, main processor, CRT and keyboard, mass storage units. It can include additional CRTs, printers, trend recorders.

Requirements of the operator interface.

The operator interface allows the operator to perform tasks in the area of process monitoring, process control and process diagnostics; process record keeping. The design of an HMI should ensure that operator can perform these tasks in an effective manner with minimum risk of confusion or error.

Process monitoring:

1. To allow the operator to observe and monitor the current state of the process. The current values of all the process variables must be available for the operator view, each process variable is identified by a tag or name, and the value must be in engineering units.
2. To detect abnormalities in the state of the process, the control and computing hardware in DCS must report the operator by alarm statistics of individual variables of the process.
3. The operator must know about the trend in time which gives the idea of the direction in which the process is moving.
4. Access to the recent history of the selected or all process variables in the plant called trended variables.

Process control:

1. The HMI should have fast access to all of the continuous control loops and logic sequences in the process control system.
2. The control functions can be automatic, manual or cascaded.
3. Logic control operations as starting and stopping pumps, opening or

closing of the valves and the interlocking logic.

4. Batch control sequence to the observe the current status of the sequence and to initiate new steps or halt as required.
5. Continuous or sequential control.

Process diagnostics:

Under abnormal or hazardous operating conditions, the system should provide enough information during failures to allow the operator to identify the equipment causing failures, take measures to correct it and move the process back to normal working conditions. It performs

1. Ongoing tests and checks on the sensors and analyzers that measure the process variables.
2. Ongoing self-test on the components and modules within the DCS, controller and communication elements.

Process record keeping:

1. Recording of short term trending information.
2. Manual entry of process data.
3. Recording of alarms
4. Periodic records of process variables information.
5. Long term storage and retrieval of data.
6. Recording of operator control activities.

4.6.2 Types of Information displays.

The VDU (Video display unit) display in an HMI provides a window for the operator to monitor and control the whole process by calling a number of displays arranged in a logical structure. A well designed display provides the operator with faster access in a smooth and efficient manner all the information. The latest feature in the VDU is the touch screen. The display structure covers the full range of details of information that is of interest to the operator from the overall plant conditions to details of each loop in the plant. It allows the operator to move from one display to the next.

The different information displays are

1. **Plant Level displays**: The displays that provide the information regarding the entire plant, if large can be divided into areas of interest.
2. **Area Level displays**: It provides the information concerning about a portion of a plant equipment that is related.
3. **Group Level displays**: The display deals with the control loops and the data points relating to a single process within the plant area
4. **Loop Level displays**: It displays the individual control loops, control sequence and data points.

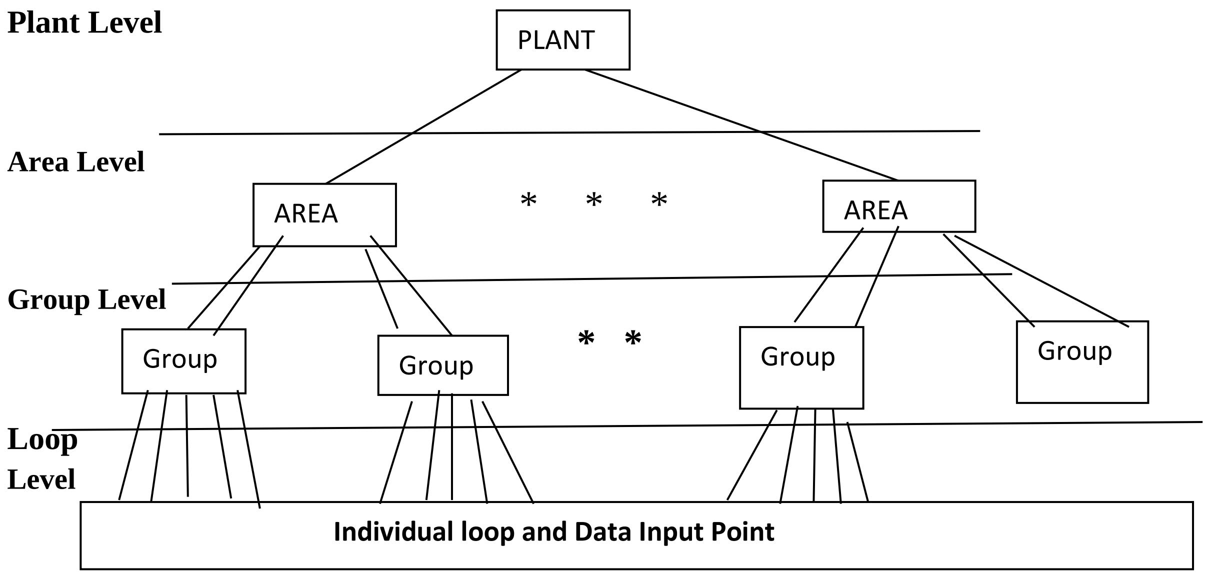


Fig 4.7 Hierarchy levels of information displays

A. Plant Level displays:

It displays the status of the overall plant conditions. It shows the overall production level at which the plant is operating .The display summarizes the key information needed to provide the operator with the big picture of the current plant conditions. It indicates how well the plant is running and displays the problem areas. The summary of the names of the various areas in the plant serves as the main menu to the next level of display. The status line of information provided in the operating display gives the summary of the process alarms and diagnostic alarms by listing the plant areas where the alarm exists.

B. Area Level display:

This display helps to look at the situation in a selected plant area. There are four displays. They are the **process variable overview display, Deviation overview, area graphics and the alarm summary**. The status line is on the top of the screen .The upper left quadrant gives **the overview display** as a bar graph of the deviations of the key process variables from their corresponding set point.

The setpoint is shown as a straight line reference. Deviation of the process variable from the set point appears as vertical bar. If the process variable for a given loop is greater than the set point a vertical line will rise up from the reference line corresponding to a particular loop. If the deviation is in the opposite direction a vertical line will drop down from the segment. If the process value is at the set point there will be no straight line. The operator on looking at the overview display will know the condition of all the loops in a number of operating areas and can quickly spot a loop that is out of control.

Discrete conditions can also be displayed on an overview display.\

Area graphics display consists of P &I drawings or mimic panels used in panel boards. It is designed to provide alarm status and current values of the process variables. **The alarm summary display** is a listing of the most current values that are outstanding in the area. It has an alarm log of information such as tag number and description of the point in the alarm, time of alarm, type of alarm, current value of the point, acknowledgement .

The tag numbers of the various loops and process variables are arranged in clusters by group. They are also assigned different colours. Any variations from the alarm limit will cause the tag number to flash indicating an emergency to the operator.

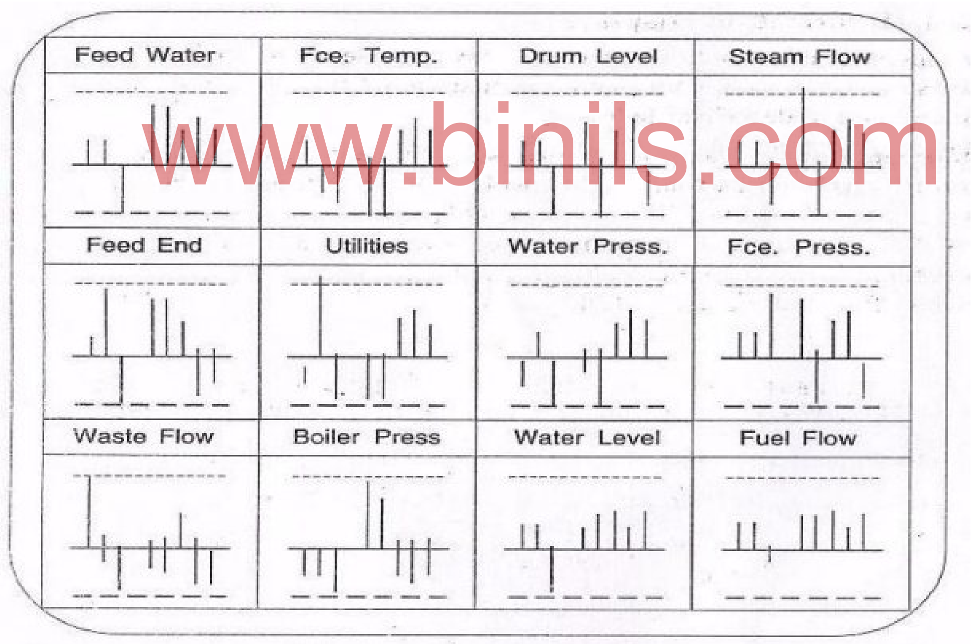


Fig 4.8 Overview display

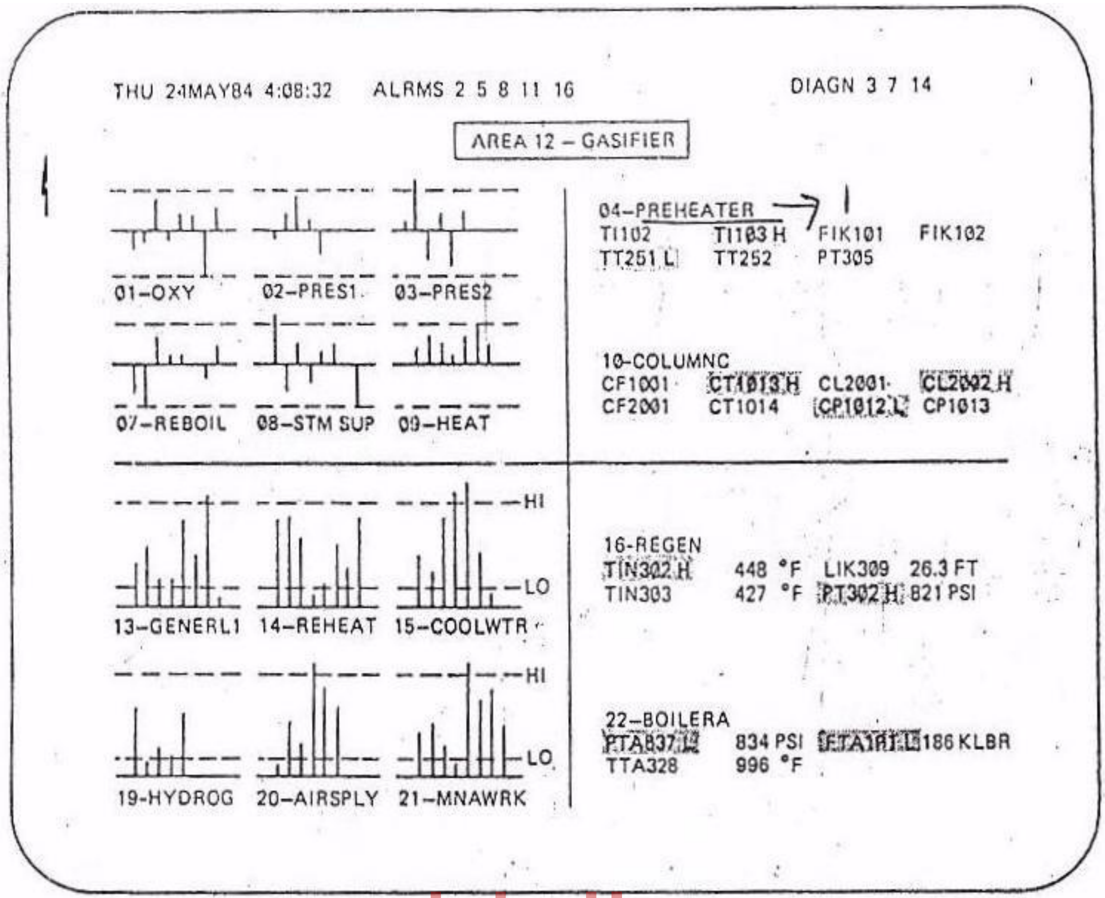


Fig 4.9 Area Level display

C. Group level display

This display is used to perform control operations at group level. Mimics of manual and automatic stations for continuous control loops occupy the left hand corner of the display. The mimics have all the elements contained in the panel board. Bar graphs showing the values of the set point, control output, process variables, manual, automatic and cascade mode indicators, high and low alarm levels and other information of each control loop is displayed

The upper right section has the indicator stations that allow the operator to view the selected variables. There is a logic station that allows the operator to perform logic functions like opening and closing of the valve. The bottom half is for the **trend display**. It plots one or more variables as a function of time. In some operator interface only one group display is on the screen for one type of the station. Switching from one display to another is possible for monitoring and control functions.

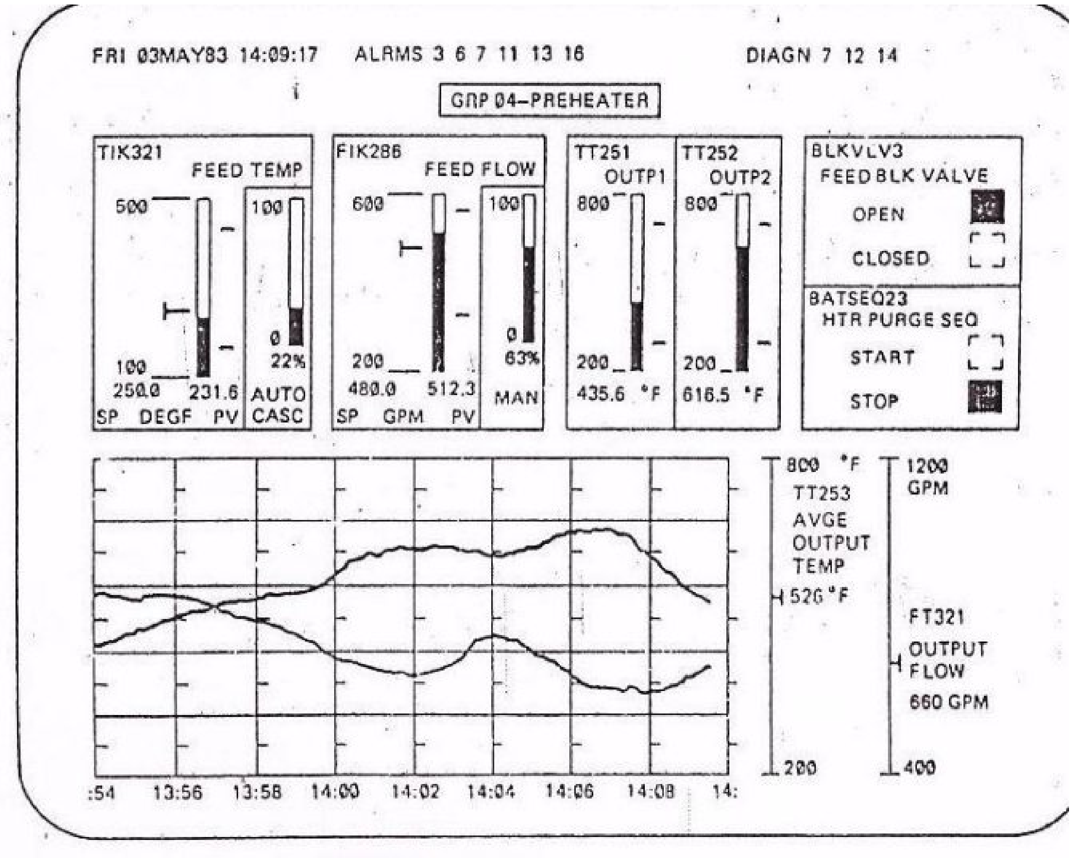


Fig 4.10 Group level display

The P & I graphics display has the process with control capability in addition to monitoring. The control station on the right side of the display performs control functions. The operator selects one of the control loops from the graphics. The controller station becomes active for that loop and the process variables can be manipulated. The capabilities of the control actions are co-ordinated in the DCS.

