Mechanical Theory Notes using Class Slides

Robot

A **robot** is a machine that can sense its surroundings, do different tasks, work on its own or with people and this is reprogrammable, multifunctional manipulator.

Why Use Robots?

1. **Improve Product Quality**: High precision, accuracy, and consistent performance for better product consistency.
2. **Boost Efficiency**: Work 24/7 without fatigue, breaks, or vacations.
3. **Enhance Safety**: Operate in hazardous environments without needing human comfort like air conditioning or noise protection.
4. **Reduce Costs**: Lower scrap rates, reduce inventory, cut labor costs, and shorten manufacturing lead times.
5. **Increase Productivity**: Faster production, quick response to design changes, and higher output per person per hour.
6. **Flexibility**: Can be reprogrammed to perform different tasks as needed.
7. **High-Speed Operations**: Can perform tasks at faster speeds than humans.
8. **Reduce Human Error**: Robots perform tasks with consistent accuracy, reducing mistakes.
9. **Improve Working Conditions**: Robots can take over dangerous, repetitive, or physically demanding tasks.

The Robot history:

- **1961**: George Devol gets the first U.S. robot patent. Joe Engelberger creates Unimation, the first company to sell robots.
- **1962**: Unimation is formed, focusing on "Universal Automation."
- **1968**: Unimation sells its first multi-robot system to General Motors.
- **1966-1972**: "Shakey," the first AI-driven mobile robot, is built at Stanford Research Institute.
- **1969**: Unimate robots help assemble Chevrolet Vega cars at General Motors.
- **1970**: General Motors uses machine vision in production for the first time.
- **1973-1979**: The Stanford Cart uses stereo vision to avoid obstacles.
- **1978**: Unimation develops the PUMA robot for General Motors.
- **1981**: IBM enters the robotics field with its 7535 and 7565 systems.
- **1983**: Westinghouse buys Unimation, which is later sold to Staubli.

PUMA (1978): The PUMA robot was made by Unimation with help from General Motors. It’s used for tasks like building and assembling things.

- **How Industrial Robots Are Used**:
  - **70%** for **welding and painting** things.
  - **20%** for **moving and placing** items.
  - **10%** for other tasks.

- **Research Areas**:
  - Making robot arms move better.
  - Designing tools for robots to use.
  - Creating devices that help robots feel and adjust to forces.
  - Making robot hands more flexible.
  - Helping robots see and feel their surroundings.
  - Allowing robots to switch between different jobs easily.
- **Robots in Other Fields**:
  - **Robot Arms**: Used in factories for assembling things.
  - **Field Robots**: Used in the military and space exploration.
  - **Service Robots**: Used for cleaning, medical help, and entertainment.

Field Robots and Service Robots:

Feature	Field Robots	Service Robots
Definition	Robots designed for use in outdoor, harsh, or complex environments, like military, agriculture, or space exploration.	Robots designed to help people with tasks in controlled environments, like homes, offices, or hospitals.
Main Use	Military, agriculture, space exploration	Cleaning, medical, entertainment
Environment	Outdoor, harsh, or complex areas	Indoor or controlled environments
Examples	Military drones, farming robots, Mars rovers	Robotic vacuum, hospital assistants, entertainment robots
Purpose	Perform tasks in challenging or dangerous locations	Help humans with everyday tasks
Mobility	Often need to move in rough terrains	Usually move in homes or offices

Robot Classification:

Japanese Industrial Robot Association (JIRA) Classes:

- **Class 1**: Robots with multiple movements controlled by an operator.
- **Class 2**: Robots with set tasks that are hard to change.
- **Class 3**: Robots like Class 2 but easier to modify.
- **Class 4**: Robots that follow human motions after being recorded.
- **Class 5**: Robots programmed by the operator instead of manually teaching them.
- **Class 6**: Robots that understand and adapt to changes in their surroundings.

The **Robotics Institute of America (RIA)** only includes **Class 3-6**.

Association Francaise de Robotique (AFR) Types:

- **Type A**: Manual control device.
- **Type B**: Automatic device with fixed tasks.
- **Type C**: Programmable robot that moves between points.
- **Type D**: Like Type C but can sense its surroundings.

Types of Applications:

- **Pick and Place**: Moves items from one place to another.
- **Continuous Path Control**: Follows a set path.
- **Sensory**: Uses sensors to get feedback and adjust.

Manipulator

This is the robot's "arm" that helps move or handle things. It's made up of joints and parts that allow it to move in different directions.

Manipulator Components:

- **Links**: These are the rigid parts that make up the robot's arm.
- **Joints**: These are the connections between two links, allowing movement.
- **End-Effector**: The tool attached to the end of the manipulator that interacts with objects to perform tasks.

Classification of Robot Manipulators:

By Motion Characteristics:

- **Planar Manipulator**: All the moving parts stay in parallel planes.
- **Spherical Manipulator**: All parts move in a spherical shape around a single point.
- **Spatial Manipulator**: At least one part moves in a 3D space.

By Kinematic Structure:

- **Open-Loop Manipulator (Serial Robot)**: The links form an open chain, meaning each part is connected in a sequence.
- **Parallel Manipulator**: The links form a closed chain, meaning they are all connected in loops.
- **Hybrid Manipulator**: Combines both open and closed chains.

Robot End-Effectors

These are the tools attached to the end of a robot's arm that help it do tasks. Most robots don't come with end-effectors, or they come with a simple gripper for basic jobs. You usually need to buy or design end-effectors separately.There are two main types of end-effectors:

1. **Grippers**: These are like a robot's "hand" with a thumb and finger to grab and hold things.Example: Gripping small parts and moving them around.
   .
2. **Tools**: These are specialized devices that help the robot do tasks like cutting, painting, or measuring.
   - **Machine Tools**: Includes drills, cutters, or grinders to shape or cut materials.
   - **Laser and Water Jet Cutters**: Use lasers or powerful water to cut metal or plastic.
   - **Spray Painting Tools**: Used for automatic painting, especially in industries like car manufacturing.
   - **Measuring Tools**: Allow robots to measure parts carefully with probes or gauges.

Robot Control Methods

Robots are controlled using a **computer**, **robot**, and **sensors** to guide their movements.

1. **Lead-Through Programming**: A person moves the robot's hand to show it what to do. The robot remembers the movements and repeats them later.
2. **Teach Programming**: A person uses a **control box** (called a teach pendant) to move the robot. The robot remembers the positions and follows them later.
3. **Off-Line Programming**: The robot's movements are planned on a computer using special software. The plan is tested on the computer before using it with the real robot.
4. **Autonomous Control**: The robot works on its own using a computer and sensors. It can sense changes around it and adjust its movements without human help.
5. **Teleoperation**: A person controls the robot using a joystick. Some joysticks also let the person "feel" what the robot feels.
6. **Telerobotic Control**: This method mixes **autonomous control** and **teleoperation**. The robot can work on its own or be controlled by a person when needed.

Robot Software

Robot software helps control robots and connect them with sensors and other devices. It allows robots to make quick decisions and complete tasks.

Main Features of Robot Software:

1. **Works with Sensors**: Helps robots change their actions based on sensor data.
2. **Understands Environment**: Uses shapes and space to "see" and move around objects.
3. **Supports CAD/CAM**: Connects with design software like CAD/CAM for better planning.
4. **Task Instructions**: Lets users give clear instructions on what the robot should do.
5. **Off-Line Programming**: Plans robot tasks on a computer before using the real robot.

Robot Programming Languages: There are over 200 robot languages, like **AML, VAL, AL, RAIL, RobotStudio**, and more.
There are no fixed rules for robot software, so different robots may use different languages.

Sensors

Sensor: A device that senses changes in things like temperature, pressure, or force and gives an output signal (like electric, mechanical, or magnetic signals).

Transducer: A device that changes one form of energy into another.

