

**TRENDS IN ELECTRICAL & MECHANICAL ENGINEERING**

**MEM-101/201**

UNIT – 4

**(INTRODUCTION TO MECHATRONICS)**

### **What do we study in Mechatronics?**

- The basics of Mechatronics, its evolution and scope.
- The advantages & disadvantages of Mechatronics.
- Industrial Applications of Mechatronics, specifically Autotronics, Bionics and Avionics.
- Various types of sensors and transducers.
- Various types of actuators, specifically mechanical, pneumatic and hydraulic actuators.

### **Why do we need to study Mechatronics?**

- To understand how mechanical systems (e.g., motors, actuators) interact with electronic systems (e.g., sensors, controllers).
- The principles of Mechatronics are applied in everyday technologies, from the electronics in consumer gadgets to the control systems in industrial machinery. Understanding these principles helps you contribute to meaningful and impactful innovations.
- To generate ability to tackle complex problems requiring a multidisciplinary approach.
- Overall, studying Mechatronics equips you with the knowledge and skills to design, analyze, and improve complex systems and technologies in a wide range of fields.

### **Where do we use Mechatronics?**

- Mechatronics is used in almost all major sectors like robotics, manufacturing, automobile industry, aerospace industry, production of medical devices, smart devices, etc.

## 4.1 INTRODUCTION TO MECHATRONIC SYSTEMS

### 4.1.1 Mechatronics:

Mechatronics is a concept originated in Japan in 1969. This term was coined by the Japanese Scientist Yoshikaza. It is a multidisciplinary engineering design approach. It can be defined as a combination of Mechanical Engineering, Electrical Engineering, Electronics, Computer Science, Information Technology and other streams of engineering in order to design and manufacture useful products.

Nowadays, Mechatronics is used vastly, for example in: Automobiles, Home appliances like Washing Machines and Air Conditioners, Heat Seeking Missiles, Elevators, Escalators, etc... The list is endless!

### 4.1.2 Key Elements (Components) of a Mechatronic System:

There are these four key elements of a mechatronic system:

(1): Physical System being controlled:

The system being controlled may be mechanical, fluidic, chemical, thermal or electrical.

(2). Sensors:

Sensors are the eyes and ears of the controller. They detect the state of system parameters and send the signal to the controller.

(3). Controller:

The controller is the brain of the mechatronic system. It reads the input signal, compares them to the required states & sends the output signal to the actuators.

(4). Actuator:

Actuators control the physical system by providing relevant physical input like force, torque, etc. They can be mechanical, hydraulic, pneumatic or electrical as per the situation.

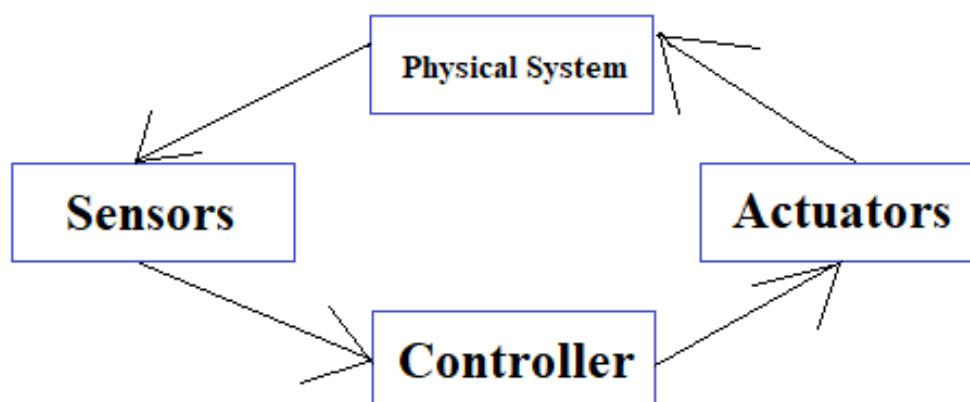


Figure 4.1 – Block Diagram: Key Elements of Mechatronic System

### **4.1.3 Evolution of Mechatronics:**

- First Stage 1969-1979: During this era, technologies used in Mechatronics developed individually & rather independently of each other.
- Second Stage 1980-1989: During this era, the integration of different technologies started taking place. A notable example is opto-electronics, which is an integration of Optics and electronics. The concept of hardware/software co-design also started in this era.
- Third Stage 1990 onwards: This era is considered as start of 'Mechatronic Age'. The most notable aspect of this stage is more and more integration of different engineering disciplines and increased use of computational intelligence in the mechatronic products and systems. Another important development in this era is the introduction of micro-actuators & micro-sensors and thereby developing the concept of "micromechatronics".

### **4.1.4 Scope of Mechatronics:**

Mechatronics has large scope for engineers from all branches of engineering. For example:

- A mechanical engineer can work in the areas like Robotics, Industrial Automation, CAD, CAM, CIM, Product Design & Development, etc.
- A computer engineer can work in the areas like Artificial Intelligence (AI), Simulation, etc.
- An electronics engineer can seek job in the areas like VLSI Design, Robotics, Avionics, etc.
- An electrical engineer can work in the areas like Inspection, Robotics; as System Engineer, etc.
- An aerospace engineer works a lot on Mechatronic Systems, can seek jobs in Avionics, etc.

### **4.1.5 Advantages of Mechatronics:**

There are many advantages associated with Mechatronics, such as:

- It provides rapid manufacturing operations.
- It helps in optimizing performance & quality.
- It provides high degree of flexibilities in operations & processes.
- It enhances plant utilization.
- Mechatronic products are better than those obtained from traditional methods.
- Mechatronics results in greater productivity.
- Mechatronics results in greater precision and high accuracy.
- Mechatronics results in better process planning & control.

### **4.1.6 Disadvantages (Limitations) of Mechatronics:**

There are some disadvantages also associated with mechatronic systems, such as:

- Mechatronics requires knowledge of different disciplines.
- The design cannot be finalized easily and it is usually complex.
- Mechatronic systems require highly skilled man power.
- Initial costs of the systems are usually high.
- Mechatronic systems involve a greater risk of component failure.
- Repairing and maintenance of mechatronic system is costly.

### 4.1.7 Objectives of Mechatronics:

The primary objective of Mechatronics is to integrate the mechanical systems with electrical, electronics & Computer systems to make useful products & systems. The Other objectives are:

- Customer Satisfaction & comfort.
- To improve existing products by better design.
- To improve overall efficiency of the system.
- To achieve higher accuracy & precision, etc.

### 4.1.8 Comparison between Traditional & Mechatronic Design Approach:

Traditional Design Approach	Mechatronic Design Approach
<ol style="list-style-type: none"> <li>1. Bulky System.</li> <li>2. It is a process involving interactions between a few disciplines of engineering.</li> <li>3. The control is accomplished manually.</li> <li>4. Synchronization is mechanical.</li> <li>5. Less accurate</li> <li>6. Low Cost</li> <li>7. Less flexible</li> <li>8. Heavy Structures</li> </ol>	<ol style="list-style-type: none"> <li>1. Compact System</li> <li>2. It is based on integration of various emerging technologies.</li> <li>3. Usually a microprocessor is used as controller.</li> <li>4. Synchronization is electronic.</li> <li>5. More accurate</li> <li>6. High Cost</li> <li>7. More flexible</li> <li>8. Lighter Structures</li> </ol>

### 4.1.9 Industrial Applications of Mechatronics:

Mechatronics is extensively used in modern industries. Specifically, automobile industry, bio-medical systems industry and aviation industry have been benefitted a lot through Mechatronics. The application of Mechatronics in these industries has created 3 specialized disciplines called Autotronics, Bionics & Avionics.

#### **Autotronics:**

Integration of Automobile Engineering & Mechatronics is called Autotronics. Autotronics results in more comfortable, safe, fuel efficient and less- polluting vehicles.

#### **Applications of Autotronics:**

A few notable applications of Autotronics are:

1. ECU (Engine Control Unit)
2. Windscreen Wiper Mechanism
3. Digital Speedometer & odometer.
4. ABS (Antilock Braking System)
5. Air bag deployment system
6. Automatic headlamps
7. Automatic cooling system for passengers
8. Transmission system

## Brief Explanation of a few Autotronic Systems -

### 1. Engine Control Unit (ECU):

It consists of an electronic control on various actuators to ensure optimal engine performance.

### 2. Windscreen Wiper Mechanism:

It is a device used to clear rain water from the front glass of the vehicles. A stepper motor microprocessor is used to oscillate the wiper back & forth in this mechanism.

### 3. Anti Lock Braking System (ABS):

#### Need for ABS:

Suppose the brakes are suddenly applied with full force. This results in locking up of wheels (ceasing rotation) and the vehicle starts skidding. This results in increased stopping distance, which may cause an accident. This is why an Anti-Lock Braking System is much needed to ensure safety during braking.