The batch control displays are menu oriented and allow the operator to observe the progression of a batch process and interact with the sequence. It can start, stop and provide permissions to continue, diagnose a problem when executing a sequence.

The operator guides are the advisory displays that provide the operator with the information regarding the problem diagnosed in an automatic system, suggested alternative course in case of an emergency or step by step procedure for start-up or shutdown in the process equipment.

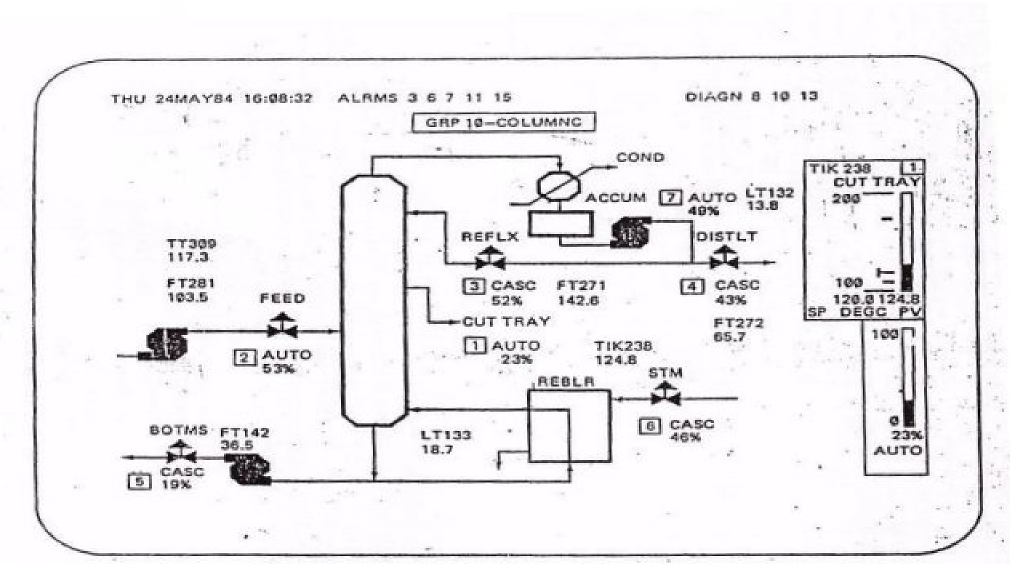


Fig 4.11 Controller station display

D. Loop Level Displays

They are operator's working displays. The operator uses the few displays dealing with single loop data points**. It is called the X-Y operating display**. One process variable is plotted as a function of another to show the current operating point of the process variables.

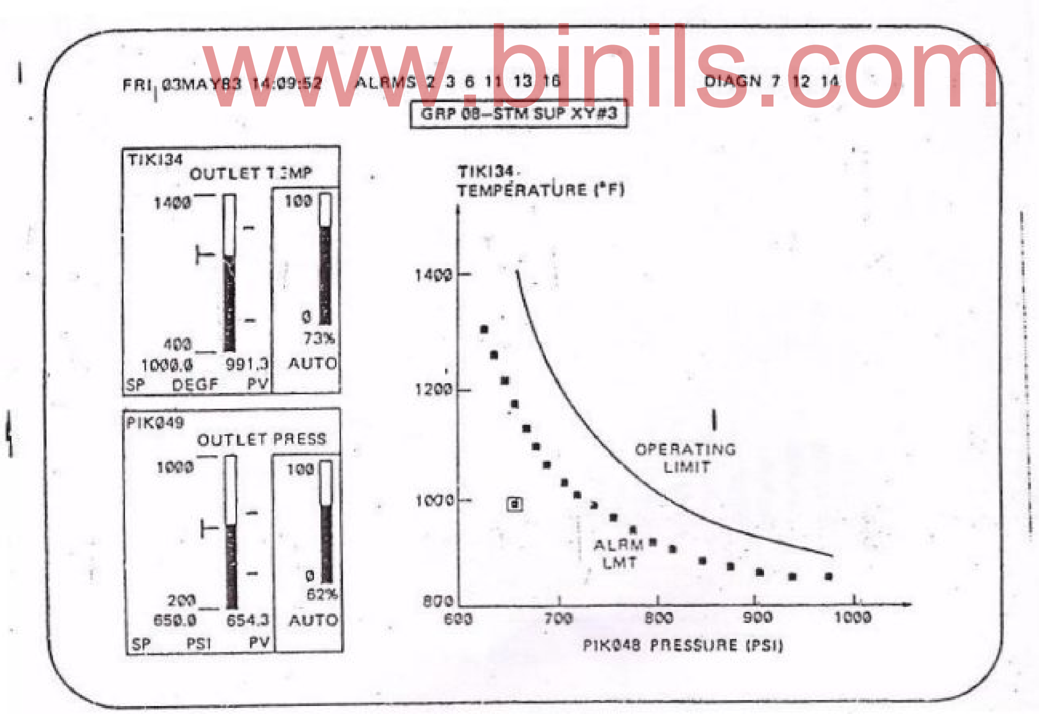


Fig 4.12 Operating display

The manual and automatic stations are included in the display for operator manipulation. **Tuning display** is another single loop display that is used both by the operators and instrumentation and control engineers. This display has several elements that make tuning possible. A fast trending capability, manual/automatic station to allow the operator to control the loop and a list of tuning parameters with the loop .**The trend graph** plots the set point changes and the resulting responses of the process variables controlled. Based on it the engineers can make online adjustments in the tuning parameters to improve the performance of the control loop.

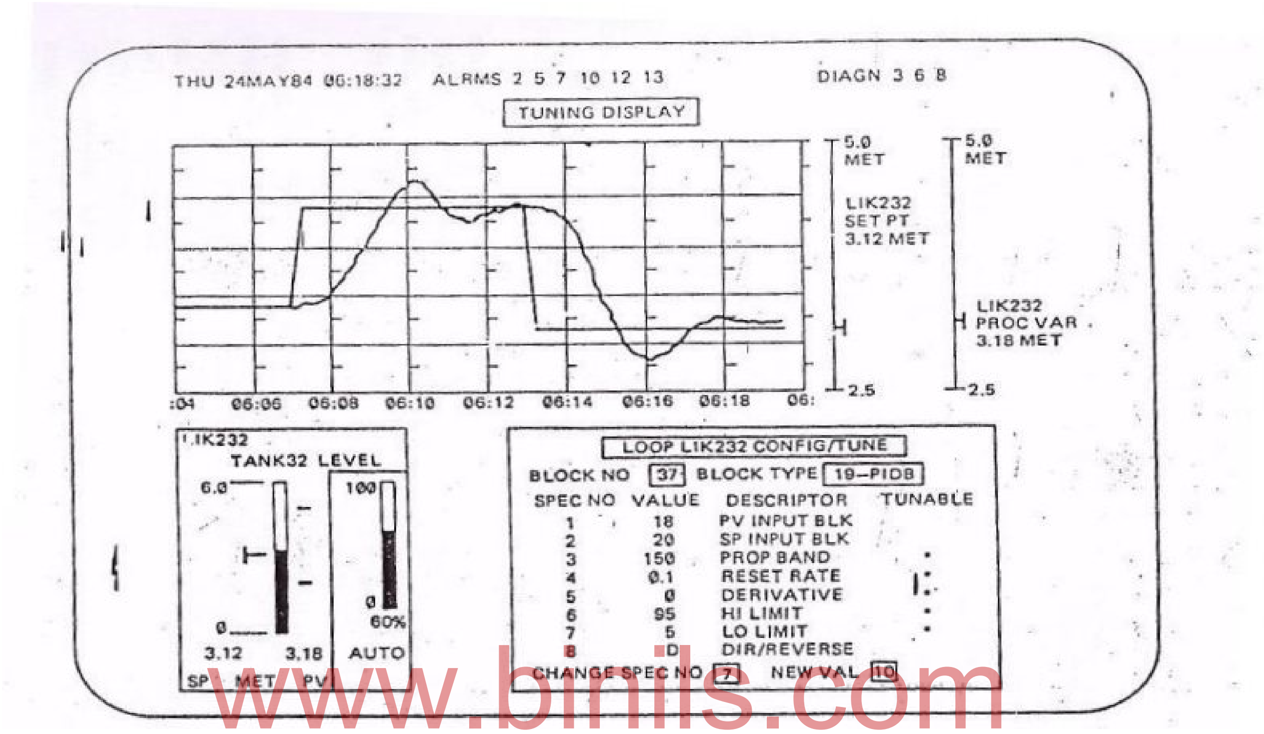


Fig 4.13 Tuning display

The graphics display has the static fields like labels, symbols and other elements that do not change, the data fields display the process information that are updated automatically and the dynamic display elements that change in size, shape ,colour according to the changing process conditions. as bar graphs, pie charts, process equipment symbols, line drawings. The operator should have the facility to zoom through the display.

4.6.3 Engineering Interface

The instrument and control system engineer manages the engineering interface in the DCS. The engineering interface consists of the hardware that is required for performing the engineering work, to configure and control the DCS.

1. **Low Level Engineering interface (LLEI)** is designed to be minimum function, inexpensive device, whose cost is justifiable for small distributed control system. It consists of a microprocessor based device as a module mounted on a rack or a hand held device. It has a small keyboard and an alphanumeric display. The human interface are the small CRTs or flat panel

displays. It communicates with one control loop or one data I/O. They may have interfaces with low cost printers and /or mass storage devices.

2. **High Level Engineering Interface (HLEI**) allows the user to benefit from the flexibility and control capabilities of a DCS. It is implemented as a CRT based console. The architecture is modular and has many microprocessors .It uses special keyboards and printers .The engineering console can interact with every element in the DCS with shared communication facility. The computational, display and data storage capabilities in a HLEI makes it to automatically configure the DCS.

The engineering interface can be designed separately or according to the functions performed **the same HMI can be used both as an operator interface or an engineering interface.**

Requirements of the Engineering Interface

1. System configuration should be defined and the interconnections, control logic and computational algorithms should be defined. The engineer defines the addresses of the input and output points in the system with respect to their location in the shared communication facility. The point number is identified within the module, the module number within the cabinet and cabinet number within the communication hierarchy.

2. The engineer must define the tag names and the associated descriptors that the humans will use to describe the points in the system and relate it to hardware addresses. The required signal conditioning of the data at the input points and the output points has to be defined.

3. The engineer must select, configure and tune the control and computational algorithms in the system. The engineer decides the format of the data and verifies the PID and other control algorithms, tuning constants, alarm limits, logic sequences, batch controls and high level language statements. The engineer must select the auxiliary functions that has to be performed at certain points like alarming, trending, logging .long term data storage and retrieval. When implementing the control and computational algorithms the engineer should define the linkages from one element to another in the shared communication facility.

4. The operator interface equipment and functions should be defined as required by the control system .The engineer should select and define the devices and mechanisms the operator will use in running the process. These include the hardware such as control stations, indicators, recorders, mimic panels, alarm indicators and related devices or their equivalent in CRT displays.

5. A mechanism for documentation of the entire configuration of the DCS both hardware and logic control functions should be made for the system and operator interface in a mass storage device and a printer can be provided for supporting documentation. The data can be displayed as tubular or graphical displays. The documentation should be automatic and must keep track of the field changes in the control system considering the original engineering design

6. The self-diagnostic algorithms provide a mechanism for the instrument engineer to locate and determine the existence of failures in a system so that the repairs can be made quickly and efficiently. In case of failures in the system the maintenance personnel may be informed.

The engineering interface will be designed for appropriate class of users of the equipment in the DCS. They should have access security, the data inputs should be understandable by the instrument engineers and the interface should track the information entered to maintain consistency. If there is a problem ,the system should prompt the engineer of the situation and correct the problem.

4.7 Functions of DCS

1. I/O signal characterization.
2. Signal filtering.
3. Alarming I/O modules.
4. Ranging and engineering units.
5. Control logic.
6. Control interlocks.
7. Sequencing.
8. Batch control
9. Passing on trending information.
10. Passing on report information.

4.8 Performance Evaluation of DCS

- Available memory for configuration
- Available idle time (based on a given scan rate)
- I/O loading or criticality
- Number of available software addresses for Input/output blocks
- Number of available software addresses for control blocks

4.9 DCS Advantages

1. System implementation can be carried out in a modular fashion
2. System overloading is less in case of DCS.
3. In case of failure of a part, DCS doesn't affect the whole system or process
4. Backup i.e. redundancy feature possible in DCS.
5. Reliability of DCS is more than that of Centralized Control.

6. Reduction of cost of interfacing to computer due to reduction in wire usage for control purpose.
7. DCS is more flexible in terms of altering the configurations within a specified range.
8. Duplicate storage of critical data can be done easily.
9. Independent or standalone processors communicate with each other which make management of computers easy.
10. Minimization of data loss as well as errors due to placement of controllers in the nearby vicinity in DCS.
11. Advanced control strategies are easy to implement in DCS.