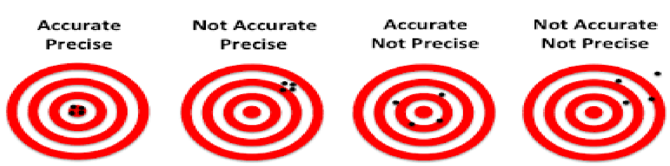
Difference: All sensors are transducers, but not all transducers are sensors. For example, a **thermocouple** senses temperature (heat) and turns it into an electric signal, so it is both a sensor and a transducer.

Sensor/Transducer Specifications (How well the sensor works)

1. **Range**: The highest and lowest values the sensor can detect.
2. **Resolution**: The smallest change the sensor can notice.
3. **Accuracy**: How close the sensor's reading is to the real value.
4. **Precision**: How often the sensor gives the same result, even if it's not perfectly accurate.
5. **Sensitivity**: How much the output changes for a small change in input.
6. **Linearity**: How closely the sensor's response follows a straight line.

Accuracy vs. Precision

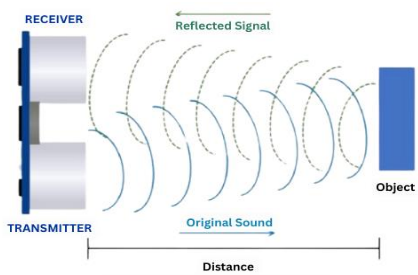
- **Accuracy**: How close the reading is to the true value.
- **Precision**: How often the sensor gives the same reading, even if it's not correct.



Types of Robot Sensors

1. **Distance Sensors**: Measure how far something is (e.g., IR, Ultrasonic, LiDAR, Encoders, Stereo Cameras).
2. **Proximity Sensors**: Detect if something is nearby (e.g., IR, Ultrasonic, Photoresistors).
3. **Contact Sensors**: Detect when the robot touches something (e.g., Bump/Touch Sensors, Tactile Sensors).
4. **Pressure Sensors**: Measure force or weight (e.g., Force-Sensitive Resistors, Barometric Sensors).
5. **Temperature Sensors**: Measure heat (e.g., Thermocouples, RTDs).
6. **Light Sensors**: Detect light levels (e.g., Photoresistors, Photodiodes, Phototransistors).
7. **Sound Sensors**: Detect sound (e.g., Microphones, Acoustic Sensors).
8. **Tilt Sensors**: Measure changes in angle or position (e.g., Accelerometers, Gyroscopes, IMUs).
9. **Navigation Sensors**: Help robots know where they are (e.g., GPS, Magnetometers, Odometry Sensors).
10. **Specialized Sensors**: Measure specific things like humidity, gases, colors, vision, or health data (e.g., Humidity, Gas, Color, Vision, Biometric Sensors).

Ultrasonic Distance Sensors



Ultrasonic Sensor

An ultrasonic sensor works by sending out a sound wave and measuring how long it takes to bounce back after hitting an object. Since sound travels at a constant speed (344 m/s in air), the sensor can use the time it takes for the sound to return to calculate the distance to the object.

How it works:

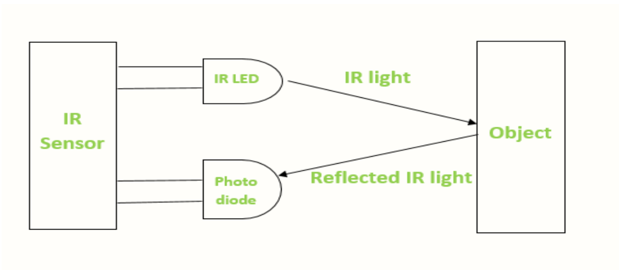
- The sensor sends a sound wave and starts a timer.
- The sound wave hits an object and bounces back.
- The sensor stops the timer when it gets the sound wave back.
- It then calculates the distance based on how long it took for the sound to return.

Advantages of Ultrasonic Sensors:

- **Works in any lighting**: They can be used indoors and outdoors.
- **Good for detecting things**: They measure presence, distance, and position.
- **Not affected by light, smoke, dust, or color**.
- **Better than infrared**: They work well even in smoky or dark conditions.

However, soft materials like wool can cause problems because they absorb the sound waves and don't reflect them well. Still, ultrasonic sensors are reliable and commonly used for tasks like helping robots avoid obstacles.

Infrared (IR) Distance Sensor



An infrared (IR) sensor measures distance using light. It sends out a pulse of infrared light, which bounces off an object. The sensor detects the reflected light and calculates the distance based on how the light returns.

How it works:

- The sensor sends out an infrared light pulse.
- The pulse hits an object and bounces back to the sensor.
- The sensor calculates the distance based on how the light comes back.

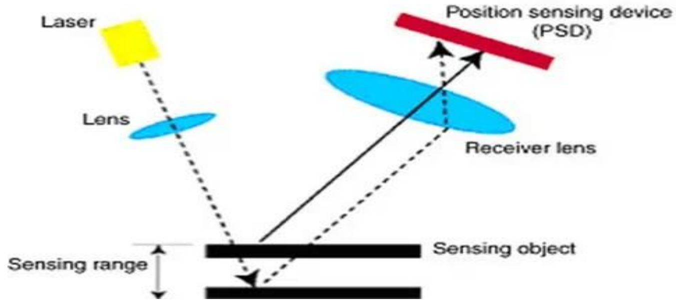
Limitations of IR Sensors:

- **Affected by light**: IR sensors can struggle in bright sunlight or very dark places.
- **Not good for outdoor use**: Sunlight can mess with the sensor, making it harder to use outside.

Comparison with Ultrasonic Sensors:

- **Ultrasonic sensors** are better for outdoor use because they use sound waves, not light, so they are less affected by lighting.
- **IR sensors** are cheaper but less reliable than ultrasonic sensors. If you need to save money and don't mind some inaccuracy, IR sensors are a good choice.

Laser Sensors



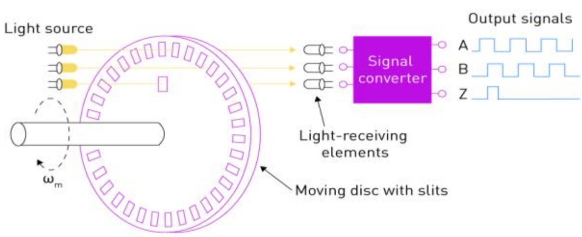
How They Work:

- Laser light is transmitted towards an object.
- The reflected light is captured and analyzed.
- Distance is calculated by measuring the time it takes for the light to return, using the speed of light.

Uses:

- **Long-Distance Measurement**: Ideal for precise measurements over long distances.
- **Industrial Automation**: Used in tasks like cutting, welding, and alignment.
- **Safety Systems**: Found in safety barriers and curtains to detect movement.

Optical Encoders



How They Work:

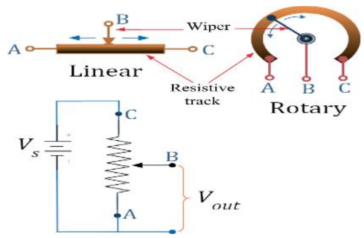
- A disc with holes rotates, and light passes through the holes.
- Sensors detect the light and create electrical signals.
- These signals show the position, movement, and direction of rotation.

<u>Key Features</u>: Optical encoders track rotation and position by measuring how much a shaft or motor turns, allowing for accurate control. They can detect the direction of rotation (clockwise or counterclockwise) using signals from different tracks on the disc. A special hole marks the "home position," enabling the system to return to a known starting point. The accuracy, or resolution, depends on the number of holes on the disc (e.g., 100 holes = 3.6° per step), with more holes providing higher precision.

Uses:

- Used in **servo motors** to measure rotation.
- Found in robots, CNC machines, and other automated systems to track movement accurately.

Potentiometer Sensors



How They Work:
A potentiometer sensor measures displacement (movement) by converting mechanical movement into an electrical signal. It consists of a resistive element and a sliding contact (called a wiper). As the wiper moves along the resistive element, it changes the resistance, affecting the output voltage. This voltage is proportional to the wiper's position.