ABS is an automobile safety system that allows the wheels on a vehicle to maintain tractive contact with the road according to driver inputs while braking, preventing the wheels from locking up. ABS offers improved vehicle control & decreases the stopping distances on dry as well as slippery surfaces. ABS typically includes a central electronic control unit, four wheel speed sensors, and at least two hydraulic valves within the brake hydraulics.

#### Operation of ABS:

The ECU constantly monitors the rotational speed of each wheel. If it detects a wheel rotating significantly slower than the others; which is a condition of impending wheel lock; it actuates the valves to reduce hydraulic pressure to the brake at the affected wheel, thereby reducing the braking force on the wheel. The wheel then turns in the desired speed. Conversely, if the ECU detects a wheel turning significantly faster than the others, it actuates the valves to increase hydraulic pressure to the brake at the affected wheel, thereby increasing the braking force to bring its rotational speed down, in the desired range.

ECU is programmed to disregard differences in wheel rotation speeds below a critical threshold; because when the car is turning, the two wheels towards the centre of the curve turn slower than the other two.

If a fault is developed in any part of the ABS; usually a warning light is illuminated on the vehicle panel, and the ABS will be disabled until the fault is rectified.

### 4. Air Bag Deployment System:

An Air Bag is a vehicle safety device. It is a type of occupant restraint system that consists of a flexible fabric bag, also known as an airbag cushion. The airbag module is designed to inflate rapidly then quickly deflate during a collision with another object. The purpose of the airbag is to provide protection to the occupants. Air Bag provides an energy-absorbing surface between the occupants and vehicle parts like windscreen, structural body, instrumental panel, steering wheel, etc.

### **Operation of Air Bags:**

The Airbags in the vehicles are controlled by a central Airbag Control Unit (ACU), which is a specific type of ECU.

ACU monitors a number of sensors within the vehicle, including accelerometers, impact sensors; door pressure sensors, wheel speed sensors, brake pressure sensors, and seat occupancy sensors.

The Airbag & its inflation mechanism is concealed within the steering wheel boss (for the driver) and within the dashboard (for the front passenger), behind plastic flaps or doors, which are designed to "tear-open" under the force of inflating bag.

Once the requisite "threshold" has been reached or exceeded; the ACU will trigger the ignition of a gas generator propellant to rapidly inflate a fabric bag. As the occupants collide with and squeeze the bags; the gas escapes in a controlled manner through small vent holes.

Typically, the decision to deploy an airbag in a frontal crash is made by the ACU within 15 to 30 milliseconds after the onset of the crash, and both the driver & passenger airbags are fully inflated within approximately 60 to 80 milliseconds after the first moment of vehicle contact.

### **Bionics:**

Bionics is the combination (integration) of Biomedical/Biological Sciences and Mechatronics. It results in enhanced functionality and control of biomedical equipments/machines, better mobility & easy navigation facilities for biomedical operators, accurate & fast diagnosis, etc.

### **Applications of Bionics:**

A few notable applications of Bionics are:

1. CGM (Continuous Glucose monitoring)
2. Photodynamic Therapy for cancer treatment
3. Biostructures (nano-scale bio-structures)
4. Bionic Limbs (Artificial Hands/Legs)
5. Biosensing
6. DNA Sensing
7. X-Ray Machine
8. ECG

### **A few notable examples of Bionics-based processes -**

#### **1. CGM (Continuous Glucose monitoring) - Glucose Detection through CGM:**

Detection of glucose levels in blood is a good Example of biosensing. Diabetic patients cannot control their insulin level if the level of blood glucose fluctuates tremendously. If the level gets too high or too low, their condition can become life-threatening. Such patients must actually draw blood on daily basis or even more often to monitor blood sugar level.

The optical conduction method & molecular recognition method are not compatible with an "implantable" simple device that could automatically show/sense the glucose level in the body.

This problem has been resolved by CGM (Continuous Glucose Monitoring), that works through a tiny sensor inserted under the skin of the patient, usually on belly or arm to measure the interstitial glucose level, which is the glucose found between the cells. The sensor tests glucose every few minutes. A transmitter wirelessly sends the information to a monitor. The monitor may be a part of an insulin pump or a separate device, which the patient might carry in a pocket or purse. An alarm can also be a part of CGM, triggering sound in case of sudden rise or sudden drop in blood sugar level.

Currently, one CGM model is approved for treatment, the Dexcom G5 Mobile. The CGM sensor is to be replaced every 3 to 7 days, depending on the model.

## **2. Bionic Implants:**

These implants aim to improve the standard of living for people who have damaged body parts such as arms, legs, eyes, or even ears. It's extremely hard to mimic the actions created by regular limbs. It's something that software and hardware engineers have a lot of trouble working with. To solve this problem, all the successful bionics systems use "Machine Learning" to mimic physical movements. Myoelectric sensors are used in bionic limbs to generate an electrical signal from muscle contractions.

\*Myo = muscles

This is useful because it can get signals from the still functional nerve endings of the amputated limb. This means that the sensors can pick up when the user wants to move that area. In some cases, to improve the accuracy of myoelectric sensors, small incisions are made to place them closer to the muscle/nerve endings.

## **Avionics:**

Avionics is the integration of Aviation & Mechatronics.  
 Avionics is widely applicable in aerospace industry.

## **Applications of Avionics:**

The major applications of Avionics are as follows:

1. Cockpit Instrumentation
2. Aircraft Safety Devices
3. Aircraft Guidance & Control
4. Air Traffic Control (ATC)
5. Aircraft Engine Control
6. Microsatellites

## **Brief Explanation of a few Avionic Systems -**

### **1. Cockpit Instrumentation:**

A cockpit flight deck is the area, usually near the front of an aircraft, from which a pilot controls the aircraft. Various instruments available in cockpit are:

#### **(1) Pitot Tube:**

It determines the airspeed of the aircraft, i.e. the speed of an aircraft relative to the air.

**(2) Aircraft Altimeters:**

It shows the live altitude of aircraft (above sea-level). For this purpose, an aneroid capsule (bellow) or a piezo-resistive silicon sensor is mostly used.

**(3) Vertical Speed Indicator (VSI):**

It indicates the rate of rise or drop in the altitude of the aircraft in feet per minute. Newer designs directly measure the static pressure of the atmospheric air using a pressure sensor to detect the changes in altitude, without measuring air-flow. A piezo-resistive Silicon Sensor is mostly used for this purpose.

**(4) Air-data Computers:**

The Air-data computers centralize the computation of air data from a number of inputs, like Static pressure, Total pressure, Air stagnation temperature, Angle of attack, etc.

**(5) Air Speed Indicators:**

It shows the speed of the air craft relative to the surrounding.

**(6) Angle of Attack Transducer:**

It measures the acute angle between the velocity vector of the aircraft & some reference axis such as chord of an aircraft.

**2. Aircraft Guidance & Control:**

To guide & control an aircraft, the following three functions are required:

**(1) Navigation:**

The determination of position and direction of an aircraft is navigation. Avionics provides the use of satellite-based systems such as GPS and WAAS, ground-based systems such as VOR and LORAN or any combination thereof.

**(2) Guidance:**

It determines and corrects the deviation from the indicated path. The aircraft guiding system measure position, velocity, acceleration and predict the destination, determining a preferred path to correct the error & controls the forces to change the path from steering instructions. All of these functions can be automated.

**(3) Steering:**

Steering is used to select a proper series of changes in the path. Steering system design is complex; it depends mainly on the weight of the aircraft.

**3. Air Traffic Control (ATC):**

Air traffic control is a service provided by ground-based controllers, who direct aircrafts on the ground and also during the flights. ATC staff can provide advisory services to pilots in controlled/non-controlled airspace. The primary purpose of ATC worldwide is to prevent collisions, to organize & expedite the flow of air traffic; and to provide information & other supports to Pilots. In some countries; ATC is operated by the military.

Position reporting by the pilot to the Air Traffic Controller over a voice radio link is the basic source of Air traffic control position data. The ground controller can ascertain the aircraft location independently using radars. Another important task of ATC is Minimum Safe Altitude Warning (MSAW). MSAW may be issued to pilots, if the aircraft is appearing to be flying too low.

## 4.2 SENSORS AND TRANSDUCERS

### 4.2.1 Similarities between Sensors and Transducers:

- Both are used to sense and measure changes in their environment.
- Both give output signals based on the changes they sense/measure.
- Both are usually used as parts of a larger system or device.

### 4.2.2 Difference between Sensors and Transducers:

A sensor may refer to just the sensing element, which may or may not convert the input signal into another format, whereas a transducer converts the input signal into a different output signal.

### 4.2.3 Definition of Sensor:

Sensor is the first element which is directly coupled to the system under study for measurement purpose. Sensor may be defined as an element that senses a variation in input energy to produce a proportional variation in another or same form of energy.