4.9.1 Limitations

- Cost is high when compared with PLC/PC Combination.
- Specialized support from engineering personnel required.
- DCSs require a clean control room environment compared to PLC/ PC environment.

4.10 VENDORS OF DCS

1. Honeywell
2. Fisher-Rosemont
3. Baily
4. Foxboro
5. Yokogawa
6. Siemens
7. GE Fanuc Intelligent Platform
8. Schneider Electrics
9. ABB

4.11 Typical applications

Processes where a DCS might be used include:

- Chemical plants
- Petrochemical (oil) and refineries
- Pulp and Paper Mills
- Boiler controls and power plant systems
- Nuclear power plants
- Environmental control systems
- Water management systems
- Water treatment plants
- Sewage treatment plants
- Food and food processing
- Agro chemical and fertilizer plants
- Metal and mines
- Automobile manufacturing
- Metallurgical process plants
- Pharmaceutical manufacturing
- Sugar refining plants

4.11 Selection criteria of DCS for an application

- Cost of hardware, software, Integration Engineering, Design, Installation, Start-up and Commissioning, Validation documentation and Execution, Training, Spare parts, Maintenance, System service contract and system life cycle.
- Reliability, Flexibility, Scalability and Validity.
- Ease of Database configuration, Graphics development, Interlocks and Batch processing.
- Integration of High-level Application.
- Control available for Centralized versus Remote Operator Console or both.
- Compliance with an Industry batch standard such as ISA SP88 and new Communication Protocol.

4.12 Architecture of a commercial DCS

Yokogawa Centum 3000 DCS

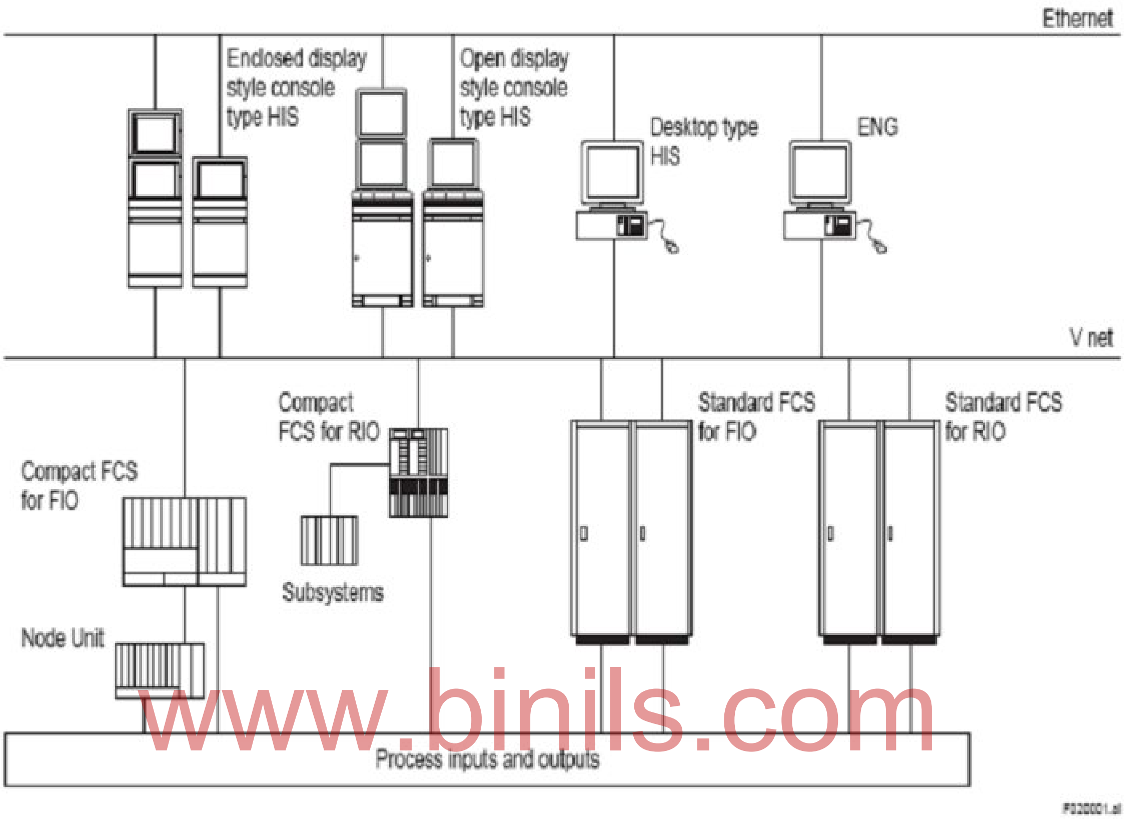


Fig 4.14 System Configuration of Yokogawa Centum 3000 DCS

The Centum 3000 DCS has the following equipments

Human Interface Station (HIS) or Operator station

The HIS is mainly used for operation and monitoring purposes. It displays process variables, control parameters, and alarms necessary for the users to quickly grasp the operating status of the plant. It also incorporates open interfaces so that supervisory computers can access trend data, messages and process data. The operator station is based on Windows XP or Windows2000. (Both are selectable).

The types of HIS are,

Console Type HIS: This is a new console type human interface station, to which a general purpose PC is installed. It can be composed of dual stacked

LCD, touch panel function, eight-control-key operation keyboard, auxiliary contact I/O and a number of console types HIS which can be installed in a row.

Desktop Type HIS: This HIS uses a general purpose PC. An IBM PC/AT compatible machine is generally used.

Engineering Station (ENG)

Engineering Station is used to do the engineering builder for all the stations like HIS, FCS, CGW, BCV etc. ENG station is a PC loaded with engineering software (Standard builder function). It is mainly used to perform CS3000 system generation and maintenance management. The HIS can be loaded with engineering software, so that it can be used as HIS as well as ENG station. By having HIS operation and monitoring functions on the same PC, we can use the test (control station emulation) functions to provide an efficient and easy-to-use engineering environment.

Maximum number of tags that can be monitored from HIS : 100,000

Maximum number of windows that can be created per HIS : 4000

Maximum number of Trend Recording Points per HIS : 2304

Field control station:

The FCS controls the plant. This is the component where all the control functions are executed and hence it is a very important and critical component in the overall system. The components of FCS are the

a) Field Control Unit (FCU)

b) Nodes for Field Input and Output(FIO)

c) Local / Remote Communication Bus

The FCS and the HIS are connected via a real time control network. This communicates with all the parameters to and from the Field Control Station to the Human Interface station. CS3000 R3 system uses VL/V net and Ethernet for data communication.

Local nodes communicate to the main FCU by ESB bus. The ESB (Extended Serial Backboard bus)is a communication bus used in connecting the local nodes, which are installed in the same cabinet for FCU, with the FCU. This bus can be dual redundant. The communication between the main FCU and individual nodes is done by ESB bus. The FCS performs process control and manages communications with subsystems. The ER bus (Enhanced Remote Bus)is a communication bus used in connecting the remote nodes with the FCU by means of the ER bus interface module installed on the local node.

In a V net/IP network, an area without communicating through a router is called a domain. Up to 64 V net/IP stations can be connected in one V net/IP domain. In a Centum CS3000 system, up to 16 domains can be defined in combinations of V net/IP domains. L2 switch is a device used to connect equipments within the V net/IP domain. The layer 2 switch, unlike a HUB, incorporates functions to send data to the destination terminal equipment only.

V net/IP uses full-duplex communication systems so that no collisions occur. The switches used on the V net/IP network include an SNMP (Simple Network Management Protocol) There are three types of connections between any V net/IP domains: bi-directional, hierarchical and bridge connections..

Process Input Output Module

Input modules convert process signals to the digital data format used in the FCS. Output modules convert the digital data format used in the FCS to analog or contact signals. Using process inputs/outputs, an FCS can receive signals from process detectors and output signals to process control elements.

Process inputs/outputs are used to exchange signals between field equipment and an FCS. There are different types of process inputs/outputs:

- Analog input/output
- Contact input/output and
- Communication input/output
- Process input/output signals are used as input/output signals for the regulatory control, arithmetic calculation and sequence control.

REVIEW QUESTIONS

	UNIT IV DISTRIBUTED CONTROL SYSTEMS
	PART A -Two marks questions
1.	What is a distributed control system?
2.	What are the functional elements of a DCS?
3.	What are the advantages of DCS?
4	What is an operator interface?
5.	What is an engineering interface?
6.	What are the types of information displays?
7.	What are the elements of the local control unit?
8.	List the manufacturers of DCS.
9.	What are the factors to select a DCS?
10.	What is shared communication facility?
	PART B -Three marks questions
11.	Write short notes on the functional elements of a DCS.
12.	What are the features in an operator interface?
13	List the features and interfaces in an engineering interface.
14	How is an LCU of the DCS evaluated?
15	Discuss the selection criteria of a DCS.
	PART C-Ten marks questions
16.	Explain the DCS with a block diagram.
17.	Explain the elements of a local control unit.
18.	Explain the operator interface in DCS.
19.	Explain the engineering interface in DCS.
20.	Explain the different types of information displays in DCS.
21.	Explain any one commercial DCS in detail.

UNIT V ROBOTICS

5.0 Definition

An industrial robot is a general purpose programmable machine which possesses certain human like characteristics. The typical human characteristics in the industrial robots are their movable arms. The robot can be programmed to move its arm through a sequence of motions in order to perform some useful tasks.

Robot: A reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks.

5.1Basic components of a robot system

The basic components of a robot system are

1. Manipulator
2. Sensory devices
3. Controller
4. Power conversion unit

Manipulator: It is made of joints and links. Motion of the joints causes the links attached to it to move. The motion of the joint is made by an actuator. The last link is mounted by an end effector.The end effector performs the required task

Sensory devices: To control the manipulator the state of each joint, its position, velocity and acceleration should be known. To achieve this sensory devices can be connected to the joint.

Controller: The controller monitors, regulates and controls a robot system. It consists of a memory, sequencer, a computation unit, an interface to receive sensory data, an interface to the power conversion unit and an interface with the peripheral devices.

Power conversion unit: The power conversion unit takes the signals from the sequencer and converts it to the form understandable by the actuators in the system. The power conversion unit consists of any one of the drive system for the robot.

5.2 Robot Anatomy

It describes the mechanical structure of the manipulator in an industrial robot. It is the physical construction of the body, arm and the wrist of the robot. The body is attached to a base and arm assembly is attached to the body. At the end of the arm is the wrist. The wrist consists of variety of components that allow it to be oriented in a variety of positions,.The end effector is attached to the wrist, it can be a gripper or a tool.

Robot manipulator consists of joints and links

- Joints provide relative motion
- Links are rigid members between joints
- Various joint types are the linear and the rotary joints.
- Each joint provides a degree-of-freedom.
- Most robots possess five or six degrees-of-freedom

Robot manipulator consists of two sections:

- Body-and-arm assembly– for positioning of objects in the robot's work volume
- Wrist assembly – for orientation of objects

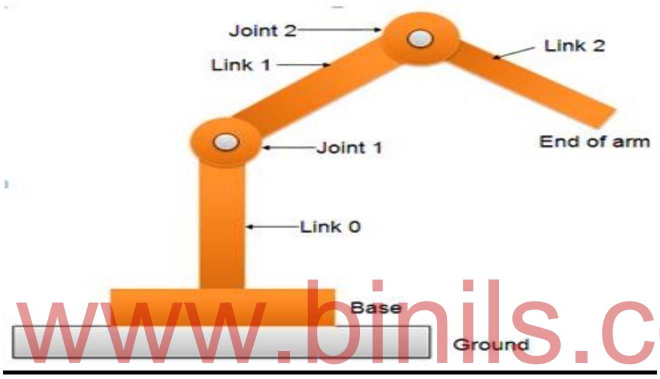


Fig 5.1 Anatomy of a robot

5.2.1Different type of joint motions

Industrial robots perform productive work. The work is enabled by making the robot to move its body, arm and wrist through a series of motions and positions. The different types of joint motions are

Translational motion

- Linear joint (type L)
- Orthogonal joint (type O)

Rotary motion

- Rotational joint (type R)
- Twisting joint (type T)
- Revolving joint (type V)

a) Linear joint (type L-joint)

The relative movement between the input link and the output link is a translational sliding motion, with the axes of the two links being parallel.

b) Orthogonal joint (type U-joint)

This is also a translational sliding motion, but the input and output links are perpendicular to each other during the move.

c) Rotational joint (type R-joint)

This type provides rotational relative motion, with the axis of rotation perpendicular to the axes of the input and output links.

d) Twisting joint (type T-joint)

This joint also involves rotary motion but the axis or rotation is parallel to the axes of the two links.

e) Revolving joint (type V-joint, V from the "v" in revolving)

In this type, axis of input link is parallel to the axis of rotation of the joint. However the axis of the output link is perpendicular to the axis of rotation.