- **Voltage Divider**: A voltage (Vs) is applied across the resistive element. The wiper acts as a voltage divider, generating an output voltage (VA) that varies with the wiper's position.
- **Output Equation**: The output voltage (VA) is calculated by the formula:
  VA = (Vs * RA) / (RA + RC)
  where RA and RC are the resistances on either side of the wiper, and VA is the output voltage.

Applications:

- **Control Systems**: Helps in feedback loops to make sure parts move to the correct position (e.g., in machines, elevators, or forklifts).
- **Manufacturing**: Used in control systems for machines like injection molding, woodworking, printing, and robots.
- **Automobiles**: Used in systems like throttle control.
- **Sports**: Helps in tracking and controlling sports equipment through computers.

Potentiometers are crucial for applications requiring precise position or displacement measurement.

Strain Gauges

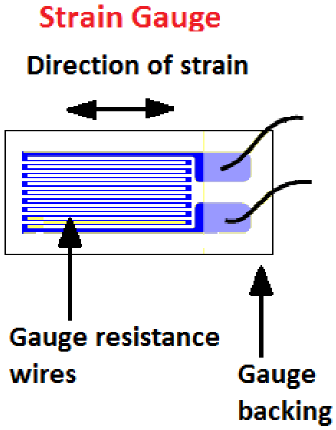


Figure #1

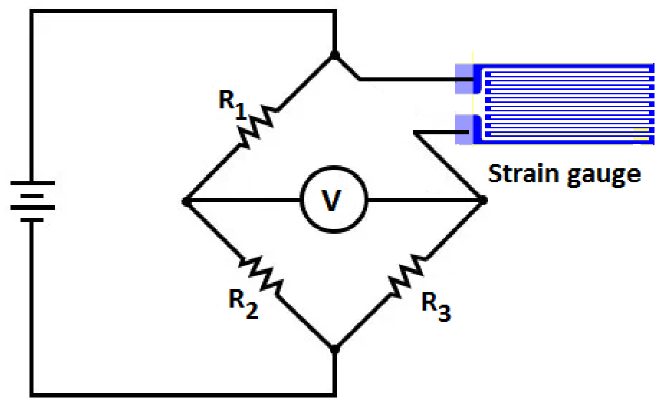


Figure #2

How They Work:
A strain gauge measures how much an object changes shape when a force is applied. This change in shape causes a change in the gauge's resistance. The more an object stretches or compresses, the more the resistance changes. The relationship between the change in resistance and the strain is given by this formula:

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

Where:

- ΔR is the change in resistance
- R is the original resistance
- G is the gauge factor (a constant)
- ε is the strain (deformation)

The strain gauge is made of a thin, resistive foil (usually copper-nickel alloy), which is attached to a backing material. When the object changes shape, the foil stretches or compresses, changing its resistance. This change is measured using a Wheatstone bridge circuit.

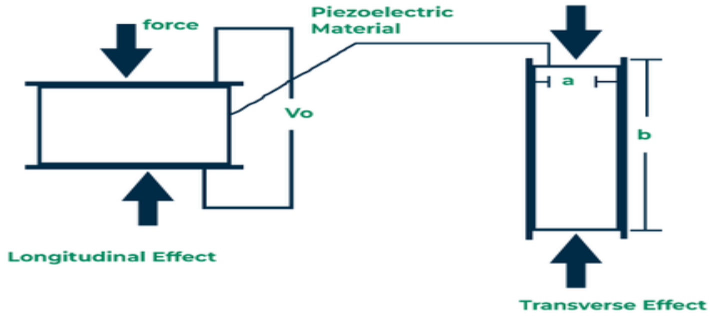
Applications:

- **Stress Testing**: Measures how much an object changes shape when stress is applied (used in machines, tools, and structures).
- **Fatigue and Vibration Testing**: Checks how materials react to repeated stress or vibrations.
- **Force Measurement**: Measures force in machines, presses, and vehicles.
- **Aerospace**: Measures impact or force in airplanes and spacecraft.

Strain gauges are essential for accurately measuring how much force or stress an object is under, especially in machines, vehicles, and safety systems.

Piezoelectric Sensor

A **piezoelectric sensor** measures changes in pressure, force, acceleration, or strain by converting them into electrical charge. When pressure or force is applied to a special material, it generates voltage. The electricity produced is directly related to the amount of pressure applied. The word *piezo* means "press" or "squeeze," and *piezoelectric* refers to electricity produced by pressure.

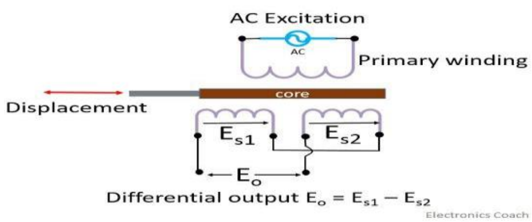


Common materials used include **quartz** (natural) and man-made crystals like **Rochelle salts** and **lithium sulfate**. These sensors are used for accurate force measurement with minimal errors due to their very small deformation.

Linear Variable Differential Transformer (LVDT)

An LVDT is a sensor used to measure **linear displacement** (movement in a straight line) within a range of **±2 to ±400 mm**. It is highly accurate with an error of only **±0.25%** of the full range.

How It Works:



- **Structure**: It has one **primary coil** in the center and two **secondary coils** on either side, all inside an insulated tube. A **magnetic core** moves inside this tube.
- **Operation**: When an AC voltage is applied to the primary coil, it creates electromagnetic forces (EMFs) in the secondary coils.
  - **Central Position**: If the magnetic core is centered, both secondary coils generate equal voltages, canceling each other out, so the output is **zero voltage**.
  - **Displacement**: If the core moves to one side, one coil produces more voltage than the other, creating a **net output voltage**. The further the core moves, the higher the output voltage, which directly relates to the displacement.

Key Features:

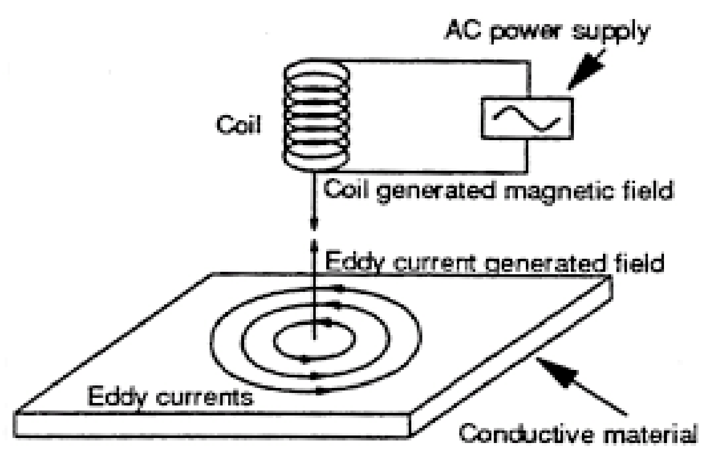
- **High Accuracy**: Measures displacement with minimal error.
- **Durability**: No contact between moving parts, so it's highly reliable.
- **Repeatability**: Gives consistent, accurate results.

Applications of LVDT Sensors:

- **Servo Valves**: Measures the position of spools in servo valves.
- **Hydraulic Systems**: Monitors the movement of hydraulic cylinders.
- **Pharmaceutical Industry**: Controls the weight and thickness of tablets and pills.
- **Product Inspection**: Automatically checks the size of products during packaging.
- **Friction Welding**: Measures the distance between two metal parts.
- **Leak Detection**: Monitors fluid levels to detect leaks.
- **ATMs**: Counts currency notes dispensed from ATMs.

LVDTs are popular because they are **precise, long-lasting, and work well in tough environments**.

Eddy Current Proximity Sensors



How They Work:

- These sensors detect conductive materials like aluminum, copper, and brass (but not magnetic ones).
- They have a coil, oscillator, detector, and trigger circuit.
- An alternating current flows through the coil, creating a magnetic field.
- When a conductive object comes close, it produces **eddy currents** in the object.
- These eddy currents create their own magnetic field, which disturbs the original magnetic field.
- This disturbance changes the coil's resistance, reducing the current.
- The sensor detects this change and activates a switch when the change reaches a set level.