### 4.2.4 Definition of Transducer:

Transducer uses a transduction principle to convert a specified input into usable output. Transducer may be defined as a device that converts the input signal into some different form for the purpose of measurement.

There are some misconceptions about transducer among various authors. Those misconceptions and corresponding facts are tabulated as follows:

Myth (Misconception)	Fact (Clarification)
1. Transducer is a device that converts non-electrical signal into electrical signal.	1. Not always true, as there are mechanical transducers as well. For example: U-Tube manometer is also a transducer, it converts pressure into the rise of manometric fluid. A clinical Thermometer is yet another example, as it converts temperature into the rise of mercury level in the glass-tube.
2. Transducer is a device that converts one form of energy into another.	2. Completely false; in that way, turbines, pumps, motors and generators will all be called Transducers. Transducer is a device which affects the transformation of information from one form of energy to another.

### **4.2.5 Types of Sensors:**

#### **Based on measurand (the quantity being measured) –**

- |                       |                        |
|-----------------------|------------------------|
| 1. Temperature Sensor | 6. Accelerometer       |
| 2. Force Sensor       | 7. Ultrasonic Sensor   |
| 3. Pressure Sensor    | 8. Displacement Sensor |
| 4. Position Sensor    | 9. Flow & Level Sensor |
| 5. Humidity Sensor    | 10. Light Sensor, etc. |

#### **Based on detection –**

- |                     |                       |
|---------------------|-----------------------|
| 1. Touch Sensor     | 4. Alcohol sensor     |
| 2. Colour Sensor    | 5. Smoke Sensor, etc. |
| 3. Proximity Sensor |                       |

#### **Based on Position (Within or outside the system) –**

##### **Internal Sensors –**

Internal sensors are for internal feedback control loop within a system. They are used to monitor & control the various elements in the mechatronic system.

Examples: Potentiometers, Tachometers, Resolvers, Optical encoders, Hall Effect sensors, etc.

##### **External Sensors –**

These are peripheral devices used in mechatronic Systems. External sensors are used when we wish to control or measure various parameters affecting the system.

Examples: Proximity Sensor, Range Sensors, Force Sensors, Machine vision Sensors, etc.

### **4.2.6 Infrared Proximity Sensor (IR Sensor):**

IR sensor is an electronic device, which emits the light in order to sense some object of the surroundings. An IR sensor can measure the heat of an object as well as detects the motion. Usually, in the infrared spectrum, all the objects radiate some form of thermal radiation. These types of radiations are invisible to our eyes, but infrared sensor can detect these radiations.

The emitter is simply an IR LED (Light Emitting Diode) and the detector is simply an IR photodiode. Photodiode is sensitive to IR light of the same wavelength which is emitted by the IR LED. When IR light falls on the photodiode, the resistances and the output voltages will change in proportion to the magnitude of the IR light received.

#### **Construction of IR Sensor –**

An IR sensor consists of an IR LED and an IR Photo diode, together they are called as Photo Coupler or Opto Coupler. IR Transmitter is a light emitting diode (LED) which emits infrared radiations called as IR LED's.

Even though an IR LED looks like a normal LED, the radiation emitted by it is invisible to the human eye. Infrared receivers detect the radiation from an IR transmitter. IR receivers come in the form of photodiodes and phototransistors.

### Working Principle of IR Sensor –

The emitter is an IR LED and the detector is an IR photodiode. The IR photodiode is sensitive to the IR light emitted by an IR LED. The photo-diode's resistance and output voltage change in proportion to the IR light received. This is the underlying working principle of the IR sensor. When the IR transmitter emits radiation, it reaches the object and some of the radiation reflects back to the IR receiver. Based on the intensity of the reception by the IR receiver, the proximity of the object is determined.

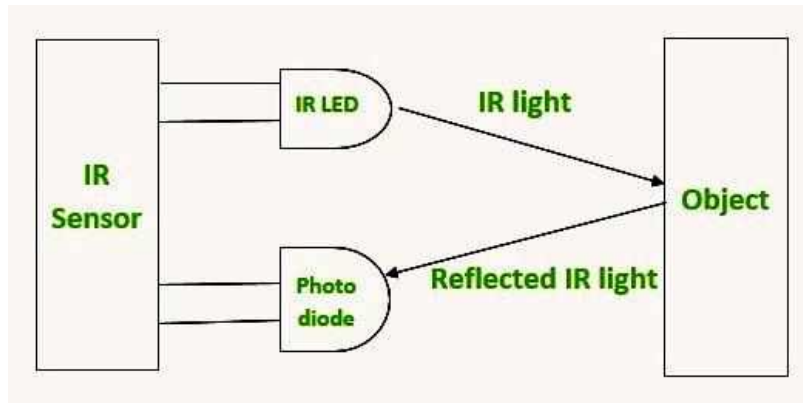


Figure 4.2 – Block Diagram of an IR Sensor

### 4.2.7 Types of Transducers:

#### Based on need of an external power source –

1. **Active Transducers** – Active Transducers are those transducers, which do not require external power source for their operations. Examples: Thermocouple, Thermometer, etc.
2. **Passive Transducers** – Passive Transducers are those transducers, which require an external power source for their operations. Examples: Strain Gauge, Thermistors, etc.

#### Based on quantity to be measured –

Pressure Transducers:	U Tube Manometer, Bourdon Tube Pressure Gauge
Temperature Transducers:	Thermometer, Thermocouple, Optical Pyrometer
Displacement Transducer:	Linear Variable Differential Transformer (LVDT)
Flow Rate Transducers:	Venturimeter, Orifice meter
Strain Gauge Transducers:	Bonded Strain Gauge, Unbonded Strain Gauge
Force Transducers:	Proving Ring
Torque Transducers:	Prony Brake Dynamometer

#### Based on principle of operation –

1. Capacitive Transducers
2. Resistive Transducers
3. Inductive Transducers
4. Photoelectric Transducers, etc.

### 4.2.8 Resistive Transducers:

A resistive transducer is a type of transducer that converts a physical phenomenon (like temperature, pressure, or displacement) into a change in electrical resistance. This change in resistance can then be measured and used to quantify the original physical quantity.

Following are a few types of Resistive Transducers:

➤ **Strain Gauge:**

It measures strain in materials by detecting changes in resistance due to stretching or compression.

➤ **Potentiometer:**

It converts linear or angular displacement into a proportional voltage change by utilizing a sliding contact along a resistive element.

➤ **Resistance Thermometer (Resistance Temperature Detector, RTD):**

It measures temperature by detecting changes in resistance of a specific metal wire (like platinum) with temperature variations. As compared to Thermistors, RTDs offer higher accuracy and a wider temperature range but are less sensitive.

➤ **Thermistor:**

It measures temperature by detecting changes in resistance of a semiconductor material (like ceramic) with temperature variations. As compared to RTDs, Thermistors have a limited temperature range, but are known for their high sensitivity and fast response time.

➤ **Humidity Sensors:**

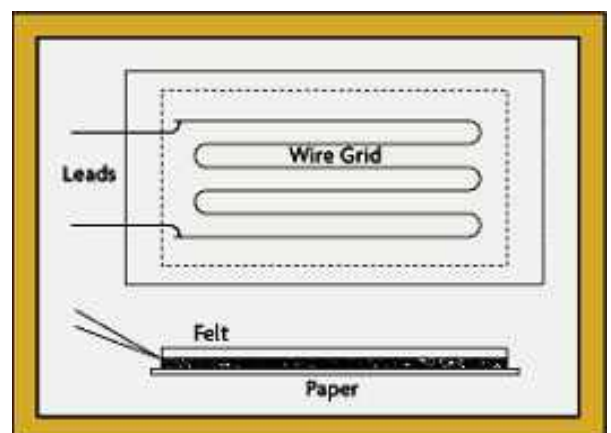
They measure humidity by detecting changes in resistance due to moisture absorption by a hygroscopic material.

### 4.2.9 Bonded Strain Gauge:

Bonded strain gauges are used to measure strain. These gauges are bonded directly to the surface of a specimen with the thin Layer of adhesive cement. In flat grid type strain gauge, the sensing wire (strain gauge wire) is wound as shown in figure. This grid is bounded to a backing material (paper epoxy) using adhesive. The adhesive acts as an electrical insulator and also holds the wire to base firmly to allow the transfer of strain from base to wire, causing change in the length of the wire.

The electrical resistance of the wire ( $R = \rho L/A$ ) will also be changed due to the strain.

R is calculated by means of an electric circuit, which eventually leads to the measurement of strain.