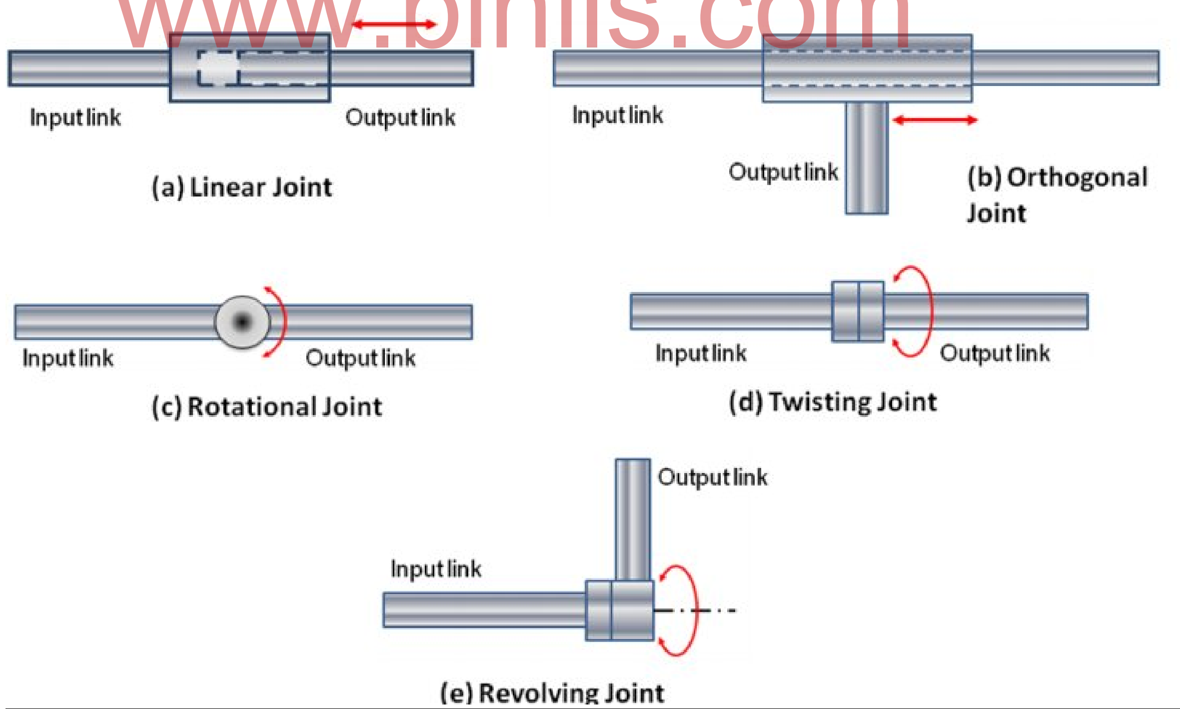


Fig 5.2 Different joint motions

5.2.2Degrees of freedom

The robot movements can be divided into

1. Arm and body motions
2. Wrist motions

The individual joint motions are referred to as degrees of freedom. An industrial robot has four to six degrees of freedom.

The robot motions are possible by means of powered joints. Three joints are associated with the action of the body and arm and two or three joints are used to actuate the wrist.

The arm and body configuration joints are designed to enable the robot to move its end effector to a desired position, within the limits of the robot size and joint movements.

The three degrees of freedom associated with the body arm motions are

- **Vertical traverse**: The capability to move the arm up or down to provide the desired vertical height.
- **Radial traverse**: This motion involves the extension and retraction of the arm from the vertical center
- **Rotational traverse**: This is the rotation of the arm about the vertical axis.

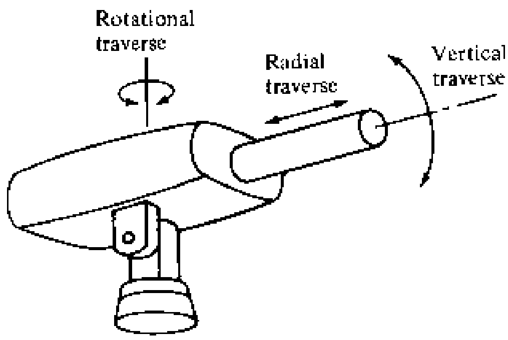


Fig 5.3 Degrees of freedom of Body Arm Configuration

5.2.3Body Arm Configurations

There are 5*5*5 body arm configurations possible out of which five body arm configurations are commonly used.

- **Polar Coordinate Body Arm Configuration**
  It consists of a sliding arm (L joint) actuated relative to the body, which can rotate about both a vertical axis (T joint) and horizontal axis (R joint)

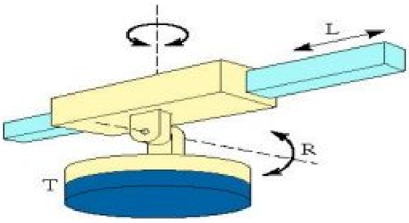


Fig 5.4a Polar co-ordinate body arm configuration

- **Cylindrical Co-ordinate body arm configuration**
  It consists of a vertical column, relative to which an arm assembly is moved up or down. The arm can be moved in or out relative to the column

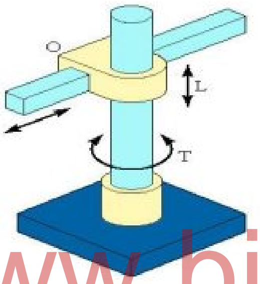


Fig 5.4b Cylindrical co-ordinate body arm configuration

- **Cartesian Co-ordinate body arm configuration**

It consists of three sliding joints, one is a linear joint and two of which are orthogonal. X axis allows the arm to move along the work piece, Y axis allows the arm to move towards and away from the work piece, Z axis allows the movement upwards and downwards. The other names of this robot are the rectilinear robot and the xyz robot.

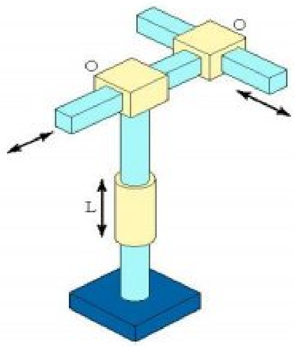


Fig 5.4c Cartesian co-ordinate body arm configuration

- **Jointed body arm assembly**
  It is made up of rotating joints. It consists of a vertical column that swivels about the base using a T joint. At the top of the column is the shoulder joint(R joint) whose output link connects to an elbow joint (R joint).

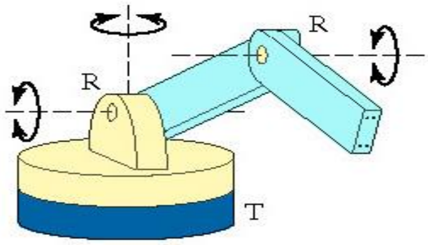


Fig 5.4d Jointed Arm body arm configuration

- **SCARA** stands for Selectively Compliant Assembly Robot Arm similar to jointed-arm robot except that vertical axes are used for shoulder and elbow joints to be compliant in horizontal direction for vertical insertion tasks

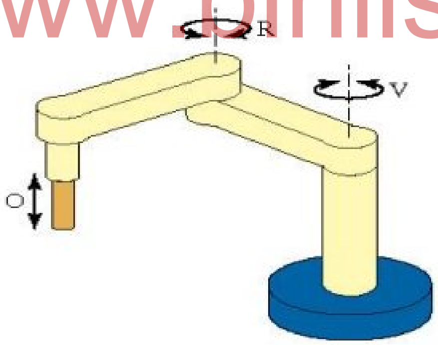


Fig 5.4 e SCARA body arm configuration

5.2.4 Wrist assembly

It is attached to the end-of-arm. End effector is attached to the wrist assembly. The function of wrist assembly is to orient the end effecter. Body and arm determines the global position of the end effector. Two or three degrees of freedom associated with the wrist assembly are

- Roll is also called wrist swivel. It is the rotation of the wrist about the arm axis.

- Pitch involves the up or down rotation of the wrist.
- Yaw involves the left or right rotation of the wrist.

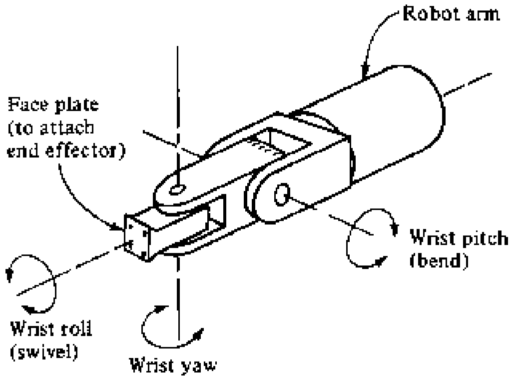


Fig 5.4 f Wrist assembly motions

5.3 Classification of Robots

Robots can be classified in various ways, depending on their components, configuration, and use. Three common methods of classifying robots are by the types of control system used, the type of actuator drive used, and the shape of the work envelope. The different classification of the robot is as follows

I Type of control

a. Point to point robots
b. Continuous point robots
c. Computer trajectory robots
d. Servo controlled robots

II Capability

a. Sequence controlled robots
b. Computed trajectory robots
c. Adaptive robots
d. Intelligent robots

III. Body- arm configuration

a. Cartesian co-ordinate robot
b. Cylindrical co-ordinate robot
c. Polar co-ordinate robot
d. Revolute co-ordinate robot
e. SCARA robot

IV. Mobility

a. Fixed type robot

b. Mobile robot

c. Walking robot

V. Power source

a. Pneumatic powered robot

b. Hydraulic powered robot

c. Electric powered robot

5.4 Robot Sensing

The use of external sensing mechanisms allows a robot to interact with the environment in a flexible manner. The function of robot sensors may be divided into internal state sensors and external state sensors.

Internal State sensors: They deal with the detection of variables such as arm joint positions used for robot control.

External State sensors: They detect the variables such as range, proximity and touch. Itis used for robot guidance as well as for object identification and handling.

External sensors can be classified as Contact or Non contact sensors

Contact Sensors: They respond to the physical contact such as touch, slip and torque.

Non-contact Sensors: They rely on the response of a detector to variations in acoustic or electromagnetic radiations. Non-contact sensors measure the range, proximity and the visual properties of an object.

5.4.1Range Sensors

A range sensor measures the distance from a reference point to the objects in the field of operation of the sensors. Range sensors are used for robot navigation and obstacle avoidance.

A.Range sensing by triangulation

The range is measured through triangulation technique. An object is illuminated by a narrow beam of light which is swept over the surface. The sweeping motion is the plane defined by the line from the object to the detector and the line from the detector to the source If the detector is focused on a small portion on the surface the detector sees the light spot at a distance D

D= B tan θ where

θ = angle of the source with the baseline

B = distance between the source and the detector. This results in point measurement.

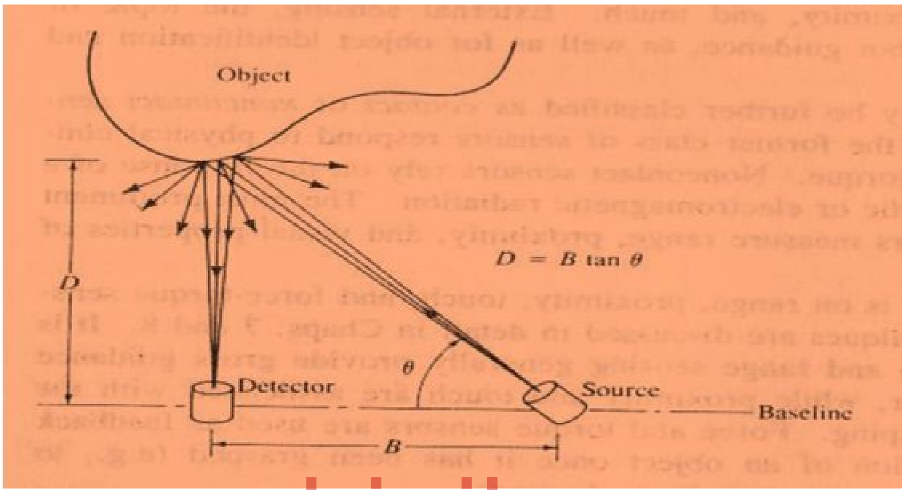


Fig 5.5 Range finding using triangulation

If the source and the detector are movable along fixed plane it is possible to obtain a set of points whose distance from the detector is known.

B. Range sensing using time of flight

Laser range finder

A continuous beam laser is used and the time delay between the outgoing and returning beams is used to calculate the range of the object.

A beam of laser light of wavelength LAMDA is split into two beams .The reference beam travels a distance L to phase measuring device and the other travels a distance D out to the reflecting surface.

The total distance travelled by the reflected beam is $D' = 2D + L$.

If $D=0$ then $D'=L$ and the reference and the reflected beams arrive simultaneously at the phase measuring device. If D increases the reflected beam travels a longer path and a phase shift is introduced between the two beams at the point of measurement.

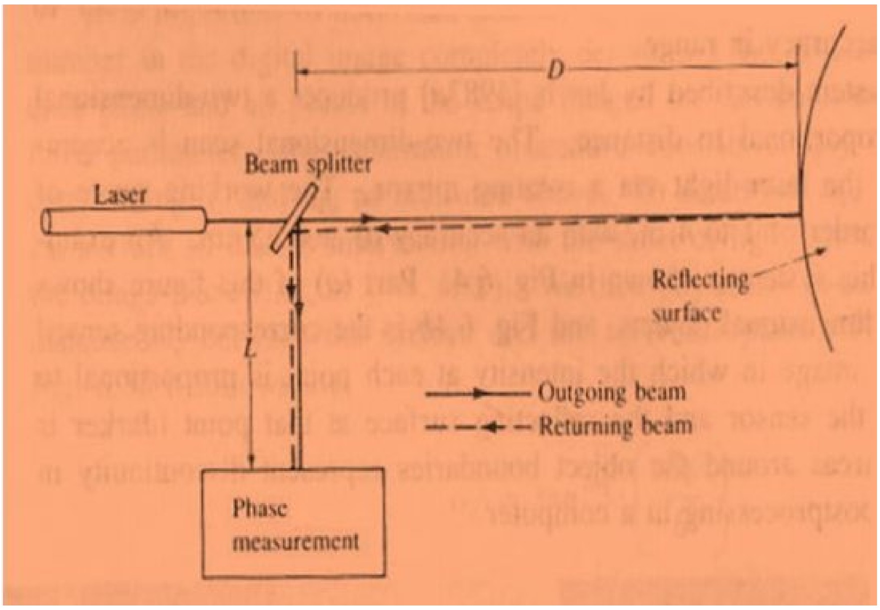


Fig 5.6 Laser Range Finder

Thus

D' = L + (θ/ 360^0) * wavelength in lamda

If $\theta = 360^0$ the waveforms are aligned and cannot be differentiated between D'= L and D'= L + n * lamda

Hence assuming $\theta < 360^0$ then

D' = L + 2D ------(1)

D' = L + (θ/360^0) * lamda -----(2)

gives

D = (θ/360^0) * (lamda /2)

This gives the distance in terms of phase shift if the wavelength in lamda is known.

C. Ultrasonic range sensor

These sensors are designed to generate high frequency sound waves and receive the echo reflected by the target.