Key Features:

- **Small & Compact:** Easy to install.
- **Reliable & Durable:** Long-lasting and wear-resistant.
- **High Sensitivity:** Detects small displacements.
- **Affordable:** Cost-effective option

Applications:

- **Automation Systems:** Detects object positions accurately.
- **Machine Tools:** Tracks the position and movement of machine tools.
- **Precision Equipment:** Used in devices like disk drives for precise assembly.
- **Vibration Monitoring:** Measures vibrations in moving parts.
- **Drive Shafts:** Monitors the rotation of shafts in vehicles and machines.
- **Moving Targets:** Tracks movement in continuously moving objects like vibrating parts.

This type of sensor is widely used in industries where non-contact, high-precision detection of metal objects is required.

Light Sensor

A photoresistor changes its resistance based on light. More light makes it less resistant, and less light makes it more resistant. Solar cells can convert sunlight into power for robots, making them energy-efficient.

Sound Sensor

A microphone that picks up sound and turns it into a voltage signal. This helps robots follow sound commands like turning or stopping based on the number of claps. The voltage from sound needs to be made stronger to be useful.

Temperature Sensor

Measures the temperature of the environment. These sensors change voltage as the temperature changes. Robots in hot places like deserts use these sensors to report temperature changes.

Contact Sensor

These sensors activate when something physically touches them, like a button or switch. Robots use these to detect obstacles and react, such as reversing or turning. Some sensors even work with just a touch, like a human's hand.

Actuator

An actuator is a device that moves or controls something in a system. It converts energy, like electric current, hydraulic pressure, or air pressure, into motion. Actuators are essential for robots as they allow them to perform actions based on commands from a controller.

Actuators in Robots: Actuators are the "muscles" of robots. They create movement, allowing robots to perform tasks. The type of actuator used depends on factors like the amount of force needed, speed, accuracy, and power. Some common types of actuators used in robots include:

- **Hydraulic actuators**: Use liquid pressure to create movement.
- **Pneumatic actuators**: Use air pressure for motion.
- **Electric motors**: Such as DC motors, servomotors, and stepper motors.
- **Direct drive motors**: Motors that directly drive the mechanical system.
- **Magnetostrictive actuators**: Use magnetic fields to generate movement.
- **Shape memory metal actuators**: Metals that change shape with heat to create motion.

Important Properties of Actuators:

1. **Power**: How strong the actuator is.
2. **Weight**: How heavy the actuator is, affecting robot movement.
3. **Price**: How much the actuator costs.
4. **Accuracy**: How precisely the actuator moves.
5. **Response Time**: How quickly the actuator reacts to signals.
6. **Reliability**: How dependable the actuator is.
7. **Maintenance**: How easy it is to take care of the actuator.

Examples for Specific Robots:

- **Underwater Robots**: Must be waterproof.
- **Space Robots**: Focus on being light and reliable.
- **Industrial Robots**: Require high power and accuracy.
- **Entertainment Robots**: Should be affordable.

Characteristics of Actuator Systems:

1. Power-to-Weight Ratio

- **Impact**: Affects how easily a robot can move.
- **Ideal**: Light actuators with high power are best.
- **Comparison**:
  - **Hydraulic**: Very powerful but heavy.
  - **Electric**: Lightweight with moderate power.
  - **Pneumatic**: Lightest but least powerful.

2. Stiffness vs. Flexibility

- **Stiff Systems (Hydraulic)**:
  - **Good**: Fast response, precise control.
  - **Bad**: Can be dangerous in case of failure.
- **Flexible Systems (Pneumatic)**:
  - **Good**: Safer and less likely to cause damage.
  - **Bad**: Slower movement and less accuracy.

3. Direct Drive vs. Gear Reduction

- **Direct Drive (Hydraulic/Pneumatic)**:
  - **Good**: Simple design, lightweight, low cost, and less noise.
  - **Bad**: Less precise movement.
- **Gear Reduction (Electric)**:
  - **Good**: Provides high precision and accurate control.
  - **Bad**: Heavier, more complex, and increases system inertia.

Summary of Actuator Types

Actuator Type	Advantages	Disadvantages
Hydraulic	Ideal for large robots and heavy loads. Strong power-to-weight ratio.	Heavy, can leak, requires extra equipment (pump, reservoir, filters), sensitive to dirt.
Electric	Works for all robot sizes, precise control, low maintenance, and clean operation.	Needs gears for better torque, requires a brake to hold position when off, can be noisy.
Pneumatic	Cheap, simple, lightweight, and good for simple "on/off" tasks.	Low power, poor position control, and lacks precision.

Types of Actuators

1. Hydraulic Actuators

Hydraulic actuators use pressurized liquid (like oil) to create motion. They are used in big machines like cranes and excavators. They are best for lifting heavy loads and moving large objects.

Advantages

- **Very Strong**: Can lift and move heavy objects.
- **Accurate**: Provides precise control of movement.
- **Compact Power**: Small size but produces a lot of force.
- **Holds Position**: Can stay in position without needing constant power.

Disadvantages

- **Heavy and Bulky**: Needs pumps, tanks, and pipes, making it large and heavy.
- **Leaks**: Oil leaks can be messy and harmful.
- **Needs Clean Environment**: Dirt and dust can affect performance.
- **Regular Maintenance**: Needs frequent checks for leaks and clean oil.

2. Pneumatic Actuators

Pneumatic actuators use compressed air to move parts. They are used in light, simple machines like pick-and-place robots. They are best for simple, light, and quick actions.

Advantages

- **Light and Simple**: Easy to use and set up.
- **Low Cost**: Cheaper than hydraulic and electric actuators.
- **Safe**: No risk of dangerous leaks or fires.
- **Clean**: Uses air, so there's no mess.

Disadvantages

- **Less Powerful**: Not good for lifting heavy objects.
- **Not Very Precise**: Hard to control exact movements.
- **Needs Air Supply**: Must be connected to an air compressor.
- **Slow Movements**: Moves slower compared to hydraulic and electric actuators.

3. Electric Actuators

Electric actuators use electric motors to create movement. They are found in home appliances, robots, and automated systems. They are best for precise, clean, and easy-to-control movements.

Advantages

- **Easy to Control**: Can control speed, position, and direction easily.
- **Clean and Safe**: No oil or fluid, so it's clean and safe.
- **Low Maintenance**: Needs less upkeep than hydraulic or pneumatic actuators.
- **Available Power**: Electricity is easy to access in most places.

Disadvantages

- **Can Overheat**: Too much use can make the motor hot.
- **Limited Strength**: Not as powerful as hydraulic actuators.
- **Needs Gears**: Gears are required to increase power, which adds weight.
- **Can Be Noisy**: Motor sounds and gear movement can be noisy.

Types of Electrical Actuators

1. Servo Motor

A servo motor moves to a specific position with **high precision** using a **feedback system**. It is widely used in robotics where accurate movement is required.

Advantages: Precise, strong torque, easy to control
Disadvantages: Limited rotation range, more expensive

Uses: Robotic arms, drones, camera gimbals

2. DC Motor

A DC motor converts **electricity into motion**. It's simple, affordable, and common in robotics.

Types:

- **Brushed DC Motor**: Uses brushes to change current direction.
- **Geared DC Motor**: Uses gears for higher torque but slower speed.
- **Brushless DC Motor**: No brushes, more efficient, needs a controller.

Advantages: Simple, cheap, easy to control
Disadvantages: Brushes wear out, noisy (brushed motors)

Uses: Toys, electric scooters, conveyor belts

3. AC Motor

AC motors run on **alternating current** and are used for high-power tasks. They are more common in **industrial robots**.

Advantages: Durable, powerful, long-lasting
Disadvantages: Fixed speed, less control, not used in mobile robots

Uses: Factory machines, home appliances, pumps

4. Brushless DC Motor (BLDC)

A **brushless motor** is like a DC motor but with **no brushes**, making it more efficient, faster, and durable.