**Figure 4.3 – Arrangement of Bonded Strain Gauge**

#### 4.2.10 Performance Characteristics of Transducers:

##### 1. Static Characteristics -

Static Performance Characteristics are considered when the system is used to measure a quantity that is either constant or varies slowly with time. Static performance characteristic parameters define the quality of measurement, they are:

1. **Accuracy** (closeness of the measured value to the true value)
2. **Precision** (repeatability of the measured value on repeating measurement of the same input)
3. **Sensitivity** (the smallest change in input that can be sensed)
4. **Threshold** (the smallest measurable value of input)
5. **Dead zone** (the range of input values that are too small to be detected)
6. **Error** (the difference between measured value & true value)
7. **Resolution** (the smallest change in input that can be detected and displayed)
8. **Hysteresis** (Hysteresis is a phenomenon in calibration, which occurs when the output of a measuring instrument does not immediately respond to a change in input as it depends not only on the current input value, but also on its past history.)
9. **Hysteresis Error** (The difference in a sensor's output when the same value is measured in opposite directions (increasing or decreasing))
10. **Drift** (the gradual change in the precision of a measuring device over time)

##### 2. Dynamic Characteristics -

The characteristics defined on the basis of Input-Output relation when the input (measurand) changes rapidly with time, are called dynamic characteristics.

The main dynamic characteristics of an instrument are:

1. **Speed of Response** (How quickly it can react to a change in its input signal.)
2. **Lag** (The delay in its output response to a sudden change in its input signal.)
3. **Fidelity** (How faithfully it converts the measured quantity into an output signal without distortion or significant dynamic errors.)
4. **Dynamic Error** (The difference between the true value of a rapidly changing physical quantity and the value indicated by the instrument if no static error is assumed.)

### 4.3 OVERVIEW OF MECHANICAL ACTUATION SYSTEM

#### 4.3.1 Mechanical Actuators:

Mechanical actuators are mechanisms that use a source of power to achieve physical movement. Examples: Gears, Belt Drive, Train-Ratchet Mechanism, Slider-Crank Mechanism, Bearings, etc.

#### 4.3.2 Kinematic Links:

A kinematic link is a rigid body or a resistant body that constitutes a part of the machine, connecting other parts having relative motion to it. Example: Connecting Rod, Crank, Piston in an IC Engine.

\*Rigid body is a solid body in which deformation is zero or negligible. Example: Crank.

\*Resistant body is a body that is rigid for the purpose it is serving. Example: A belt in a belt drive is a resistant body, because it doesn't undergo deformation when shear force is applied on it.

### 4.3.3 Kinematic Pair:

A kinematic pair consists of two elements, typically called the driver and the follower, that are connected in a way that allows relative motion between them. The driver is the component that imparts motion, while the follower is the element that responds to the motion of the driver.

Example: Sliding Pair, Turning Pair, Rolling Pair, Screw Pair, CAM-Follower, etc.

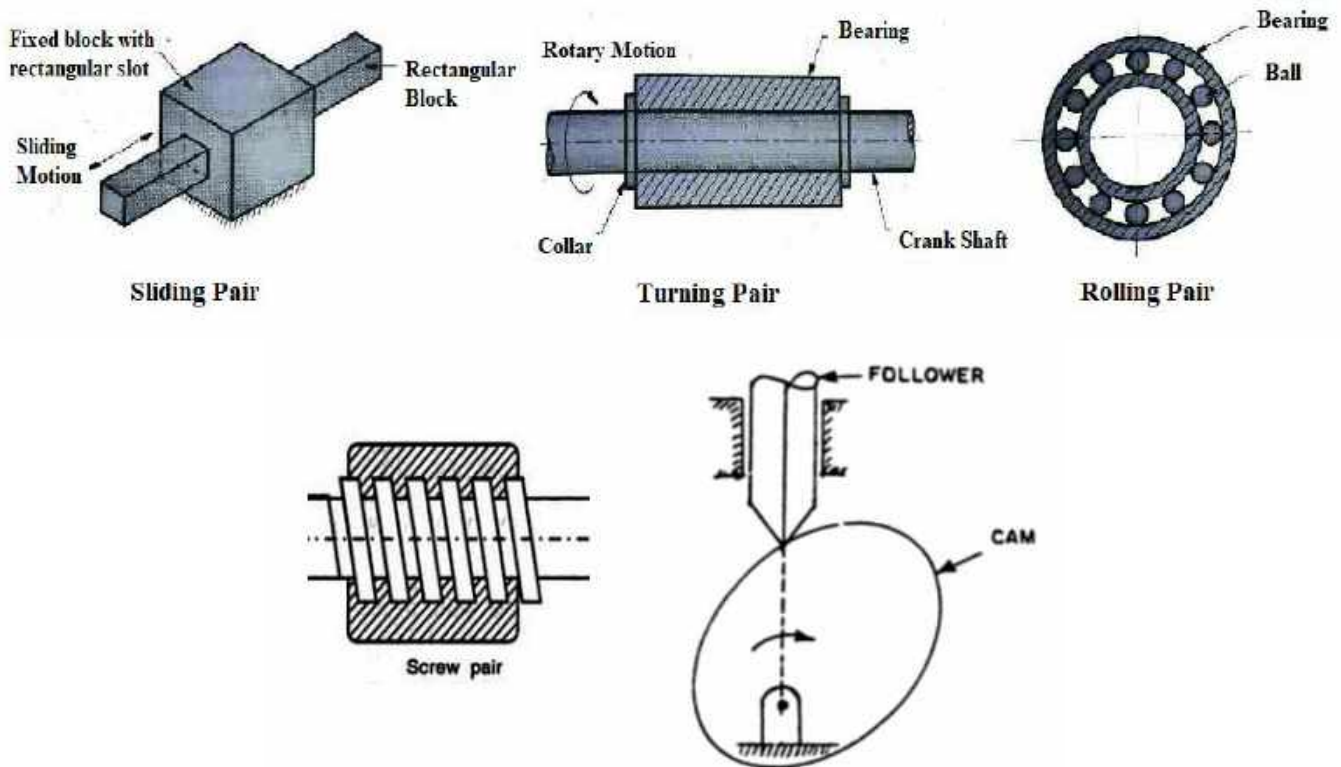


Figure 4.4 – Various Kinematic Pairs

### 4.3.4 Kinematic Chain:

When two or more kinematic pairs are joined together, they form kinematic chain.

Example: 4 bar chain, slider-crank mechanism, etc.

#### Inversions of a Kinematic Chain-

Inversions of a kinematic chain are obtained by fixing different links, one at a time as shown below:

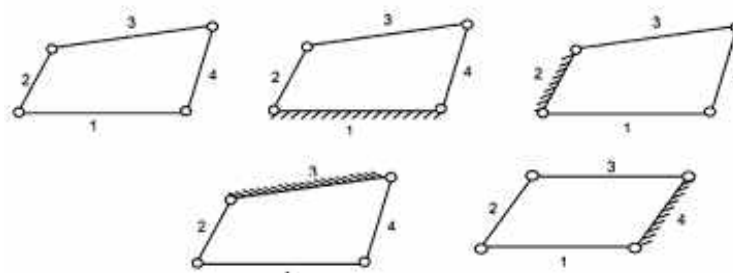


Figure 4.5 – Four bar chain and its inversions

### 4.3.5 Mechanism:

A mechanism is a kinematic chain, whose one link is fixed and the other parts are having definite relative motion among them. For Example: slider-crank mechanism, an arrangement of mechanical parts designed to convert straight-line motion to rotary motion, as in an IC Engine, or to convert rotary motion to straight-line motion, as in a reciprocating piston pump.

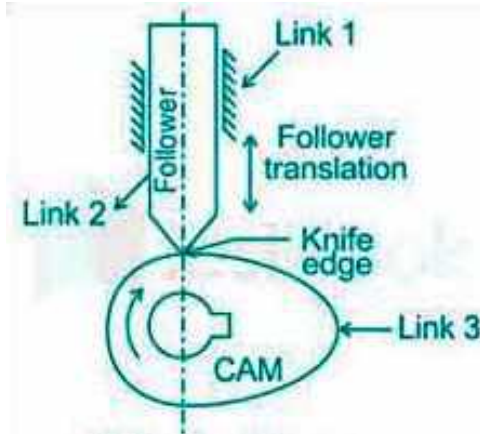


Figure 4.6 –  
Cam-follower mechanism

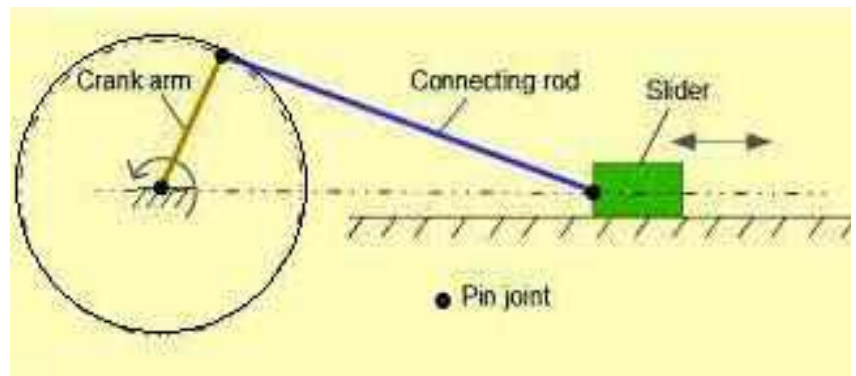


Figure 4.7 –  
Slider-Crank Mechanism

### 4.3.6 Cam-Follower:

A cam is a rotating or sliding link used to transmit motion to a follower. Both rotating and sliding cams provide oscillatory motion to the follower. Cam is the driver member and follower is the driven member in the Cam-Follower pair.