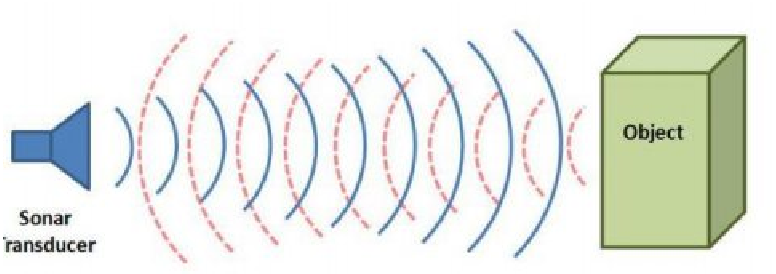


Fig 5.7.a Ultrasonic Sensor

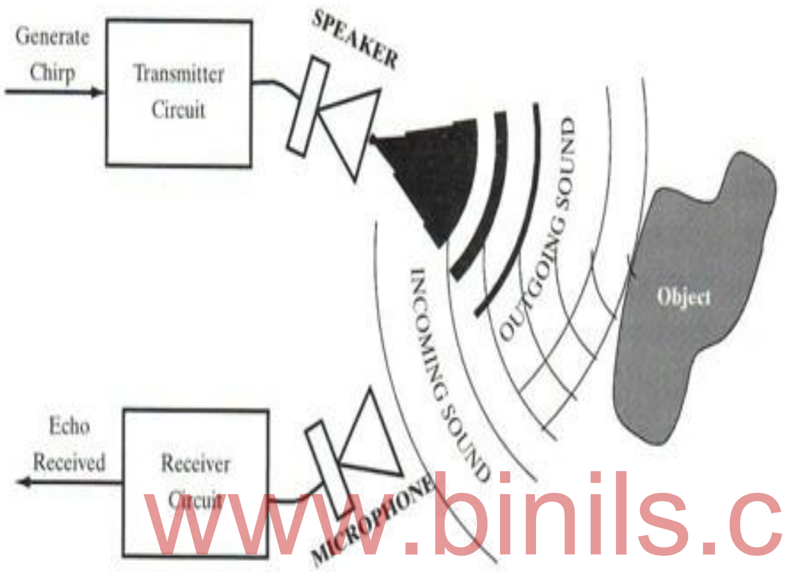


Fig 5.7 .b Range finding using ultrasonic sensor

Advantages of Ultrasonic sensors

- The output value is linear with the distance between the sensor and the target;
- Sensor response is not dependent on the colors, transparency of objects, optical reflection properties or by the surface texture of the object.
- These sensors are designed for contact-free detection.
- Sensors with digital (ON/OFF) outputs have excellent repeat sensing accuracy.
- Accurate detection even of small objects.
- Ultrasonic sensors can work in critical conditions such as dirt and dust;
- They are available in cuboid or cylinder forms, which is better for a freedom design.

Disadvantages of Ultrasonic sensors

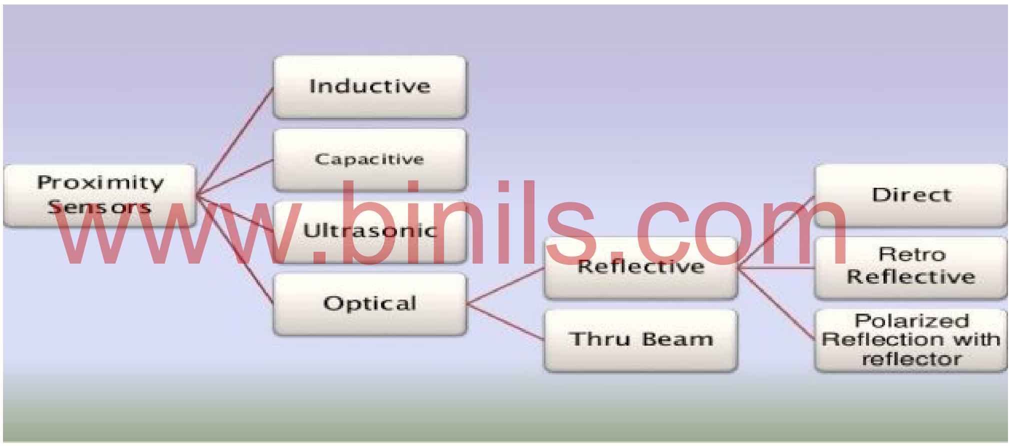
- Ultrasonic sensors must view a high density surface for good results.

- Could have false response for some loud noises such as air hoses.
- The ultrasonic sensors may have a weak echo due to dispersion and absorption of the sound waves.
- An ultrasonic sensor has a minimum sensing distance,
- Some changes in the environment can affect the response of the sensor (temperature, humidity, pressure, etc.).

5.4.2Proximity sensors

Proximity sensors are devices that indicate when one object is close to another. The sensors have binary output which indicates the presence of an object within a specified distance interval.

The proximity sensors are used in robotics near field work, i.e ,object grasping and avoidance...



A. Inductive Proximity Sensor

Sensors are based on a change of inductance due to the presence of a metallic object. The sensor consists of a wound coil located near to a permanent magnet packaged in a rugged housing.

When a ferromagnetic material is brought near the sensor, it causes a change in the position of the flux lines of the permanent magnet. Under static conditions, there is no movement of the flux lines and hence no current is induced in the coil. As a ferromagnetic object enters or leaves the magneticfield, there is a change in the flux lines. It induces a current pulse whose magnitude is proportional to the rate of change of flux linkages.

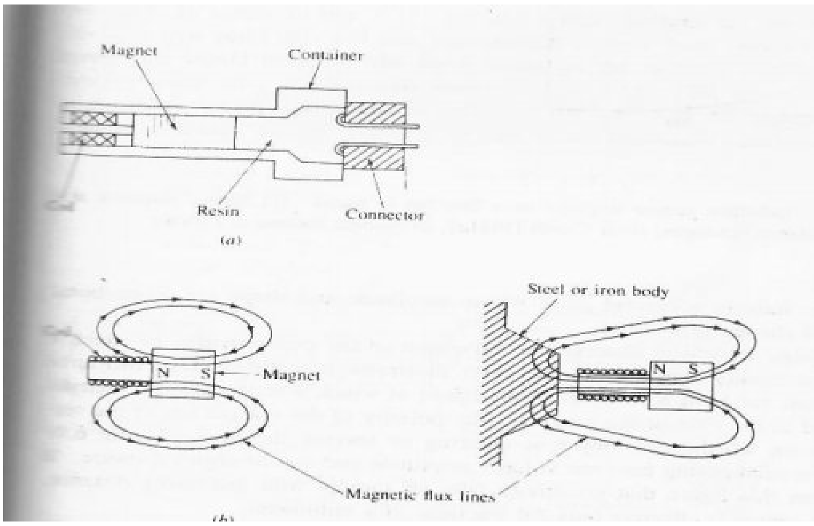


Fig 5.8 Inductive Proximity Sensor

The output voltage at the coil varies as a function of the speed at which the ferromagnetic object is introduced in the field of the magnet. The polarity of the voltage depends on whether the object is leaving or entering the field.

B. Hall Effect Proximity Sensor

Hall Effect sensor when used with permanent magnet is used to detect ferromagnetic objects.

The Hall Effect sensor works on the principle of the Hall effect which relates the voltage between the two points in a conducting or semiconducting material to a magnetic field across the material.

The force due to the Hall Effect acts on a charged particle travelling through a magnetic field in a direction perpendicular to both the direction of the charged particle motion and the direction of the magnetic field.

F = q (v *B)

Where F = Lorentz's force in Newtons

q = charge of the particle in Coulombs

v = velocity of motion of the charged particle in m/s

B = magnetic field strength in Webers / m^2

Hall Effect sensor senses a strong magnetic field in the absence of a ferromagnetic object near the field. When an object is in close proximity with the sensor the magnetic field weakens at the sensor due to the bending of the field lines through the material of the object.

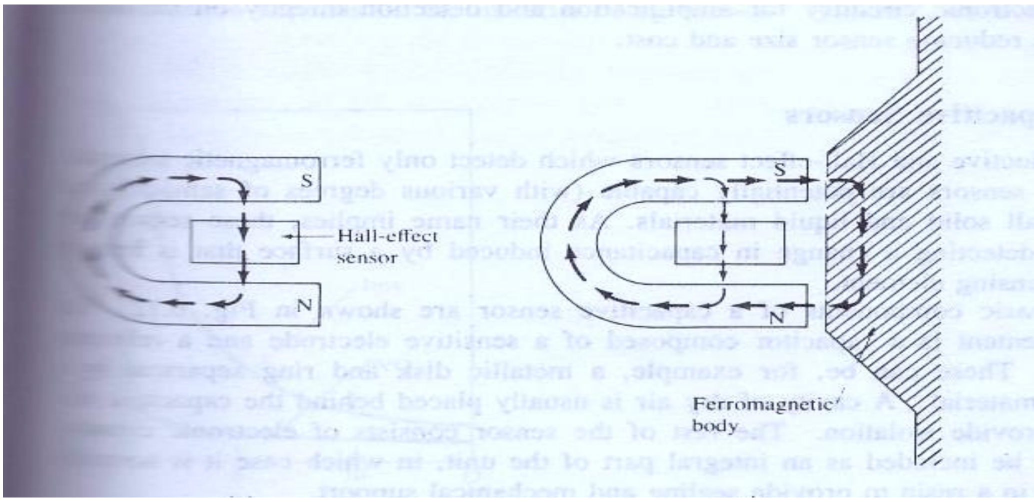


Fig 5.9 Hall effect Sensor

Bringing a ferromagnetic object (semiconductor or a conductor) will reduce the strength of the Lorentz force and the voltage across the semiconductor in the Hall effect sensor. This drop in voltage is used for sensing the proximity in the Hall Effect sensor. By thresholding the voltage, the decision can be made on the presence of the object.

C. Capacitive Proximity Sensor

The capacitive sensor is used to detect all solid and liquid materials. The sensor works on the detection of a change in capacitance induced by a surface that is brought near the sensing element.

The capacitive sensor consists of a sensitive electrode and a reference electrode basically a metallic disc and a ring separated by a dielectric material. A cavity of dry air is placed behind the capacitive element to provide isolation. The rest of the sensor consists of an electronic circuitry embedded in a resin to provide sealing and mechanical support.

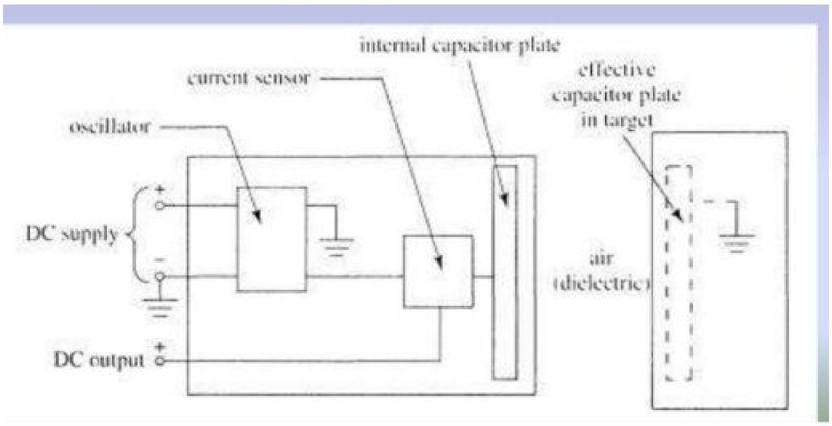


Fig 5.10 Capacitive Proximity Sensor

The various techniques to measure the proximity based on change in capacitance are

1. The capacitor can be a part of an oscillator circuit, so that oscillations will start only when the change in capacitance exceeds a threshold value. The start of oscillations produces an output voltage indicating the presence of an object.
2. The capacitance element forms a part of a circuit driven by a reference voltage. A change in capacitance causes a phase shift between the signal output and the reference signal. The phase shift is proportional to the change in capacitance.

The sensor operates in binary mode. The change in capacitance above a threshold value indicates the presence of the object while below the threshold value indicates the absence of the object.

D.**Optical Proximity sensor**

They detect the proximity of an object by its influence on a light wave as it travels from a transmitter to a receiver.

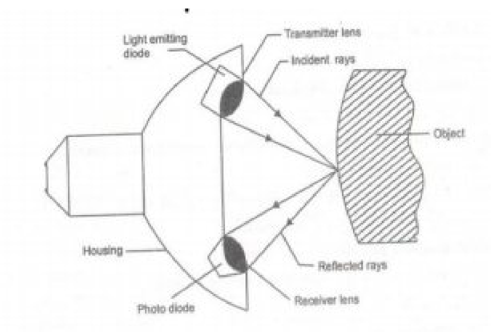


Fig 5.11 Optical sensor

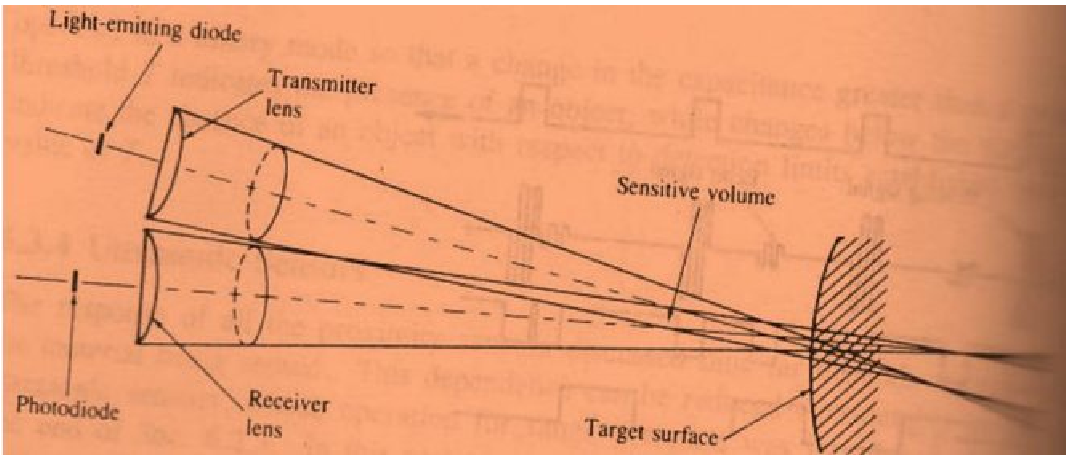


Fig 5.12 Optical proximity Sensor

The sensor consists of a LED which acts as a transmitter of infrared light and a photodiode that acts as a receiver. The cone of light formed by focusing the source and the detector on the same plane intersect in a long pencil like volume. This volume is the field of operation of the sensor.