Advantages: Long-lasting, fast, more efficient
Disadvantages: Needs a controller, more expensive

Uses: Drones, electric vehicles, robots

5. Stepper Motor

A stepper motor moves in **small, precise steps**. It is ideal for **accurate positioning**.

Advantages: Precise control, no feedback system needed
Disadvantages: Less torque, slower movement

Uses: 3D printers, CNC machines, robotic arms

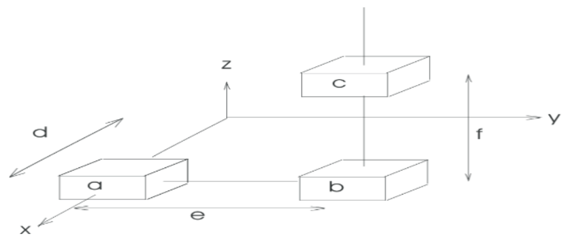
Motor Type	Precision	Power	Speed	Cost
Servo Motor	Very High	Medium	Medium	High
DC Motor	Low	Medium	High	Low
AC Motor	Low	Very High	Fixed	Medium
Brushless DC	High	High	High	High
Stepper Motor	Very High	Low	Low	Low

Piezoelectric Actuators

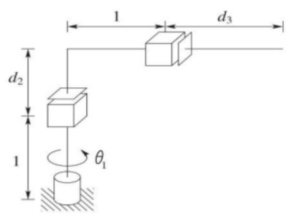
When electricity flows through a piezoelectric material, it changes shape. This small movement allows for very precise positioning, accurate up to micrometers. The movement is usually less than 100 µm but can be increased if needed.

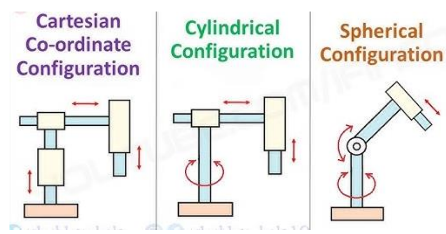
Types of Robot Axes

1. **Cartesian Robot** - Moves in X, Y, and Z directions using 3 linear joints (L1, L2, L3), ideal for pick-and-place tasks and moving heavy loads.



2. **Cylindrical Robot** - Moves up/down, rotates, and extends/retracts using 1 linear joint, 1 rotational joint, and 1 linear joint, ideal for assembly tasks and tracing cylindrical shapes.





3. **Spherical Robot** - Rotates around two axes and moves in/out using 2 rotational joints and 1 linear joint, suitable for tasks requiring spherical movement.

Refrigeration

Refrigeration is the process of removing heat from an enclosed space or substance and transferring it to a place where it has little to no effect. Its primary purpose is to lower and maintain a substance's or space's temperature.

Applications of Refrigeration

- Ice Making
- Preservation and Transportation of Perishables
- Special Industrial Processes
- Air Cooling

Types of Refrigeration Systems

1. Vapour Compression Refrigeration System (VCRS)
2. Vapour Absorption Refrigeration System (VARS)
3. Solar Energy-Based Refrigeration System

4. Air Cycle Refrigeration System
5. Steam and Vapour Jet Refrigeration System
6. Thermoelectric Refrigeration System
7. Vortex Tube Refrigeration System
8. Low-Temperature Refrigeration System
9. Electrolux Refrigeration System
10. Magnetic Cooling Refrigeration System

Units of Refrigeration

A tonne (TR) of refrigeration is defined as the amount of refrigeration effect required to uniformly melt one tonne (1000 kg) of ice at 0°C in 24 hours. The latent heat of ice is 335 kJ/kg, so:

1 TR=1000×335 kJ in 24 hours

This gives:

(1000×335)/(24×60)=232.6 kJ/min

In practical applications, 1 tonne of refrigeration is considered equivalent to:

1 TR=210 kJ/min or 3.5 kW (3.5 kJ/sec)

Vapor Compression Refrigeration System (VCRS)

The **Vapor Compression Refrigeration System** (VCRS) uses a refrigerant to cool a space by absorbing heat and then releasing it elsewhere. The system has four main parts:

1. **Compressor –** Compresses the refrigerant gas to a high pressure.
2. **Condenser** – Cools the hot gas and turns it into a liquid.
3. **Expansion Device** – Reduces the pressure of the liquid refrigerant.
4. **Evaporator –** The cold refrigerant absorbs heat from the air around it, making the air cooler.

How It Works:

1. **Compressor**: The refrigerant enters the compressor as a gas and gets compressed to a higher pressure and temperature. It becomes a very hot gas.
2. **Condenser**: The hot gas moves into the condenser, where it's cooled down by air (usually from outside). This causes the gas to turn back into a liquid.
3. **Expansion Device**: The liquid refrigerant then flows through an expansion device, where the pressure drops quickly. This causes part of the liquid to turn into gas, making the refrigerant colder.
4. **Evaporator**: The cold mixture of liquid and gas enters the evaporator, where it absorbs heat from the air around it, making the air cooler. As it absorbs heat, the refrigerant turns back into a gas and returns to the compressor to begin the cycle again.

Vapor Compression Refrigeration System

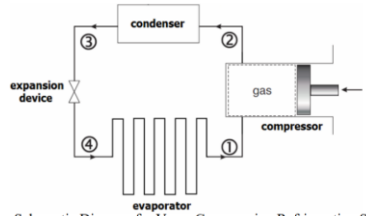
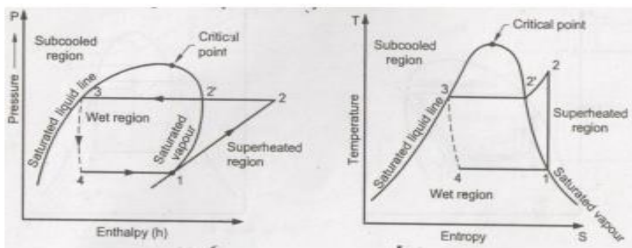


Fig.: Schematic Diagram for Vapor Compression Refrigeration System

Thermodynamic Steps:

- **1–2**: The refrigerant is compressed, which increases its pressure and temperature.
- **2–3**: The refrigerant releases heat in the condenser and turns back into a liquid.
- **3–4**: The refrigerant goes through a pressure drop and gets cooler.
- **4–1**: The refrigerant absorbs heat from the space being cooled and evaporates.



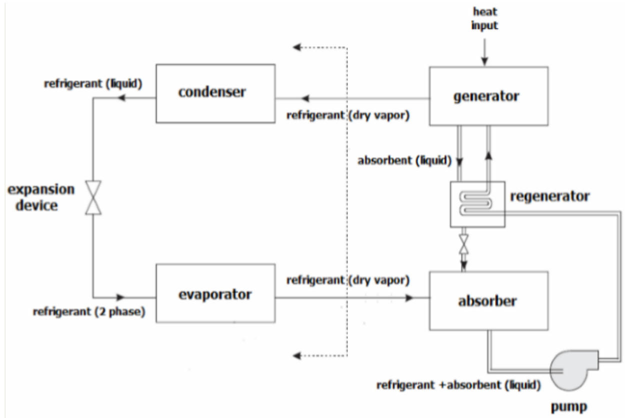
1. **Compression (1 → 2)**: The refrigerant is compressed, increasing both its pressure and temperature, turning it into high-pressure vapor.
2. **Condensation (2 → 3)**: The high-pressure, high-temperature refrigerant releases heat and condenses into a liquid state.
3. **Expansion (3 → 4)**: The refrigerant passes through an expansion valve, which lowers its pressure, causing it to become a mixture of liquid and vapor.
4. **Evaporation (4 → 1)**: The refrigerant absorbs heat from the surroundings, evaporating and turning into a low-pressure vapor.

This cycle continuously repeats to cool the space, making the **Vapor Compression Refrigeration System** widely used in air conditioners, refrigerators, and freezers.

Key Points:

- The system works by moving the refrigerant between liquid and gas forms to absorb heat from one place and release it elsewhere.
- It is used in refrigerators, air conditioners, and other cooling systems to maintain a desired temperature.