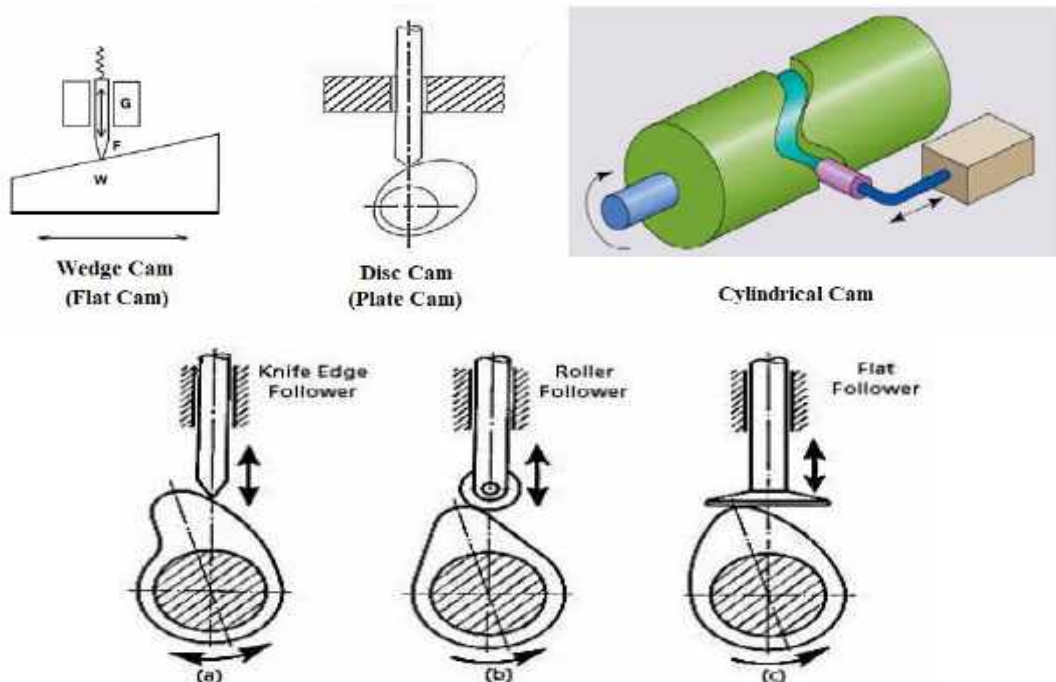


Figure 4.8 – Various Types of Cams & Followers

### 4.3.7 Train Ratchet Mechanism (Ratchet-Pawl Mechanism) –

The train-ratchet mechanism is an asymmetric mechanism that allows something to turn in one direction only. This mechanism consists of a pawl attached to the oscillating link. This pawl has a relative motion with respect to the ratchet wheel having teeth on its periphery in a shape to allow rotation of wheel only in one direction. The ratchet wheel is connected to a shaft.

This mechanism is used to produce an intermittent output motion from an oscillating input motion.

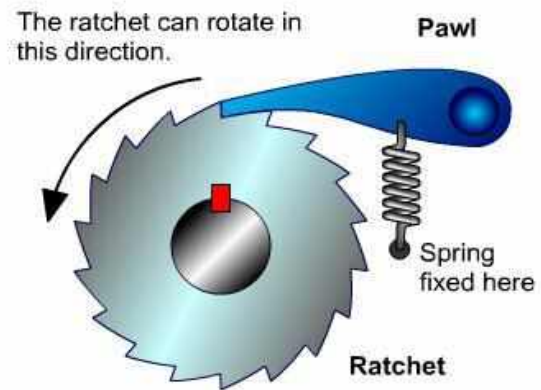


Figure 4.9 – Ratchet-Pawl Mechanism

### 4.3.8 Gears and its types:

**Gear** – A gear is a wheel provided with teeth on its periphery to mesh with the teeth on another wheel or on a rack; to transmit motion from one component to another.

All such teeth must be equi-spaced & of equal size & shape.

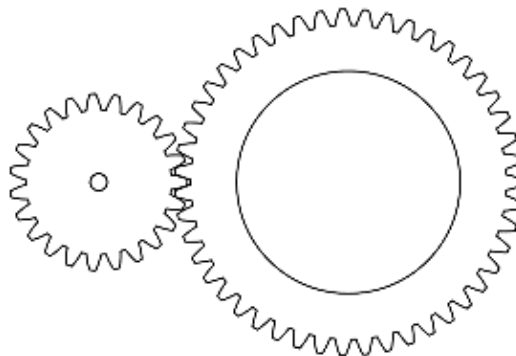


Figure 4.10 – Meshing of Gears

**Gear Train** – Two or more gears working together constitute a gear train. A gear train may be defined as "a system of gears arranged to transfer torque from one component to another".

**Gear Ratio** – Gear Ratio is the ratio of input angular speed to the output angular speed in a gear train.

$$\text{G.R.} = \tilde{\omega}_1 / \tilde{\omega}_2 = R_2 / R_1 = T_2 / T_1 = \tau_2 / \tau_1$$

Where;

$\tilde{\omega}_1$  = Angular speed of the driver gear (driving gear)

$\tau_1$  = Input Torque

$\tilde{\omega}_2$  = Angular speed of the driven gear

$\tau_2$  = Output Torque

$R_1$  = Radius of driver gear (driving gear)

$T_1$  = No. of teeth on driver gear

$R_2$  = Radius of driven gear

$T_2$  = No. of teeth on driven gear

### Various Types of Gears –

**(a). Spur Gear:**

Spur gears transmit power through shafts that are parallel. Their teeth are parallel to the axes of shaft.

**(b). Helical Gear:**

Helical gears are having teeth that are oriented at an angle to the shaft.

**(c). Herringbone Gear:**

Herringbone gears are very similar to the double helical gears, but they do not have a gap as in case of the gap separating the two helical gears.

**(d). Bevel Gear:**

Bevel gears are conical shaped gears used to transmit power between shafts intersecting at 90°.

**(e). Worm Gear:**

A worm gear & worm wheel are used transmit power through shafts intersecting at 90°.

**(f). Rack & Pinion:**

Rack & Pinion are used to convert rotary motion into translational motion & vice-versa. A rack (Linear Gear) & a pinion (Circular Gear) are used for this purpose.



(a) Spur Gear



(b) Helical Gear



(c) Herringbone Gear



(d) Bevel Gear



(e) Worm Gear



(f) Rack and Pinion

**Figure 4.11 – Various Types of Gears**

### 4.3.9 Belt:

A belt is a loop of flexible but resistant body used to link two or more rotating shafts to transmit rotational kinetic energy from one place to another. Belts may transmit power from a shaft to another shaft, which is parallel or non-parallel to the 1st shaft. Belts are looped over a pulley and may have a twist between the pulleys & the shafts need not to be parallel.

#### Types of Belt-drives –

Belt-drive consists of two pulleys over which a belt is passed. There are two types of belt-drives:

1. **Open-Belt Drive** – It provides rotation in same direction.

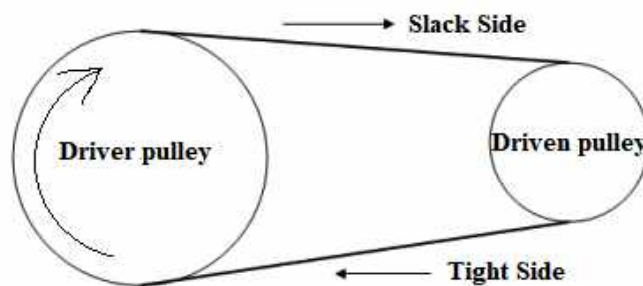


Figure 4.12 – Open-Belt Drive

2. **Cross-Belt Drive** – It provides rotation in opposite direction.

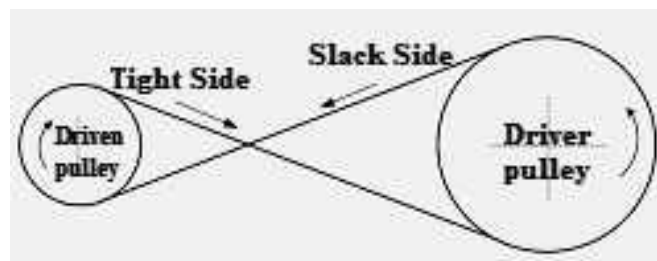


Figure 4.13 – Cross-Belt Drive

#### Types of Belts –

The most commonly used belts are as follows:

1. Flat Belts – They have rectangular cross-section.
2. V-Belts – They have trapezoidal cross-section.
3. Round-Belts – They have circular cross-section.