A reflecting surface loaded anywhere in this volume will produce a reading. The intensity of these readings are calibrated as a function of distance for known object orientations. The signal is generated when the received light exceeds a threshold value.

5.4.3 Tactile sensors

Tactile sensors indicate the contact between themselves and some other solid object. Tactile sensing devices are divided into

1 Touch sensors

2. Force and torque sensors

A. Touch Sensor

It indicates that contact has been made between two objects without regard to the magnitude of the contacting force. They include devices like the limit switches, micro switches. In binary touch sensor, a switch is placed in the inner surface of each finger of the manipulator. It determines if a part is present between the fingers. By moving the hand over the object, sequentially making contact with its surface, the hand can be centered for grasping and manipulation

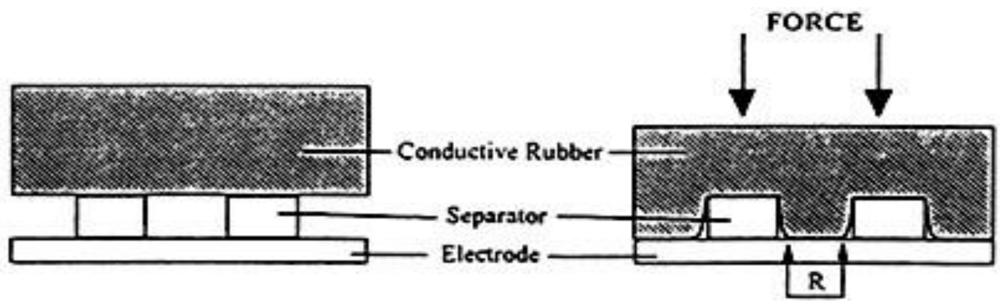


Fig 5.13 Touch Sensor

Multiple binary touch sensors on the inside surface of each finger can provide tactile information. They are also provided on the external surface of a manipulator wrist to provide control signals to guide the hand through the work space.

A touch sensor can also be a part of an inspection probe which is used to measure the dimensions on a work part.

They can be used to indicate the presence or absence of parts in a fixture or pickup point along a conveyor.

B. Tactile Sensor Array

A tactile array consists of a matrix of force sensing elements .The robot hand has the inner surface of each finger covered with a tactile sensing array.

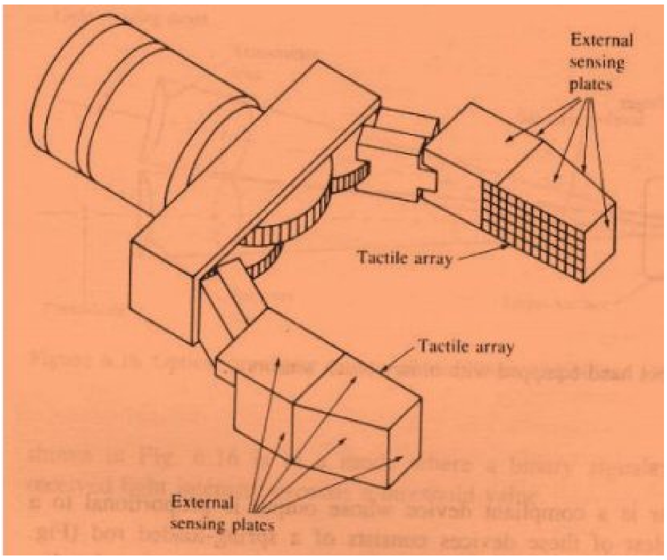


Fig 5.14 Tactile Sensor Array

The sensing array is formed by using multiple individual sensors consisting of an array of electrodes in electric contact with a conductive material (graphite surface).The resistance varies as a function of compression.

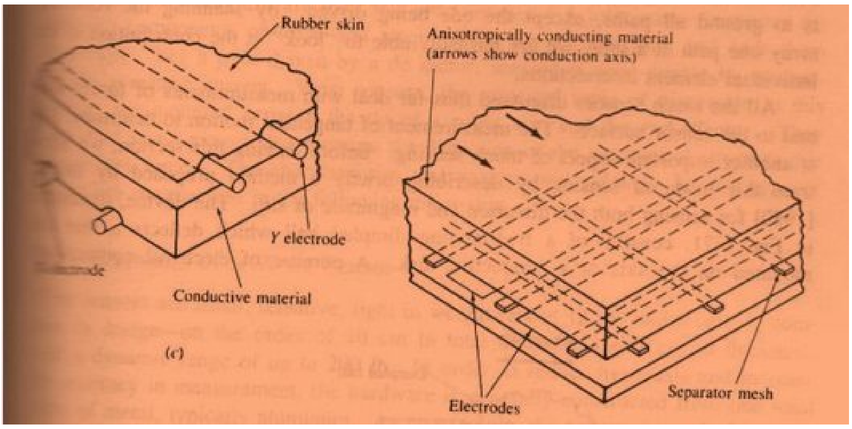


Fig 5.15 Tactile Sensor Array using electrodes

The sensor array can also be formed using artificial skin. An object pressing the surface causes local deformations which are measured as continuous resistance variations .It is transferred into electrical signals whose amplitude is proportional to the force applied at any given point on the surface of the material.

There are many approaches in the construction of the artificial skin. The conductive material is located between two arrays of thin, flat, flexible electrodes that intersect perpendicularly. Changes in resistance as a function of material compression is measured as a flow of current whose magnitude is proportional to the compression of the material.

The device can also be composed of an array of elastomer pads. As each pad is squeezed its electrical resistance changes to the amount of deflection in the pad which is proportional to the applied force. An impression of the object is pictured on a CRO.A force sensing skin of polyvinyl dine di-fluoride is developed. It is a piezoelectric material and generates an output voltage when it is squeezed. It is a pyro electric material and can be used to sense force and temperature. Tactile sensors can be used with pattern recognition techniques and their characteristics like

1. Presence of an object
2. The object's contact area, shape ,location and orientation
3. The pressure distribution

4. Force magnitude and location of the object from the impression of the object on the surface can be determined

C. Force and Torque sensors

The force sensing capability of a robot makes it to do a number of tasks. This includes the capability to group parts of different sizes in material handling, machining, loading and assembly work. In assembly force sensing sensors can be used to find if the screws are cross threaded or the parts are jammed.

1. Force Sensing Wrist

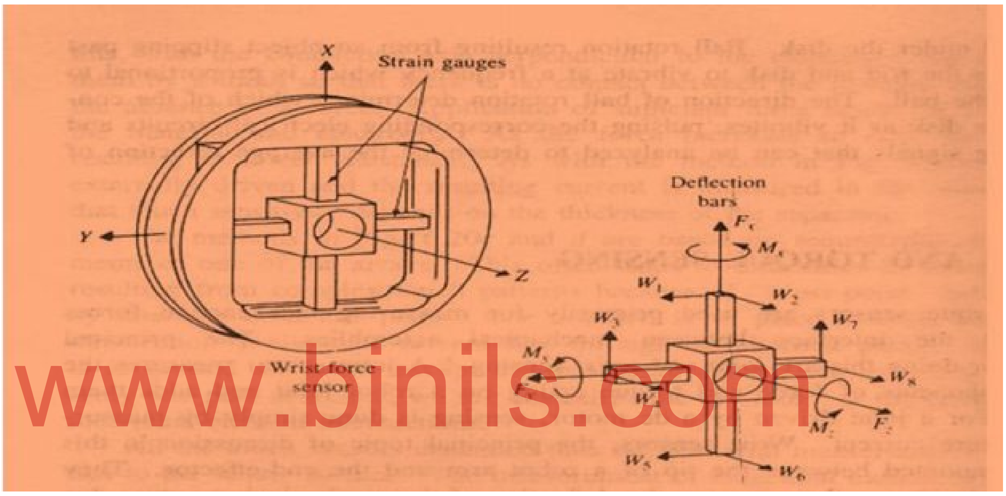


Fig 5.16 Force Sensing Wrist

The force sensing wrist provides the information about the three components of force (F_x,F_y,F_z) and the three moments (M_x ,M_y ,M_z)applied at the end of the arm.

The forces are applied to the wrist in combination and hence they have to be resolved into six components (F_x,F_y,F_z ,M_x ,M_y ,M_z)

The force sensing wrist consists of strain gages that are used to measure the deflection of the mechanical structure due to external forces. Wrist sensors are mounted between the tip of the robot arm and the end effector. They are small, sensitive and light in weight.

The sensor has eight pairs of semiconductor strain gages mounted on four deflection bars, one gage on each side of the deflection bar. The gages on opposite sides of the deflection bars are wired differentially to a potentiometer circuit whose output voltage is proportional to the force component normal to the plane of the strain gage.

5.5 End Effectors

The end effector is a device connected in the wrist of a robot arm and enables the robot to perform a specific task. The various types of end effectors are classified as Grippers and Tools

5.5.1.**Grippers**

They are the end effectors used to grasp and hold objects. The applications are machine loading and unloading, picking parts from a conveyor and arranging parts on a pallet. Grippers are classified as single gripper, double gripper and multiple grippers.

Single gripper: One gripping device is mounted on the robot arm.

Double gripper: It has two gripping devices attached to the wrist and the devices are actuated independently.

Multiple gripper: It has more than two gripping fingers which are actuated separately.

The industrial robot uses the following grippers

1) Mechanical grippers:

It consists of two or more fingers that can be actuated by the robot controller to open and close to grasp the workpart. The fingers are the appendages that make contact with the object. The gripper mechanism translates the power input (hydraulic, pneumatic or electric) into the grasping action of the fingers.

There are two ways of constraining the part in the gripper, physical constriction within the fingers and holding by friction between the fingers and the workpart. The gripping mechanism can use the pivoting movement and the linear movement to open and close the fingers. The finger movement can be actuated by the gear and rack arrangement, cam actuation, screw actuation, rope and pulley actuation and the linkage actuation

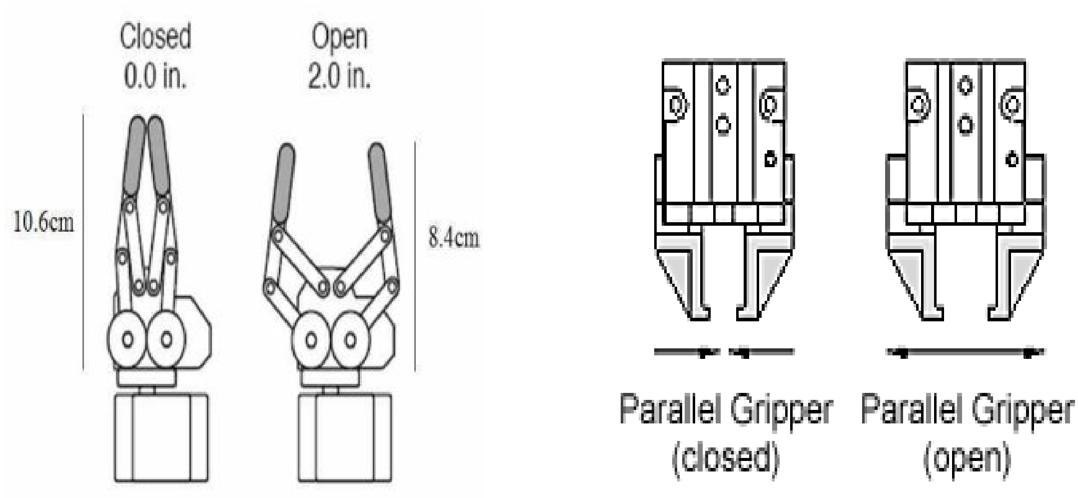


Fig 5.17 Mechanical grippers

2) **Vacuum cups**: They are called suction cups and are used as gripper devices. The objects to be handled should be flat, smooth and clean, to form a vacuum between the object and the suction cup. The suction cups are made of rubber or soft plastic. Vaccum pump and venturi are used to create vaccum. Vacuum pump is a piston operated by an electric motor. The venturi is driven by the differential pressure. It is reliable and simple. The lift capacity depends on the effective area of the cup and the negative air pressure between the cup and the object.

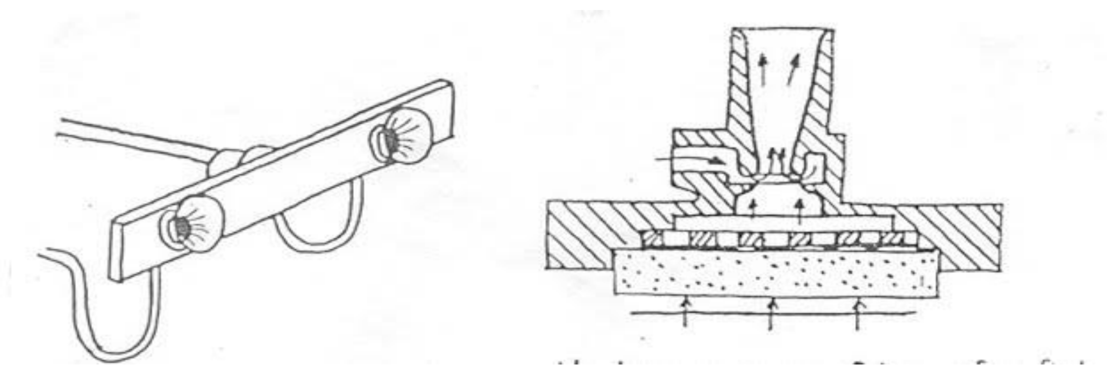


Fig 5.18 Vacuum Grippers

3) **Magnetic grippers**: They are used for handling iron particles. They are fast, the variations of parts sizes are tolerated and parts with holes can be handled .The magnetic grippers are permanent magnets or electromagnets.

4) **Adhesive grippers**: Grippers with adhesive material performs the grasping. It can be used to handle fabrics and other lightweight particles. The items can be gripped on one side only and the adhesive substance may lose its stickiness on repeated usage.

5) **Hooks, Scoops and Miscellaneous devices**: Hooks may be used to handle containers of parts and to load and unload parts from overhead conveyors. The items should have a handle for the hook to hold on. Scoops and Laddles are used to handle materials in liquid or powder form. Chemicals, food particles, granular substances and molten materials are handled. Other type of grippers are diaphragms or bladders that are expanded to grasp the object.