Vapor Absorption Refrigeration System



In a vapor absorption refrigeration system, instead of a compressor, we use components like an absorber, pump, generator, regenerator, and valve. Here's how it works:

1. **Absorber**: The refrigerant vapor (gas) enters the absorber, where it is absorbed by a liquid absorbent (such as water or lithium bromide solution). This process releases heat and is more efficient at cooler temperatures.
2. **Pump**: The absorbent solution, now containing the refrigerant, is pumped to the **generator** under high pressure.
3. **Generator**: In the generator, heat is added to the solution, causing the refrigerant to separate from the absorbent. The refrigerant vapor is sent to the **condenser**.
4. **Condenser**: The refrigerant vapor cools down and condenses into a liquid form, releasing heat to the surroundings.
5. **Expansion Device**: The liquid refrigerant flows through the expansion device, where its pressure decreases rapidly. This causes part of the liquid to evaporate, which lowers its temperature.
6. **Evaporator**: The cold refrigerant enters the evaporator, where it absorbs heat from the space to be cooled (such as a room or refrigerator). As the refrigerant absorbs heat, it turns back into a gas and flows back to the **absorber** to repeat the cycle.
7. **Regenerator (Optional)**: Some systems use a regenerator to recover heat from the absorbent solution before it enters the absorber, reducing the energy needed to vaporize the solution in the generator.

Advantages of Vapor Absorption Refrigeration System:

- **Uses Less Power**: It consumes less energy because it uses a pump instead of a compressor to circulate the refrigerant.
- **Uses Waste Heat**: The system can utilize waste heat from other sources like exhaust gases from boilers or turbines, improving overall energy efficiency.
- **Efficient**: Compared to vapor compression systems, it uses less electrical energy since it operates mainly on heat.

Common Refrigerant-Absorbent Combinations:

- Examples include ammonia-water and lithium bromide-water.

Coefficient of Performance (COP):

COP is the measure of the system's efficiency. A COP of 2.0 means the system removes 2 units of heat for every 1 unit of energy it uses

$COP = Q/W$

Where:

- Q = Amount of heat removed from the cold space (cooling effect) (in kJ or kWh)
- W = Work input (energy consumed) (in kJ or kWh)

Refrigerants

A **refrigerant** is a substance used in a refrigeration system that changes from gas to liquid and back to absorb and remove heat.

Types of Refrigerants:

1. **Primary Refrigerants**: These are the main refrigerants that change phase (from gas to liquid or liquid to gas) to absorb or release heat. Examples include:
    - **R-12** (Dichlorodifluoromethane)
    - **R-22** (Mono-chloro-difluoro-methane)
    - **R502** (Refrigerant 502)
2. **Secondary Refrigerants**: These are substances like air, water, or brine, which are cooled by the primary refrigerant. They carry heat away from the area to be cooled and then return to the system for re-cooling.

Desirable Properties of Refrigerants:

- **High Critical Temperature**: This helps in condensing the refrigerant effectively at higher pressures.
- **Low Boiling Temperature**: Allows the system to operate efficiently without requiring high vacuum pressures.
- **Low Freezing Point**: Prevents the refrigerant from freezing and blocking pipes.
- **Low Density**: Allows the use of smaller pipes and reduces pressure drops.
- **High Latent Heat of Vaporization**: Helps absorb more heat, improving cooling efficiency.
- **Low Gaseous Volume**: Reduces the size of equipment and increases compressor efficiency.
- **Low Viscosity and High Thermal Conductivity**: Ensures better heat transfer and overall system performance.
- **Chemical Stability**: The refrigerant should not break down or react with other materials in the system.
- **Non-reactive with Lubricating Oil**: Prevents damage to the system components.
- **Non-toxic, Non-corrosive, and Inert**: Ensures safety for users and the environment.

These properties ensure that refrigerants are efficient, safe, and effective in a refrigeration system.

Air Conditioning Systems

Air conditioning (AC) is the process of cooling and drying indoor air for comfort. It can also involve heating, ventilation, and air cleaning, depending on the system. An air conditioner controls the temperature and humidity in a space using a refrigeration cycle or sometimes evaporation.

Comfort vs. Industrial Air Conditioning

1. **Comfort Air Conditioning**:
   - Made for human comfort.
   - Controls temperature, humidity, air movement, and cleaning.
   - Common in homes, offices, and cars.

2. **Industrial Air Conditioning**:
   - Not for human comfort.
   - Used in places like factories, mills, and laboratories.
   - Maintains specific conditions needed for industrial work, such as temperature or air quality control.

Air conditioning is essential for both comfort and industrial needs.

Human Comfort

Human comfort is influenced by both physical and mental factors. It's hard to define exactly, but the **American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)** defines it as "the condition of mind that expresses satisfaction with the thermal environment." There are four main factors that affect comfort, and an air conditioning system helps control them to keep the environment comfortable.

Factors Affecting Human Comfort:

1. **Temperature**: The air temperature should be maintained at a comfortable level (around **21°C** with **56% humidity**).
2. **Humidity**: Humidity should be controlled. In summer, it should be **at least 60%**, and in winter, it should not go above **40%**.

3. **Purity of Air**: Clean air is important. If the air is dirty, it can make people uncomfortable even if the temperature and humidity are right. The air needs to be filtered and purified.
4. **Air Movement**: Air should flow evenly throughout the space to ensure a consistent temperature everywhere. Proper circulation of air is key to comfort.

Equipment in an Air Conditioning System

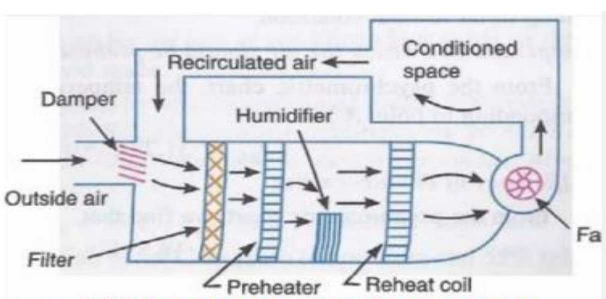
1. **Circulation Fan**: Moves air in and out of the room.
2. **Air Conditioning Unit**: Cools and dehumidifies the air in summer, and heats and humidifies it in winter.
3. **Supply Duct**: Carries the conditioned air into the room.
4. **Supply Outlets**: Distribute the conditioned air evenly throughout the room.
5. **Return Outlets**: Allow the air from the room to flow back into the system.
6. **Filters**: Remove dust, dirt, and other harmful particles from the air.

Classification of Air Conditioning Systems

1. **According to Purpose**:
   - (a) Comfort air conditioning system
   - (b) Industrial air conditioning system

2. **According to Season of the Year**:
   - (a) Winter air conditioning system
   - (b) Summer air conditioning system
   - (c) Year-round air conditioning system
3. **According to Arrangement of Equipment**:
   - (a) Unitary air conditioning system
   - (b) Central air conditioning system

Winter Air Conditioning System



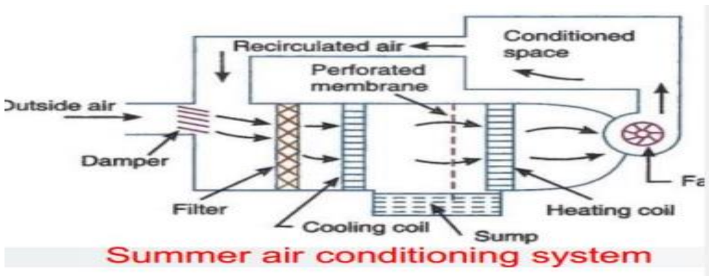
Winter air conditioning system

What it does: This system heats the air and adds moisture (to stop the air from being too dry) during the cold months.

How it works:

- **Outside Air**: Cold air from outside comes in.
- **Recirculated Air**: Some air from inside the room is mixed with the outside air.
- **Filter**: The air is cleaned by a filter to remove dust and dirt.
- **Preheater**: The air is warmed a little to keep it from freezing.
- **Humidifier**: Moisture is added to make the air less dry.
- **Reheat Coil**: The air is heated up to the right temperature.
- **Conditioned Air**: The warm and moist air is blown into the room.
- **Recirculated Air**: Some air is taken out of the room, and the rest is used again.