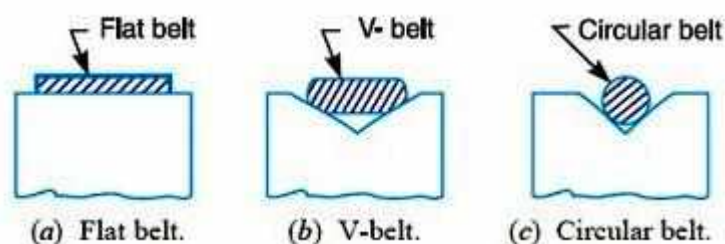


Figure 4.14 – Various Types of Belts

### 4.3.10 Bearings:

A bearing is a device which supports, guides and restrains motion between two mating parts of a machine to provide the desired motion. It also reduces the friction between the mating parts.

**Types of Bearings** – Bearings may be classified into 2 categories:

#### 1. Sliding Contact Bearings-

It is a type of bearing, where relative sliding is seen between the mating parts.  
Example: Shaft moving in housing, separated by sliding contact bearing bush.

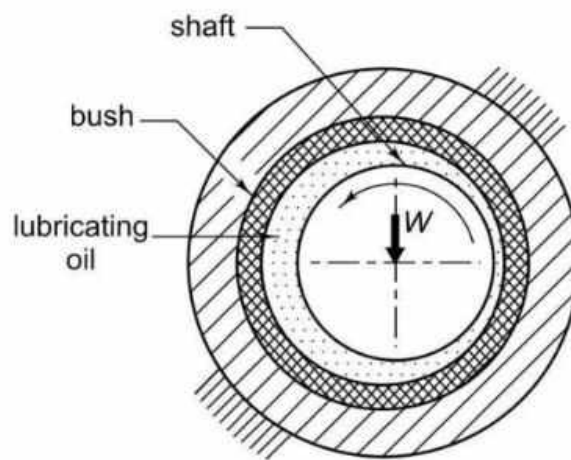


Figure 4.15 – Sliding Contact Bearings

#### 2. Rolling Contact Bearings-

A type of bearing, where there is rolling between the mating parts.  
Example: Ball Bearings (The rolling elements as shown in figure)

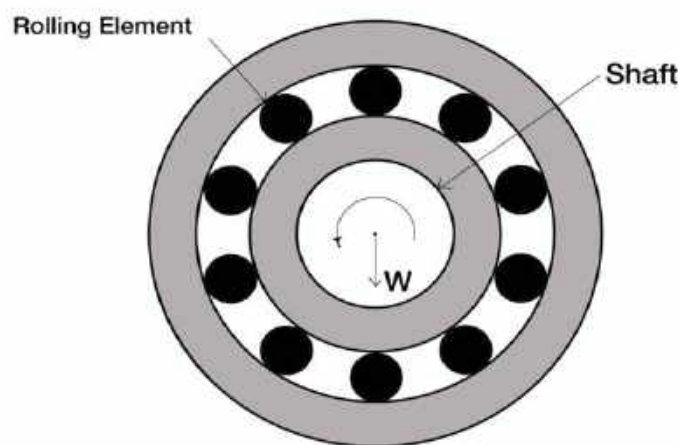


Figure 4.16 – Rolling Contact Bearings

## 4.4 HYDRAULIC AND PNEUMATIC ACTUATION SYSTEMS

### 4.4.1 Hydraulic Actuators:

Hydraulic actuators use fluid pressure to facilitate mechanical movement.

Examples: Pressure Control Valves, Direction Control Valves, Hydraulic Cylinders, etc.

### 4.4.2 Pneumatic Actuators:

Pneumatic actuators use compressed air or pressurized gas to create a controlled movement.

Examples: Pressure Control Valves (PCV), Direction Control Valves (DCV) etc.

### 4.4.3 Pressure Control Valves:

Pressure control valves control the pressure of the air/fluid flowing through the valve or confined in the system controlled by the valve.

There are three types of pressure control valves:

1. Pressure limiting valve or pressure relief valve
2. Pressure sequence valve
3. Pressure regulator or pressure reducing valve

#### Pressure Relief Valve:

A pressure relief valve protects motors, pumps and actuators from becoming damaged from high pressure.

Pressure limiting valve prevents the pressure in a system from rising above a permissible limit. The valve remains closed for normal operation. The valve performs a safety relief function by opening to the atmosphere if a predetermined pressure is exceeded in the system, thus releasing the excess pressure.

As soon as the pressure is thus relieved to the desired limit, the valve is closed again by the spring force.

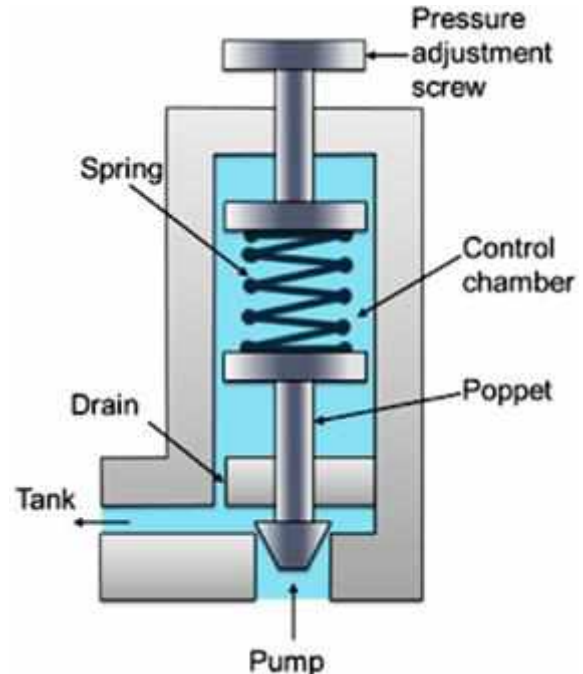


Figure 4.17 – Pressure Relief Valve

#### 4.4.4 Directional Control Valves:

Directional control valves are used to control the direction of fluid flow in hydraulic circuits. They contain ports for fluid to enter and exit. Directional control valves perform these three functions:

Stop fluid flow, Allow fluid flow, and Change direction of fluid flow.

Directional control valves can be classified in a number of ways:

1. According to type of construction:
  - Poppet valves
  - Spool valves
2. According to number of working ports:
  - Two way valves
  - Three way valves
  - Four way valves.
3. According to number of switching position:
  - Two position
  - Three position
4. According to actuating mechanism:
  - Manual actuation
  - Mechanical actuation
  - Electric actuation
  - Hydraulic actuation
  - Pneumatic actuation

#### 2/2 Ball Seat Poppet Type DCV:

A 2/2 valve is one which has 2 port connections and two positions only. In a poppet valve; discs, cones or balls are used to control flow. The valve shown in figure 5.35 is normally closed type (it can be normally open type also). Its construction is simple. A spring loaded ball is actuated by pressing the button. In normal position the connection between port 'P' and port 'A' is closed.

But when the operator presses the valve manually, it opens the connection between the port P and Port A., thus allowing the fluid to pass to port A. This valve is used for actuating single acting cylinder, which doesn't need oil/air for returning.