5.5.2 **Tools**:

They are used in applications where the robot must perform some processing operation on the workpart. Examples of the tools are the

a. Spot welding gun
b. Arc welding gun
c. Spray painting gun
d. Assembly tool
e. Heating torch
f. Water jet cutting tool

The robot must be able to transmit control signals to the tool for starting, stopping and regulating the tool actions.

5.6 Drives in a Robot System

A robot will require a drive system for moving their arm, wrist, and body. A drive system is usually used to determine the capacity of a robot. For actuating the robot joints, there are three different types of drive systems available such as:

- Electric drive system,
- Hydraulic drive system, and
- Pneumatic drive system

5.6.1Hydraulic Drive System

A hydraulic system generally consists of the following parts:

1. Hydraulic linear or rotary cylinders and rams to provide the force or torque needed to move the joints and are controlled by servo valve or manual valve.

2. A hydraulic pump to provide high pressure fluid to the system

3. Electric motor to operate the hydraulic pump.

4. Cooling system to get rid of heat (cooling fans, radiators, and cooled air).

5. Reservoir to keep fluid supply available to the system.

6. Servo valve which is a very sensitive valve that controls the amount and the rate of the fluid to the cylinders. The servo valve is generally driven by a hydraulic servomotor.

7. Sensors to control the motion of the cylinders (position, velocity, magnetic, touch,..)

8. Connecting hoses to transport the pressurized fluid.

9. Safety check valves

The hydraulic drive systems are completely meant for the large – sized robots. It can deliver high power or speed than the electric drive systems. This drive system can be used for both linear and rotational joints. The rotary motions are provided by the rotary vane actuators, while the linear motions are produced by hydraulic pistons. The leakage of hydraulic oils is considered as the major disadvantage of this drive. An example for the hydraulic drive system is Unimate 2000 series robot. Applications in mobile robotics are limited.

5.6.2 Electric Drive System

The electric drive systems are capable of moving robots with high power or speed. The actuation of this type of robot can be done by either DC servo motors or DC stepping motors. It is well suited for rotational joints and linear joints. The electric drive system will be perfect for small robots and precise applications. Most importantly, it has got greater accuracy and repeatability. The one disadvantage of this system is that it is slightly costlier. An example for this type of drive system is Maker 110 robot.

The electric motors are playing a major role as actuators in the robots. It is because they deliver high controllability with less maintenance. One of the most commonly used electric motors in the robots is DC servomotors. DC servomotors can be classified into two types such as Brushed DC servomotors and Brushless DC servomotors. The Ac servomotors can also be used.

5.6.3 Pneumatic Drive Systems

Pneumatic drive uses compressed air to move the robot arm.The pneumatic drive system consists of a compressor driven by an electric motor, FRL unit, check valves, pressure valves, directional control valves and actuators. Actuators can be air motors or cylinders (Single Acting or Double Acting).

The pneumatic drive systems are especially used for the small type robots, which have less than five degrees of freedom. It has the ability to offer fine accuracy and speed. This drive system can produce rotary movements by actuating the rotary actuators. The translational movements of sliding joints can also be provided by operating the piston. The price of this system is *less* when compared to the hydraulic drive. The drawback of this system is that it will not be a perfect selection for the faster operations. The pneumatic drive system may be used for fixed applications and rarely used for mobile applications.

5.7 Robot Programming

The robot programming is accomplished by the two programming methods

1. Lead through methods

2. Textual robot languages

The lead through method requires the programmer to move the manipulator through the desired motion path and that path is stored in the memory of the robot controller. This method is known as teach by showing method.

The robot programming by textual languages uses English like language to teach the robot the location of points in the workspace. The robot program defines the path in space. These are required as the computers are used for programming the robots. It increases the complexity of the task that robots can perform with the need to embed logic decisions into the robot work cycle.

The modern robots can accept input from the sensors and other devices. They can send signals to operate the equipment and can make decisions. They can communicate with computers to receive instructions and report the production data. All these capabilities require robot programming.

5.7.1 LeadthroughProgramming methods.

There are two methods to do leadthrough programming

1. Powered leadthrough and 2.Manual leadtrough

Powered Leadthrough Programming

It uses a teach pendant to control the various joint motions and to power drive the robot arm and wrist through a series of points in space. Each point is recorded into the memory for playback during the workcycle .The teach pendant is a small handheld control-box with combinations of toggle switches. dials and buttons to regulate the robot's physical movements and programming capabilities. It is the common method. It is limited to point to point motions. A number of robot applications like part transfer tasks, machine loading and unloading and spot welding are performed.

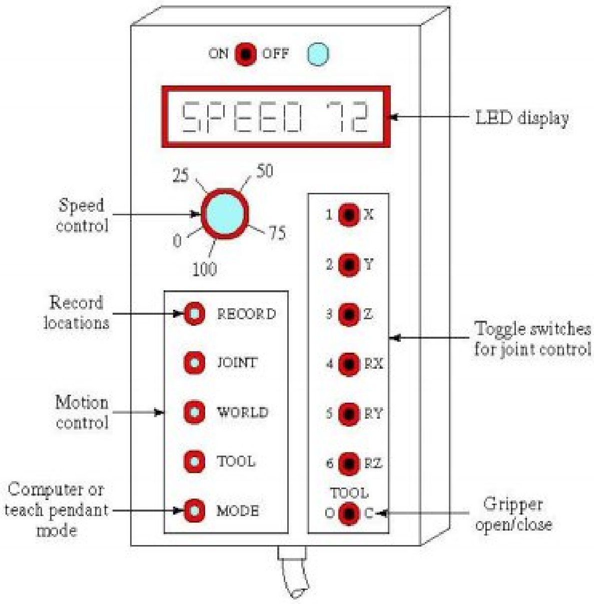


Fig 5.19 Teaching Pendant

Manual Leadthrough Programming

It is used for continuous path programming. The motion cycle involves smooth complex curvilinear movements of the robot arm.The example is spray painting. The robot wrist with the spray paint gun as the end effector must execute smooth regular motion patterns in order to apply paint evenly on a surface. The programmer physically grasps the robot arm and manually moves it through the desired motion cycle.

A teach button is located near the wrist of the robot which is depressed during the movements of the manipulator that will become the part of the programmed cycle. The programmer can allow extraneous moves of the arm. The motion cycle is divided into thousands of closely spaced points along the path and is recorded in the controller memory.

The control systems for the two methods operate in teach mode or run mode. The teach mode is used to program the robot and the run mode is used to execute the program.

The two methods are simple procedures that teach the robots to perform simple repetitive operations in factory environment.

Leadthrough programming is not compatible with modern computer based technologies, data communication networking and integrated manufacturing systems.

5.7.2Textual Programming Languages

The first generation robot programming languages use a combination of command statements and teach pendant procedures for developing robot programs. They possess a variety of structures and capabilities. They were developed to implement motion control.

The second generation language enables the robot to perform intelligent complex tasks. The features and capabilities include motion control, advanced sensor capabilities, limited intelligence and communication and data processing. Another importance of the language was extensibility .The language is designed to operate the robot system. It supports the programming of the robot, control of robot manipulator and interfacing with the peripherals in the workcell. It also performs data communication with other computers in the factory.

The robot programming language elements and functions are

1. Constants ,variables and data objects
2. Motion commands
3. End effector and sensor commands
4. Computations and operations
5. Communication and data processing
6. Monitor mode commands

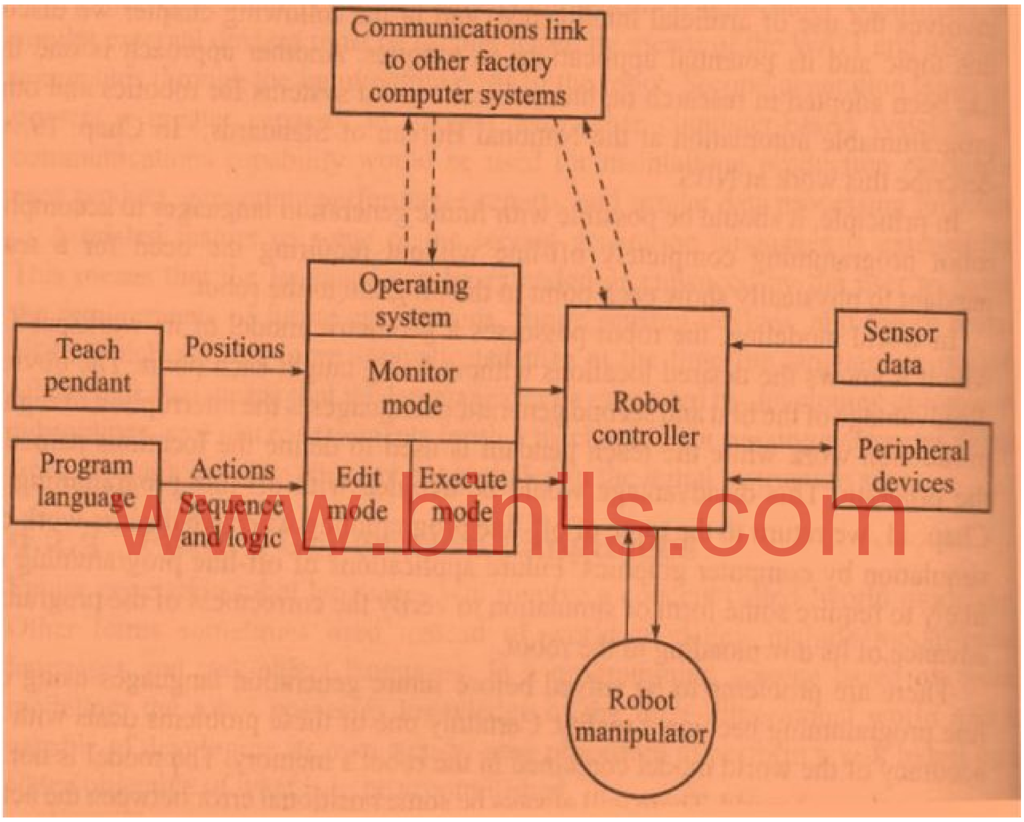


Fig 5.20 Second generation programming language structure

The future generation languages involve world modeling. The robot possess a knowledge of the three dimensional world and is capable of developing its own step by step procedure to perform a task based on the objective to be accomplished.

The features and capabilities of a few programming languages are

1. AL Language

It was a second generation robot language developed by Stanford University.It can be executed on a VAX computer and areal time control of the arms are performed on a stand alone PDP-11.Its characteristics are

- High level language with features of ALGOL and PASCAL.
- Supports robot level and task level programming
- Compiled into low level language and interpreted on areal time control machine.
- Has real time programming constructs like synchronization, concurrent execution and ON conditions.
- Support for world modeling.

2. AML language

A Manufacturing **L**anguage developed by IBM.t is the control language for IBM RS/1 assembly robot. The RS/1 is a Cartesian manipulator with six degrees of freedom. Its first three joints are prismatic and last three joints are rotary.

- It provides a convenient environment where different user interfaces can be built.
- It has the features of LISP and APL.
- Supports data aggregation.
- Supports joint space trajectory planning subject for position and velocity constraints.
- Provides absolute and relative motions.
- Provides sensor monitoring for interrupt motion.

These two languages are used for robot oriented programming.

3. RAIL language

It was developed by AUTOMATIX INC. for the control of both vision and manipulation.

- It was an interpreter based on PASCAL.
- Many constructs to support inspection, assembly and arc welding systems.
- The central processor is MOTOROLA 68000.
- It is supplied with custom designed Cartesian arm for assembly tasks and a Hitachi process robot for arc welding.

4. RPL language.

It was developed at SRI International to facilitate development, testing and debugging of control algorithms for a medium automatic manufacturing system.

- It is similar to LISP and FORTRAN.
- The RPL language is implemented using Subroutine calls.
- The RPS robot programming system has a compiler and an interpreter.

5. VAL II language

It is a robot programming language designed for use with Unimation Robots.

- It has structures of BASIC with many command words.
- It has its own operating system.
- VAL is implemented using C and assembly language.
- It is released for use with Unimate 2000 and 4000 series.

5.8 Robot Applications

The industrial environment that makes the use of robots necessary are

- Work environment hazardous to human beings
- Repetitive tasks
- Boring and unpleasant tasks
- Multishift operations
- Performing at a steady pace
- Operating for long hours without rest
- Responding to automated environment
- Minimizing variations

The basic robot applications are

- **Material handling applications**
  They involve the movement of material or parts from one location to another. Material may be raw material for production or product ready for shipment. The robot is connected with a gripper. The material handling operations include part placement, palletizing, and/or de-

palletizing, machine loading and unloading. Stacking and insertion operations.

- **Processing operations**
  The operation requires the robot to manipulate a special process tool as the end effector. The applications include welding, riveting, spray painting, machining, polishing and applying adhesives and sealants operations.
- **Assembly operations**
  Assembly operations involve part handling, manipulationof special tool and other automatic tasks and operations.

- **Inspection operations**
  The robot positions the work part to an inspection device or loads a part into an inspection machine for testing. The robot may also manipulate a device or a sensor to perform the inspection.

5.8.1 Material handling applications.

A robot is equipped with a gripper designed to handle the transfer the materials or parts.

The operations performed are

- Part placements
- Palletizing and/or De-palletizing
- Machine loading and/or unloading
- Stacking and insertion applications

For material handling capability the robot must have the features.

- The manipulator must be able to lift the part safely.
- The work volume of the robot should cover the work cell.
- The robot must be a cylindrical co-ordinate type.
- The robot controller must have a large memory to store all the programmed points so that the robot can move from one location to another.
- The robot must have the speed required for the transfer cycle.

1) Part Placement

The primary purpose is to pick a part from one location and move it to another location. The part is presented to the robot by a mechanical feeding device or a conveyor in a known location and orientation. The known location is a stationary location, achieved either by stopping the conveyor at the appropriate location or by using a mechanical stop to hold the part at the stationary location. An input interlock, a limit switch is designed to indicate that the part is in position and is ready for pickup. The robot would grasp the part, pick it up, move it and position it at the desired location. The orientation of the part remains unchanged during the move. The desired location is usually at a position where there is a capability to move the part for the next delivery by the robot.