Summer Air Conditioning System

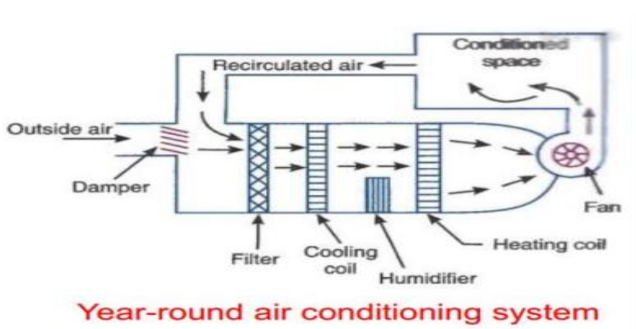


What it does: This system cools the air and removes moisture (to stop it from feeling too sticky) during the hot months.

How it works:

- **Outside Air**: Hot air from outside comes in.
- **Recirculated Air**: The outside air is mixed with air from inside the room.
- **Filter**: The air is cleaned by a filter to remove dust.
- **Cooling Coil**: The air is cooled down, and moisture is removed from it (the moisture turns into water).
- **Perforated Membrane**: The air loses even more moisture, and the water is collected.
- **Heating Coil**: The air is warmed a little to the right temperature.
- **Conditioned Air**: The cool and dry air is sent into the room.
- **Recirculated Air**: Some air is taken out of the room, and the rest is reused.

Year-Round Air Conditioning System



What it does: This system keeps the air comfortable all year by cooling in summer and heating in winter.

How it works:

- **Outside Air**: Air from outside comes in.
- **Recirculated Air**: The outside air mixes with the air already inside.
- **Filter**: The air is cleaned by a filter to remove dust.
- **Cooling Coil (Summer)**: In summer, the air is cooled, and moisture is removed.
- **Heating Coil (Winter)**: In winter, the cooling coil is turned off, and the heating coil warms up the air.
- **Humidifier**: In winter, moisture is added if the air is too dry.
- **Conditioned Air**: The air, whether cooled in summer or heated in winter, is sent into the room.
- **Recirculated Air**: Some air is taken out of the room, and the rest is reused.

Summary:

- **Winter System**: Warms the air and adds moisture when it's cold outside.
- **Summer System**: Cools the air and removes moisture when it's hot outside.
- **Year-Round System**: Cools in summer and heats in winter, while also adding moisture when needed.

IC Engine

Engine & Machine

- **Machine**: A machine is something that changes energy into useful work. For example, a lathe machine or a drilling machine.
- **Engine**: An engine is a type of machine that changes heat (thermal energy) into mechanical work. Examples are diesel engines, petrol engines, steam engines, and jet engines.

Key Point: All engines are machines, but not all machines are engines.

Types of Engines

- **External Combustion Engine**: In these engines, the fuel burns outside the engine. The heat created is then used to make the engine move. Examples are steam engines and steam turbines.
- **Internal Combustion Engine (IC Engine)**: In these engines, the fuel burns inside the engine. The heat from the burning fuel is turned into motion. Examples include gasoline engines and diesel engines.

Differences Between Steam Engine and IC Engine

S. No.	Steam Engine	IC Engine
1	Fuel burns outside the engine (in a boiler).	Fuel burns inside the engine.
2	Runs quietly and smoothly.	Noisy because fuel burns inside the engine.
3	Works at low heat and pressure.	Works at high heat and pressure.
4	Made from regular materials due to low pressure.	Made from special materials because of high pressure.
5	Heavy and needs extra parts like a boiler.	Light and compact.
6	Efficiency is about 15-20%.	Efficiency is about 35-40%.
7	Takes time to start.	Starts right away.

Classification of Internal Combustion (IC) Engines

1. **According to the type of fuel used**:
   - Petrol Engines
   - Diesel Engines
   - Gas Engines
2. **According to the method of igniting the fuel**:
   - Spark Ignition Engines (Fuel is ignited by a spark, typical in petrol engines)
   - Compression Ignition Engines (Fuel is ignited by compression, typical in diesel engines)
3. **According to the number of strokes per cycle**:
   - Four Stroke Cycle Engines
   - Two Stroke Cycle Engines
4. **According to the cycle of operation**:
   - Otto Cycle Engines (Used in petrol engines)
   - Diesel Cycle Engines (Used in diesel engines)
   - Dual Cycle Engines (A combination of Otto and Diesel cycles)
5. **According to the speed of the engine**:
   - Slow Speed Engines
   - Medium Speed Engines
   - High Speed Engines
6. **According to the cooling system**:
   - Air-Cooled Engines
   - Water-Cooled Engines
7. **According to the method of fuel injection**:
   - Carburetor Engines
   - Air Injection Engines
8. **According to the number of cylinders**:
   - Single Cylinder Engines
   - Multi-Cylinder Engines
9. **According to the arrangement of cylinders**:
   - Vertical Engines

- Horizontal Engines
- Radial Engines
- In-line Multi-Cylinder Engines
- V-Type Multi-Cylinder Engines
- Opposite-Cylinder Engines
- Opposite-Piston Engines

10. **According to the valve mechanism**:
    - Overhead Valve Engines
    - Side Valve Engines
11. **According to the method of governing**:
    - Hit-and-Miss Governed Engines
    - Quantitatively Governed Engines
    - Qualitatively Governed Engines

Parts of an Internal Combustion (IC) Engine

1. **Cylinder**: The cylinder is where the piston moves up and down to create power. It is made from strong materials to handle the heat and pressure inside the engine.
2. **Cylinder Head**: The cylinder head is on top of the cylinder. It has valves that let air in and gases out. In petrol engines, it also has spark plugs, and in diesel engines, it has fuel injectors.
3. **Piston**: The piston moves inside the cylinder. It takes the energy from the burning fuel and passes it to the connecting rod. Pistons are made of light but strong materials.
4. **Piston Rings**: Piston rings are metal rings that fit around the piston. The top rings stop gases from escaping, and the bottom rings stop oil from entering the cylinder.
5. **Connecting Rod**: The connecting rod links the piston to the crankshaft. It turns the up-and-down motion of the piston into the rotating motion of the crankshaft.
6. **Crankshaft**: The crankshaft takes the piston’s movement and turns it into spinning motion. It has parts called "cranks" where the connecting rod is attached.
7. **Crankcase**: The crankcase holds the cylinder and crankshaft. It also stores the oil that keeps the engine parts lubricated. The bottom part is called the bed plate.
8. **Flywheel**: The flywheel is a heavy wheel attached to the crankshaft. It helps keep the engine running smoothly by storing energy and releasing it when needed.

Frequently Used Terms in IC Engines:

1. **Bore**: The inside diameter (width) of the engine's cylinder.
2. **Top Dead Centre (T.D.C.)**: The highest point the piston reaches in the cylinder.
3. **Bottom Dead Centre (B.D.C.)**: The lowest point the piston reaches in the cylinder.
4. **Stroke**: The distance the piston moves between T.D.C. and B.D.C.
5. **Clearance Volume**: The space above the piston when it is at the top dead center.
6. **Swept Volume**: The space moved by the piston between the top and bottom dead centers.
7. **Compression Ratio**: The ratio of the total cylinder volume to the clearance volume. It indicates how much the air-fuel mixture is compressed before ignition.
8. **Scavenging**: The process of removing burnt exhaust gases from the combustion chamber.
9. **Supercharging**: The process of increasing the density of the air-fuel mixture or compressed air entering the cylinder to enhance engine power.