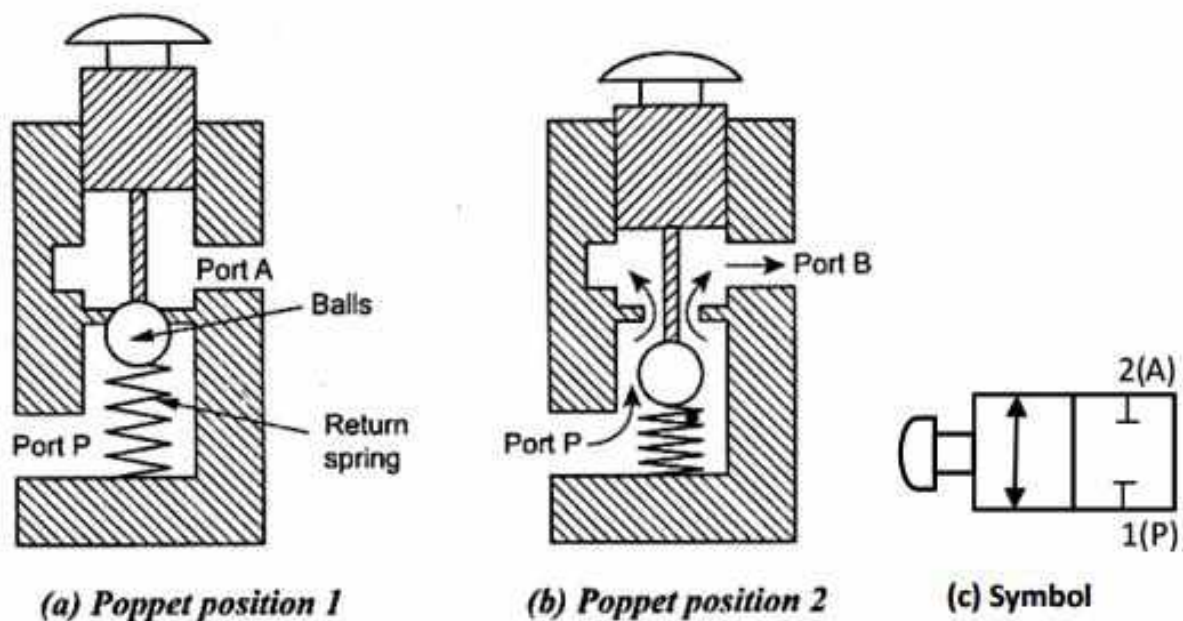


Figure 4.18 – Manually operated Ball Seat Poppet Type 2/2 Direction Control Valve

### 3/2 Hand Operated Spool Type DCV:

The cross sectional views of a hand operated 3/2 DCV (normally closed) based on spool design is shown in figure 5.36. When the valve is not actuated, port 2 and 3 are connected and port 1 is blocked. When the valve is actuated then port 2 and 1 are connected and port 3 is blocked.

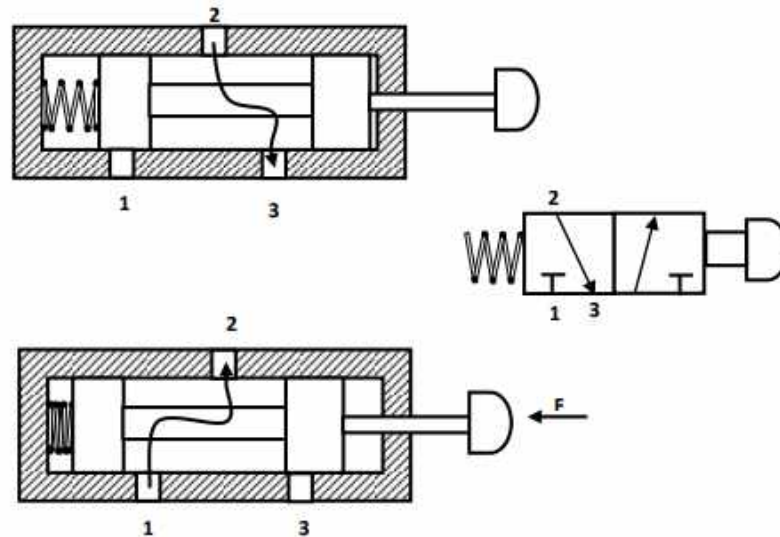


Figure 4.19 – Hand Operated Spool Type 3/2 Direction Control Valve

### 3/2 Pneumatically Actuated DCV:

The cross-sectional views of pneumatically actuated NC type 3/2 DCV in normal and actuated positions are shown in figure 5.37. In normal position, the working port (2) is closed to the pressure port (1) and open to the exhaust port (3). When the compressed air is applied through the pilot port (12), the spool is moved against the spring. In this actuated position, the working port (2) is open to the pressure port (1) and closed to the exhaust port (3). Thus, the application of the compressed air to the port 12 causes the pressure port (1) to be connected to the working port (2).

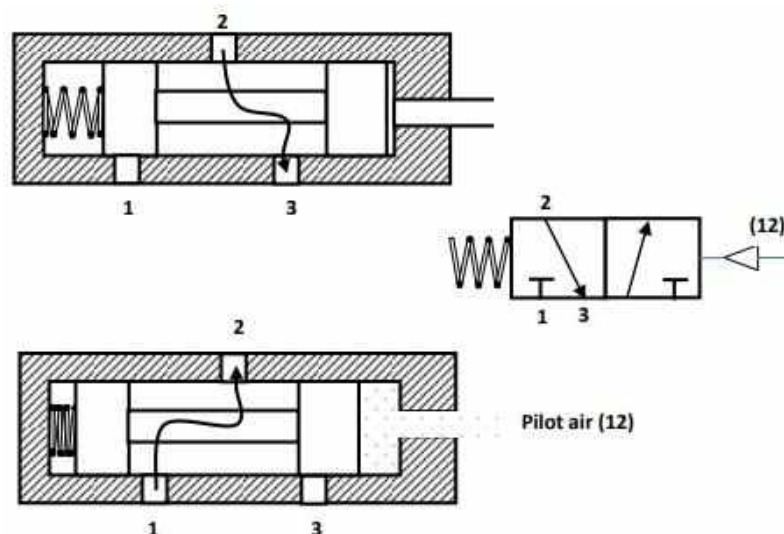


Figure 4.20 – Pneumatically Actuated 3/2 Direction Control Valve

**Symbols used for Directional Control Valves:**

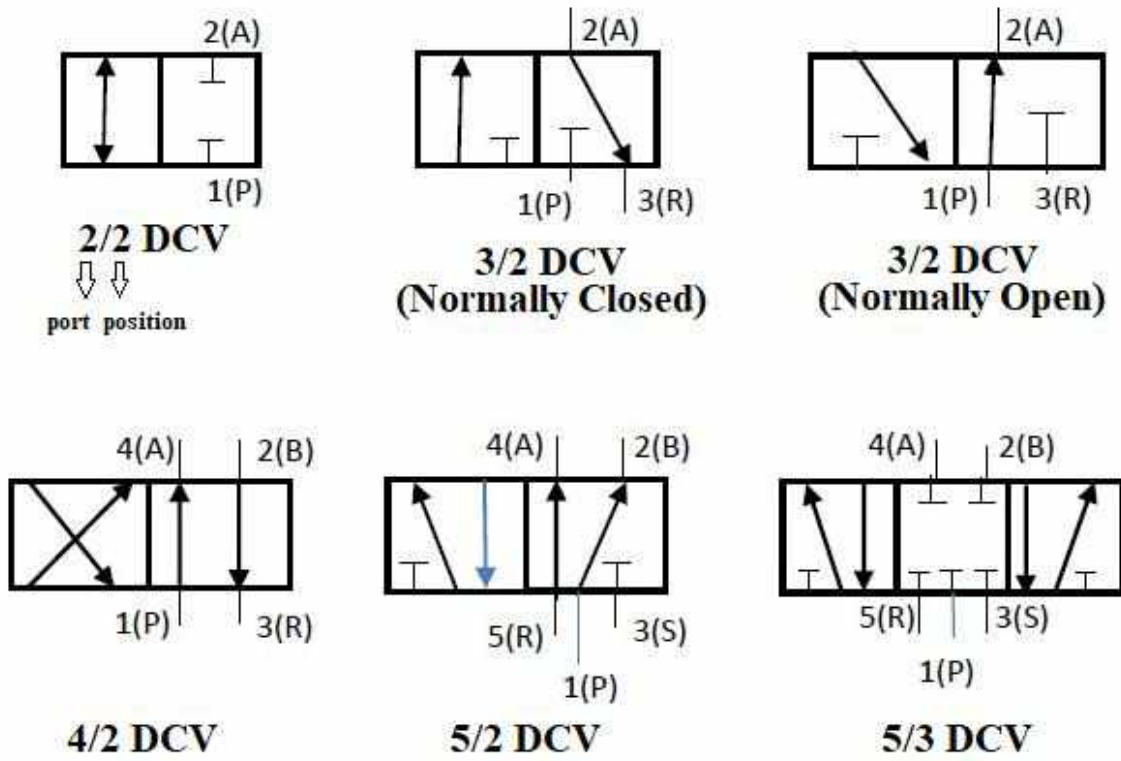


Figure 4.21 – Symbols used for Various Directional Control Valves

**4.4.5 Linear Actuators:**

Linear actuators are mechanical devices that provide linear movement. The source of energy used by linear actuators can be electric, hydraulic or pneumatic. The linear motion provided by linear actuators can be used to push, pull, lift, lower, tilt, or adjust objects in a controlled and repeatable manner. Few examples of Linear Actuators are as follows:

**Single Acting Hydraulic Cylinder:**

Single Acting Hydraulic Cylinders operate in one direction only. They have a single port at one end of the cylinder, so when the fluid is pumped into the port, it pushes the rod, causing it to extend. The rod returns because of an external force such as the load or a spring.