The robot needs only two degrees of freedom, the first degree of freedom is to lift the part from the pick up place and put it down at the drop off point and the second degree of freedom is to move the part between these two points. In some pick and place operations the part may be reoriented during the move and this requires additional degree of freedom. The two complications in this operation are when the part is on a moving conveyor and the parts are of different sizes which would require additional sophisticated sensing and interlocking capabilities.

2) Palletizing and De-palletizing operations.

The use of pallets for material handling and storage is widely used in industry. Instead of handling individual cartons or containers, a large number of these containers are placed on a pallet and the pallet is handled. The pallet can be move mechanically within the plant or warehouse by forklift trucks or conveyors. Shipment of palletized product to the customer is common because of the convenience in handling. The handling of the individual cartons is done when the product is placed on a pallet or when it is removed from a pallet.

Palletizing: The loading of the cartons onto pallets is a heavy work and repetitive work. Hence robots are used here. They are programmed using textual languages. The variation of the carton location during palletizing uses a computer controlled robot that manipulates the different pallet locations required during loading of a given pallet. The number of variations on the palletizing operations, all use the same work cycle uses a robot with features to perform the specific operation.

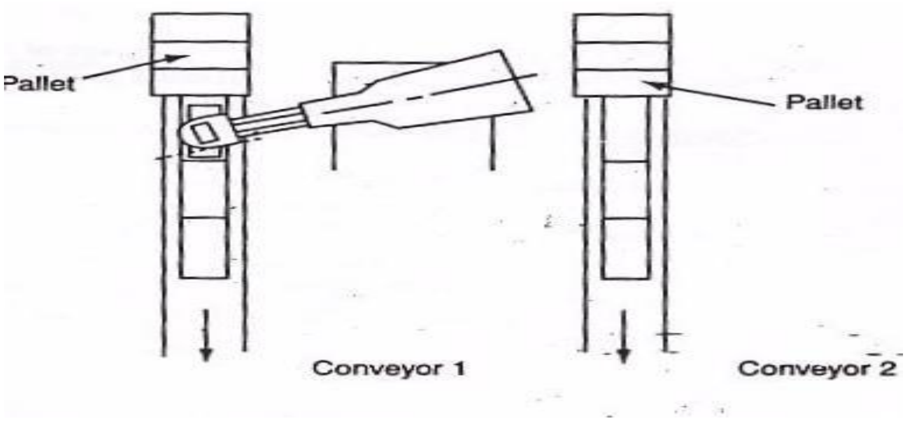


Fig 5.21(a) Palletizing operation1

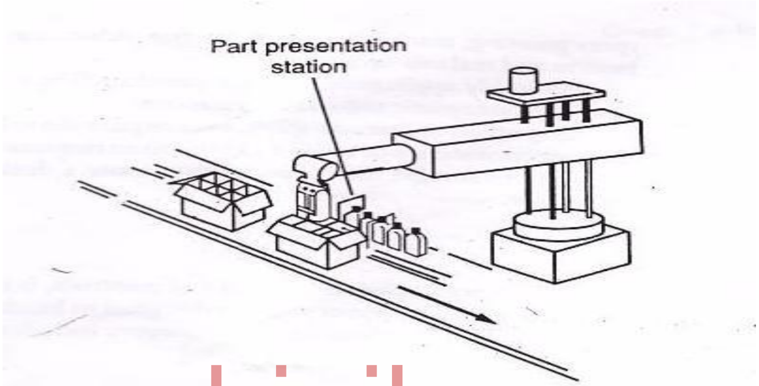


Fig 5.21(b) Palletizing operation2

The robot operations may have the following problems during palletizing, the pallets may vary in size, different products may be loaded on the pallets and there may be difference in the number and combination of cartons sent to different consumers. To deal with these cases, new methods may be devised such as using subroutines for programming intheworkcell and using optical reading schemes to identify the variations in the work cycle.

De-palletizing is the process in which the robot removes the cartons from a pallet and places it on a conveyor or a different location.

3) Machine loading and unloading

Machine loading: The robot must load the raw material or work part into the machine but the part is ejected from the machine by some other means. In pressworking operation the robot is programmed to load metal planks into the press and the finished products are allowed to drop by gravity.

Machine unloading: The machine produces finished parts from raw materials that are loaded directly into the machine without robot assistance.

Machine load /unload: The robot loads the raw work part into the process and unloads a finished product

Die casting is an example of machine unloading. To increase the productivity of a cell it may include more than one production machine. Die casting is a manufacturing process in which molten metal is forced into a cavity of a mould at high pressure. The mould is called a die The process is used to cast metal parts with sufficient accuracy. Common metals used in die casting are alloys of zinc.tin, lead, aluminium ,magnesium and copper.

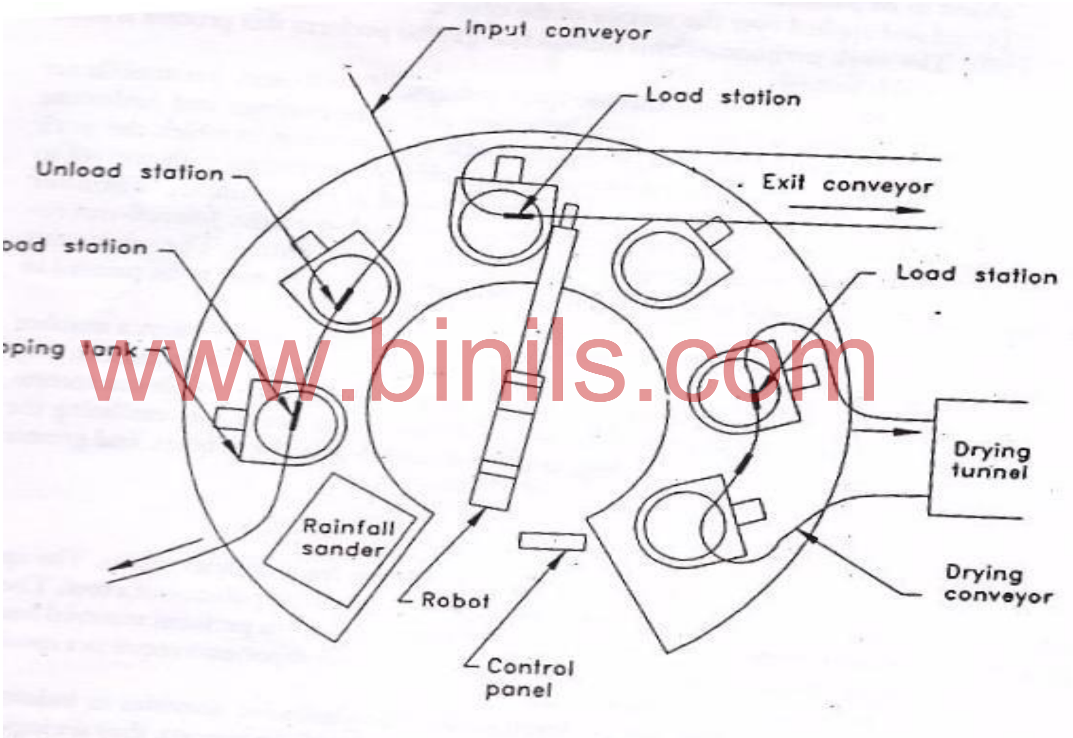


Fig 5.22 Die casting operation

The die includes two halves that are opened and closed by a die casting machine. During operation, the die is closed and molten metal is injected into the cavity at high pressure by a pump. To ensure the cavity is filled, the metal is allowed to overflow as flush in between the halves. When the metal has solidified the die is opened and the cast is ejected from the mould cavity. When the part is removed from the machine it is quenched. The flush created during the casting process is removed by trimming process which cuts around the periphery of the part. The die casting production cycle consists of casting, removing the part from the machine, quenching and trimming.

The production rate includes 100 to 700 openings of the die per hour. The work tends to be hot, repetitive, dirty and unpleasant. This was the first process where an industrial robot was first used in the year 1961.This is straight forward robot application. The robot cycle is interlocked with the machine cycle using limit swatches.

5.9Automated Guided Vehicle

A Computer-Controlled, Non-manned, Electric Powered Vehicle Capable of Handling Material

The AGV is a

- Driverless Vehicle
- Electric motors, battery powered
- Programming capabilities
- Destination
- Path selection
- Positioning
- Collision avoidance
- System Discipline

Modern AGVs are computer controlled vehicles with onboard microprocessors. They have

- Position feedback system to correct path
- Communication between vehicles via system controller
- RF communication
- Electric signals
- System management computers
- Optimizing the AGV utilization
- Tracking the material in transfer and directing the AGV traffic

5.9.1 Components of an AGV

- The Vehicle
- No operator
- The guide path– The path for the AGV
- The control Unit – Monitors and Directs system operations including feedback on moves, inventory, and vehicle status.

- The computer interface – Interfaces with mainframe host computer, the automated storage and retrieval system (AS/RS), and the flexible manufacturing system.

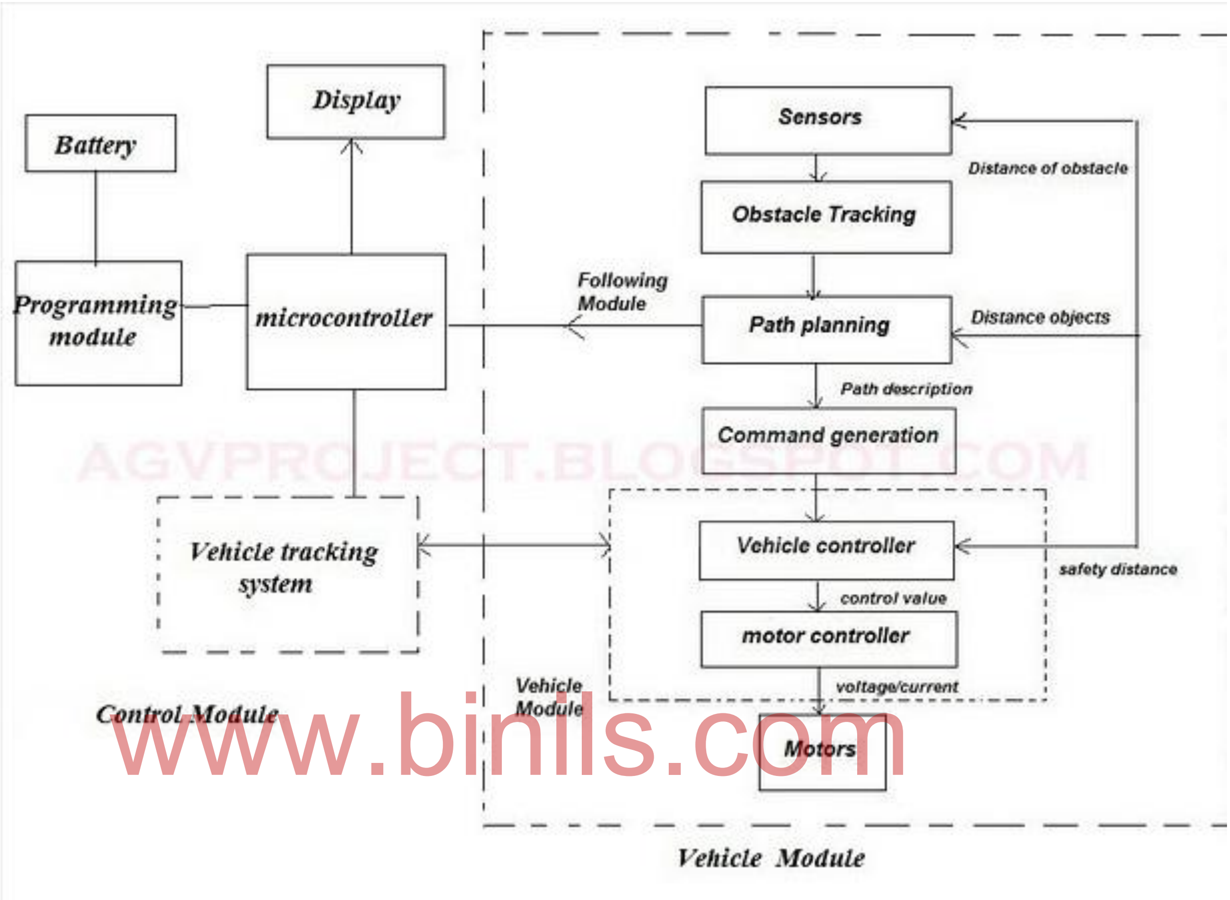


Fig 5.23 Block diagram of an AGV

5.9.2 Examples of AGV

- AGVS towing vehicle
- AGVS unit load carriers
- AGVS pallet trucks
- AGVS forklift trucks
- AGVS light-load transporters load transporters
- AGVS assembly-line vehicles

The goal of an AGVS guidance system

- Keep the AGV on track/predefined path

- One of the major advantages of AGV is ease in modification given by the guidance system for changing the guide path at low cost compare to conveyors, chains, etc.
- Another benefit is the guide path is flexible which means intersection of path is possible.
- Generally, guide path does not obstruct another system.
- The guidance systems can be selected based on the type of AGV selected, its application, requirement and environmental limitation

Fig 5.24 Example of Fork Lift AGV

REVIEW QUESTIONS

	UNIT V ROBOTICS
	PART A -Two marks questions
1.	What is an industrial robot?
2.	What are the applications of a robot?
3.	What are the advantages of a robot?
4	What is robot anatomy?
5.	What is a proximity sensor?
6.	What is a range sensor?
7.	What is a tactile sensor?
8.	What is an end effector?
9.	What is leadthrough programming?
10.	What are the types of robot drives?
11.	What is an automated guided vehicle?
12.	What is degree of freedom?
	PART B-Three marks questions
13	How are the robots classified?
14.	Discuss in brief the robot anatomy.
15.	Differentiate contact and non- contact sensors.
16.	Write short notes on the different robot body arm configurations.
17.	What are material handling operations?
	PART C- Ten marks questions
18.	Explain the robot anatomy with a diagram.
19.	Explain the construction and working of a proximity sensor.

20.	Explain the construction and working of a range sensor
21.	Explain the construction and working of a tactile sensor
22.	Explain the types of end effectors in a robot.
23.	Explain the robot programming,
24.	Explain the machine handling applications of robot.
25.	Explain the different drives in a robot.
26.	Explain the automated guided vehicle system.

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