10. **Turbocharger**: A type of supercharger that uses a turbine powered by exhaust gases to force more air into the engine, boosting power.
11. **Indicated Power (I.P.)**: The power developed by the combustion of fuel inside the engine cylinder, representing the total power output before mechanical losses.
12. **Brake Power (B.P.)**: The usable power available at the crankshaft after accounting for mechanical losses.
13. **Frictional Power (F.P.)**: The power lost due to friction within the engine, calculated as the difference between I.P. and B.P.
    Formula: F.P. = I.P. - B.P.
14. **Detonation**: The knocking or pinging sound caused by premature ignition of the air-fuel mixture in the engine, potentially damaging the engine.
15. **Specific Fuel Consumption (SFC)**: The amount of fuel consumed (by weight) to produce one unit of power per unit of time, indicating the engine's fuel efficiency.
16. **Blow-by**: Gases that leak past the piston rings into the crankcase. Some blow-by is normal in all engines, even new ones, due to imperfect sealing between the piston rings and cylinder walls.

SI Engine (Spark Ignition Engine)

In this engine, fuel is ignited by a spark plug or a predefined ignition source. **Example**: Petrol Engine.

CI Engine (Compression Ignition Engine)

In this engine, fuel ignites because of the heat generated when the air inside the cylinder is compressed. **Example**: Diesel Engine.

Feature	SI Engine (Spark Ignition)	CI Engine (Compression Ignition)
Ignition	Uses a spark plug to ignite fuel.	Fuel ignites due to heat from compression.
Fuel Type	Uses petrol (gasoline).	Uses diesel.
Compression Ratio	Lower (6:1 to 10:1).	Higher (14:1 to 22:1).
Efficiency	Less efficient.	More efficient.
Power Output	Lower power.	Higher power.
Noise	Quieter engine.	Noisier engine.
Cost	Cheaper to make.	More expensive to make.
Operation	Works at lower temperatures and pressures.	Works at higher temperatures and pressures.
Maintenance	Needs more maintenance.	Needs less maintenance.
Emissions	Makes more CO and unburnt fuel.	Makes more NOx and soot.

Differences Between Diesel Engine and Petrol Engine:

S. No	Petrol Engine	Diesel Engine
1	Uses a mix of petrol and air during the intake.	Uses only air during the intake.
2	A carburetor mixes petrol and air.	An injector sprays fuel into the engine.
3	Compression pressure is about 10 bar.	Compression pressure is about 35 bar.
4	Fuel is ignited by a spark plug.	Fuel is ignited by the hot compressed air.
5	Combustion happens at constant volume (Otto cycle).	Combustion happens at constant pressure (Diesel cycle).
6	Compression ratio is between 6 to 10.	Compression ratio is between 15 to 25.
7	Easier to start because of low compression.	Harder to start because of high compression.
8	Lighter and cheaper.	Heavier and more expensive.
9	Higher running cost because petrol is expensive.	Lower running cost because diesel is cheaper.
10	Lower maintenance cost.	Higher maintenance cost.
11	Thermal efficiency is about 26%.	Thermal efficiency is about 40%.
12	More chance of overheating.	Less chance of overheating.
13	High-speed engine.	Low-speed engine.
14	Used in small vehicles like cars and motorcycles.	Used in big vehicles like trucks and buses.

Difference Between Two-Stroke and Four-Stroke Engines

Two-Stroke Engine: Completes one power cycle in 2 strokes of the piston (1 revolution of the crankshaft).

Four-Stroke Engine: Completes one power cycle in 4 strokes of the piston (2 revolutions of the crankshaft).

Advantages of Two-Stroke Engine Over Four-Stroke Engine

1. **More Power**: Produces **more power** since it fires once every revolution, unlike a four-stroke which fires once every two revolutions.
2. **Smaller and Lighter**: **Lighter and more compact** than four-stroke engines, so they fit well in small devices like scooters.
3. **Cheaper to Build**: It has a **simpler design** with fewer parts, so it costs less to make.
4. **Easier to Start**: Starts easily, making it suitable for tools like chainsaws and small motorcycles.

Disadvantages of Two-Stroke Engine

1. **Less Fuel Efficient**: Burns more fuel than a four-stroke engine.
2. **Consumes More Oil**: Uses more lubricating oil, increasing maintenance costs.
3. **Noisy and Polluting**: Produces more noise and smoke because it doesn't burn fuel as cleanly.
4. **Lower Efficiency**: Loses some power due to incomplete fuel combustion.

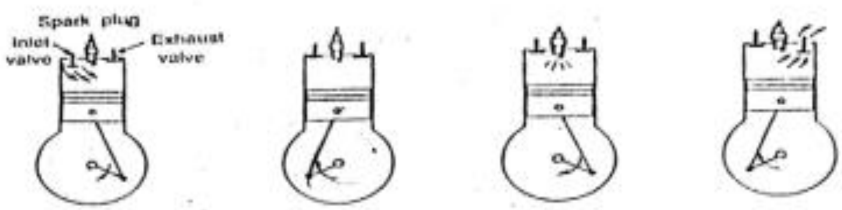
Applications of Four-Stroke Engines

- Cars, buses, and trucks
- Generators
- Aircraft engines
- Construction machinery (like diggers and drills)

Applications of Two-Stroke Engines

- Motorcycles, scooters, and mopeds
- Small boats (outboard motors)
- Lawn mowers and chainsaws
- Small generators

Four-Stroke Petrol Engine



(a) Suction or charging stroke. (b) Compression stroke. (c) Expansion or working stroke. (d) Exhaust stroke

A four-stroke engine works in **four simple steps** to produce power. Here's an easy explanation of each step:

1. <u>Suction Stroke (Intake)</u>: The **inlet valve opens**, and a mixture of **air and fuel** enters the engine. The piston moves **down** to make space for the mixture. The **exhaust valve stays closed**.

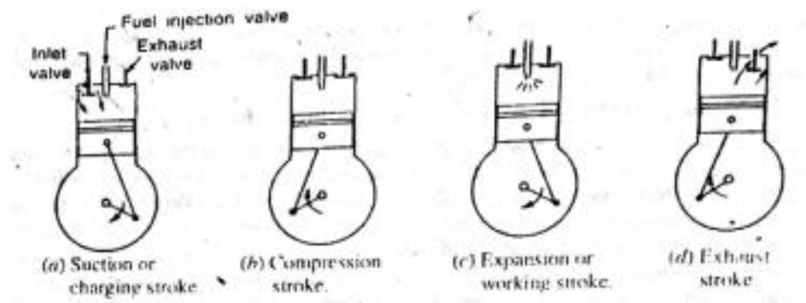
2. <u>Compression Stroke</u>: The piston moves **up**, squeezing the air-fuel mixture into a smaller space. This makes the mixture **hot and pressurized**, ready for burning. Both **inlet and exhaust valves stay closed**.

3. <u>Power Stroke (Explosion)</u>: A **spark plug** ignites (burns) the air-fuel mixture, causing an **explosion**. This explosion pushes the piston **down** with force. This stroke **produces power**. Both **inlet and exhaust valves stay closed**.

4. <u>Exhaust Stroke</u>: The **exhaust valve opens**, and the piston moves **up**, pushing out the burnt gases. The **inlet valve stays closed**.

These four steps repeat again and again to keep the engine running. This process powers cars, bikes, and other machines.

Four-Stroke Diesel Engine



A diesel engine works in **four simple steps** to produce power. Unlike petrol engines, it doesn't need a spark plug. The **heat from the compressed air** makes the fuel burn. Here are the four steps in simple words:

1. <u>Suction Stroke (Air In)</u>: The **inlet valve opens**, and **clean air** enters the engine. The piston moves **down** to make space for the air. The **exhaust valve stays closed**.

2. <u>Compression Stroke (Air Squeeze)</u>: The piston moves **up**, squeezing the air into a small space. This makes the air **very hot**. Both the **inlet and exhaust valves stay closed**.

3. <u>Power Stroke (Power Out)</u>: The engine sprays **fuel** into the hot air. The heat makes the fuel **burn and explode**, pushing the piston **down** with force. This is where the engine **gets power**. Both the **inlet and exhaust valves stay closed**.

4. <u>Exhaust Stroke (Smoke Out)</u>: The **exhaust valve opens**, and the piston moves **up**, pushing the **burnt gases (smoke)** out of the engine. The **inlet valve stays closed**.

These four steps repeat again and again to keep the engine running. This process powers trucks, buses, and big machines.