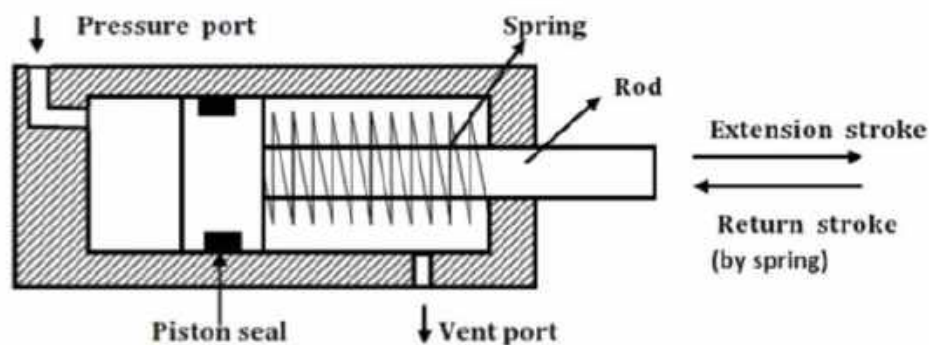


Figure 4.22 – Single Acting Hydraulic Cylinders

### Double Acting Hydraulic Cylinder:

Unlike single acting cylinders which can only push or pull, double acting cylinders do both. They have ports both ends of the cylinder so that when oil is pumped into the head port, the piston moves and extends the rod. Oil in the rod end of the cylinder is pushed out into a reservoir. To achieve the opposite movement and retract the rod, the oil flow is reversed.

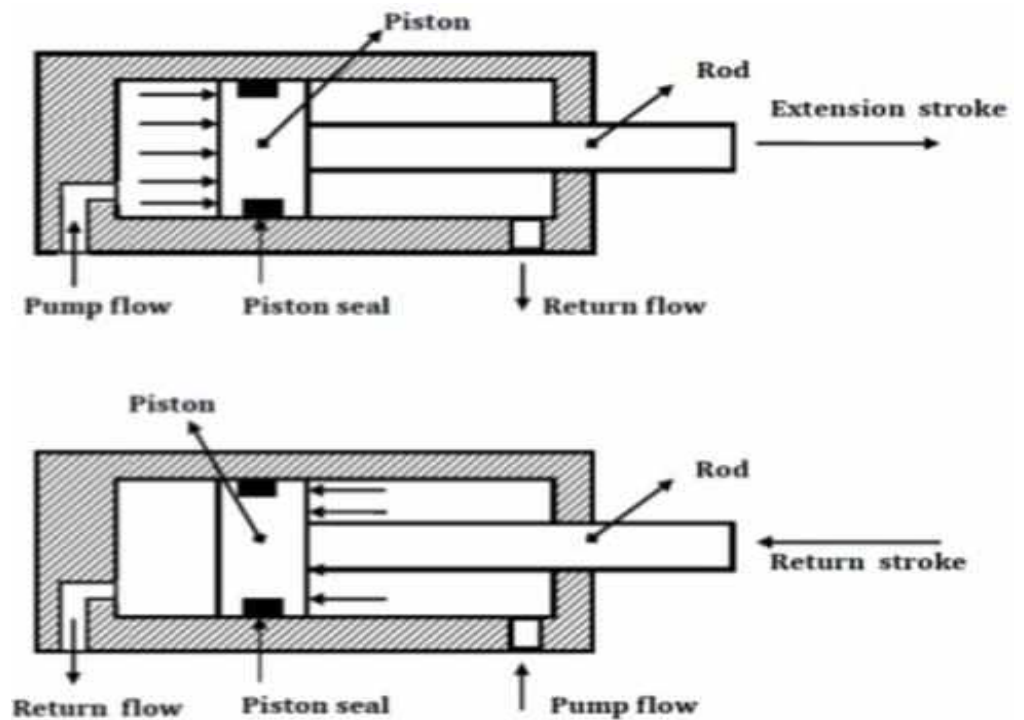


Figure 4.23 – Double Acting Hydraulic Cylinders

### Tandem Hydraulic Cylinder:

In a tandem hydraulic cylinder, two interconnected cylinders operate together to generate a greater force than one cylinder would be able to create on its own. The two cylinders are supplied by different hydraulic systems, but they are connected mechanically so that the rod of the first cylinder enters the second cylinder, pushing its base.

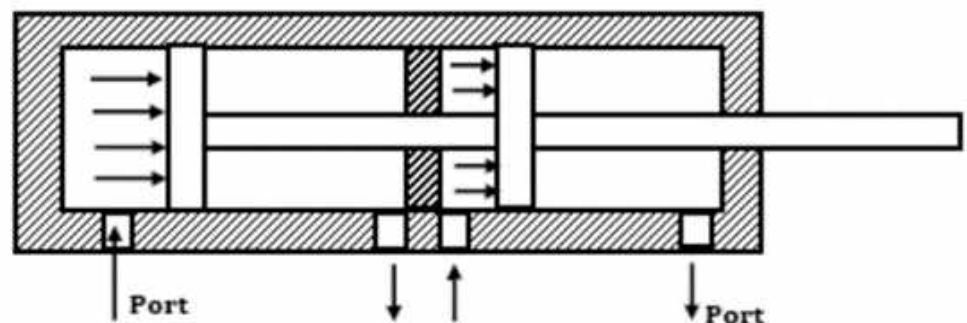


Figure 4.24 – Tandem Hydraulic Cylinders

#### 4.4.6 Pneumatic Sequencing Problems:

Pneumatic sequencing problems often involve issues with the order of operations in a pneumatic system, where one action needs to follow another in a specific sequence. These problems can stem from component wear, leaks, pressure drops, incorrect valve adjustments, etc. Troubleshooting involves identifying the faulty component, ensuring proper air pressure and flow, and checking the sequence valve settings.

Pneumatic sequencing problems, which affect the reliable and efficient operation of pneumatic systems, can lead to production delays and increased costs.

Common pneumatic sequencing problems are as follows:

- **Air leaks:** Worn-out seals, faulty valves, or loose connections can lead to air escaping the system, resulting in decreased performance and increased energy consumption.
- **Pressure drops:** Clogged filters, faulty regulators, or air leaks can cause reduced pressure, impacting the power and speed of pneumatic actuators.
- **Slow or erratic cylinder movement:** This can stem from insufficient or inconsistent air supply, lubrication issues, or internal leaks within the cylinder or associated components.
- **Contamination:** Dust, moisture, and debris in the air supply can damage components, clog filters and valves, and shorten the lifespan of the system.
- **Sticking or jamming:** This can occur due to misalignment, contamination, or insufficient lubrication, leading to reduced efficiency and potential damage to associated machinery.
- **Valve malfunctions:** Valves may become stuck or misaligned, preventing proper airflow and disrupting the sequence of operations.
- **Component wear and tear:** Over time, seals, valves, and cylinders wear out, leading to leaks, reduced efficiency, and eventual failure.

**Questions Bank from Unit-4**

- Q4.1 - Define Mechatronics. Write the advantages, disadvantages and application of Mechatronics.
- Q4.2 - What are the key elements of a mechatronic system? Explain briefly.
- Q4.3 - Compare the traditional and mechatronic design approach.
- Q4.4 - How Mechatronics has evolved over the period of time?
- Q4.5 - Discuss the scope of Mechatronics for engineers.
- Q4.6 - What are the industrial applications of Mechatronics?
- Q4.7 - What are Autotronics, bionics and avionics?
- Q4.8 - What are sensors and transducers? Enumerate the various types of sensors and transducers.
- Q4.9 - Classify transducers by function, performance and on the output basis.
- Q4.10 - List any four types of sensors and mention their features.
- Q4.11 - Write the names of sensors or transducers used to measure force, pressure and temperature.
- Q4.12 - Explain the working of IR Sensor with neat diagram.
- Q4.13 - What are the similarities between sensors and transducers?
- Q4.14 - What are proximity sensors? Explain any one.
- Q4.15 - Discuss any one force transducer in detail with neat diagram.
- Q4.16 - Discuss the working of a torque transducer in detail with neat diagram.
- Q4.17 - Define Kinematic chain with the help of diagram.
- Q4.18 - Discuss various types of CAM and followers.
- Q4.19 - Describe different types of gears with diagram.
- Q4.20 - Define gear ratio and gear train.
- Q4.21 - Explain the mechanism of Train-Ratchet and its applications.
- Q4.22 - What is a belt drive?
- Q4.23 - What are the various types of belts used for power transmission?
- Q4.24 - Write the definition of bearing and its classification.
- Q4.25 - What is pressure control valve? Also explain its working.
- Q4.26 - Explain the constructional detail and working of Pressure relief valve with neat diagram.
- Q4.27 - What is direction control valve? Describe a 2/2 Poppet type DCV.
- Q4.28 - Describe the working of a 3/2 Pneumatically Actuated DCV.
- Q4.29 - What are linear actuators? Describe the working of a single acting hydraulic cylinder.
- Q4.30 - What are common pneumatic sequencing problems?