Mechatronics

UNIT –I

Introduction of sensors and actuators

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Syllabus

Introduction to Sensors & Actuators

• Introduction to Mechatronics, Measurement characteristics: - Static and Dynamic

• Sensors:
  • Position Sensors: - Potentiometer, LVDT, Encoders; Proximity sensors:- Optical, Inductive,
  • Capacitive; Motion Sensors:- Variable Reluctance; Temperature Sensor: RTD, Thermocouples; Force /
  • Pressure Sensors:- Strain gauges; Flow sensors: - Electromagnetic

• Actuators: Stepper motor, Servo motor, Solenoids
Objectives

1. Understand key elements of Mechatronics system, representation into block diagram
2. Understand concept of transfer function, reduction and analysis
3. Understand principles of sensors, its characteristics, interfacing with DAQ microcontroller
4. Understand the concept of PLC system and its ladder programming, and significance of PLC systems in industrial application
5. Understand the system modeling and analysis in time domain and frequency domain.
6. Understand control actions such as Proportional, derivative and integral and study its significance in industrial applications.
Outcomes

1. Identification of key elements of mechatronics system and its representation in terms of block diagram
2. Understanding the concept of signal processing and use of interfacing systems such as ADC, DAC, digital I/O
3. Interfacing of Sensors, Actuators using appropriate DAQ micro-controller
4. Time and Frequency domain analysis of system model (for control application)
5. PID control implementation on real time systems
6. Development of PLC ladder programming and implementation of real life system
What is Mechatronics

- Mechatronics is the synergistic combination of mechanical engineering ("mecha" for mechanisms), electronic engineering ("tronics" for electronics), and software engineering.

- The word "mechatronics" was first coined by Mr. Tetsuro Moria, a senior engineer of a Japanese company, Yaskawa, in 1969.
Mechatronics is the synergistic integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software to manage complexity, uncertainty, and communication in engineered systems.
Elements of Mechatronics

MECHANICAL SYSTEM
- system model  - dynamic response

ACTUATORS
- solenoids, voice coils
- DC motors
- stepper motors
- servo motors
- hydraulics, pneumatics

SENSORS
- switches  - strain gage
- potentiometer - thermocouple
- photoelectrics - accelerometer
- digital encoder - MEMs

INPUT SIGNAL CONDITIONING AND INTERFACING
- discrete circuits  - filters
- amplifiers  - A/D, D/D

GRAPHICAL DISPLAYS
- LEDs  - LCD
- digital displays - CRT

OUTPUT SIGNAL CONDITIONING AND INTERFACING
- D/A, D/D
- amplifiers  - power transistors
- PWM  - power op amps

DIGITAL CONTROL ARCHITECTURES
- logic circuits  - sequencing and timing
- microcontroller  - logic and arithmetic
- SBC  - control algorithms
- PLC  - communication
Basic Measurement System

Sensor
- RTD
- Potentiometer
- Strain Gage
- LVDT

Processor or Signal Conditioner
- Wheatstone Bridge
- Operational Amplifier

Display
- Digital
- Analog

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Characteristics of measurement systems

• To choose the instrument, most suited to a particular measurement application, we have to know the system characteristics.

• The performance characteristics may be broadly divided into two groups, namely ‘static’ and ‘dynamic’ characteristics.

• **Static characteristics**
  • the performance criteria for the measurement of quantities that remain constant, or vary only quite slowly.
  • The static characteristics are defined for the instruments which measure quantities which do not vary with time.

• **Dynamic characteristics**
  • the relationship between the system input and output when the measured quantity (measurand) is varying rapidly.
The main static characteristics are:

1. Accuracy
2. Sensitivity
3. Reproducibility
4. Drift
5. Static error
6. Dead zone
7. Precision
8. Threshold
9. Linearity
10. Stability
11. Range or Span
12. Bais
13. Tolerance
14. Hysteresis
Accuracy

• It is the degree of closeness with which an instrument reading approaches the true value of the quantity being measured.
• The accuracy of a measurement indicates the nearness to the actual/true value of the quantity.
• Accuracy is the Difference between the measured value and the true value.
Precision

• It is a measure of the reproducibility of the measurement that is given a fixed value of variable.
• Precision is a measure of the degree to which successive measurements differ from each other.
• For example consider an instrument on which readings can be taken upto 1/100th of unit.
• The instrument has zero adjustment error. So, when we take a readings, the instrument is highly precise. However as the instrument has a zero adjustment error the readings obtained are precise, but they are not accurate.
• Thus, when a set of readings show precision, the results agree among themselves. However, it is not essential that the results are accurate.
Accuracy and Precision

- Low accuracy, low precision
- Low accuracy, high precision
- High accuracy, low precision
- High accuracy, high precision
Reproducibility

• Reproducibility is defined as the degree of closeness by which a given value can be repeatedly measured.
• The reproducibility is specified for a period of time.
• Perfect reproducibility signifies that the given readings that are taken for an input, do not vary with time.
• Describes the closeness of output readings for the same input when there are changes in the method of measurement, observer, measuring instruments, location etc

Repeatability

• Describes the closeness of output reading when same input is applied repetitively over a short periods of time with the same measurement condition, same instruments and observer, same location and same conditions of use maintained throughout.
Drift

• The drift is defined as the gradual shift in the indication over a period of time where in the input variable does not change.
• Drift is a variation in the instrument output which is not caused by any change of input, it may caused by internal temperature changes and component instability
• Drift may be caused because of environment factors like stray electric fields, stray magnetic fields, thermal e.m.f s, changes in temperature, mechanical vibrations etc.

Drift is classified into three categories:
• Zero drift
• Span drift or sensitivity drift
• Zonal drift
Sensitivity

• Sensitivity is the ratio of change in output of an instrument to the change in input.

• Sensitivity states that smallest change in the value of measured variable to which the instrument/device responds

• The manufactures specify sensitivity as the ratio of magnitude of the measured quantity to the magnitude of the response. This ratio is called as Inverse sensitivity or deflection factor

• If the sensitivity changes due to ambient condition then it is called as sensitivity drift.
Sensitivity = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}

\frac{\Delta q_o}{\Delta q_i}
Sensitivity Meter
Threshold

- Threshold is the smallest measurable input, below which no output change can be identified.
- While specifying threshold, manufactures give the first detectable output change.

**Range or span**

- The minimum and maximum values of a quantity for which an instrument is designed to measure is called its range or span.
- Sometimes the accuracy is specified in terms of range or span of an instrument.
Linearity

• Linearity is defined as the ability of an instrument to reproduce its input linearly.
• Linearity is simply a measure of the maximum deviation of the calibration points from the ideal straight line.
• Linearity is defined as,
• linearity=Maximum deviation of o/p from idealized straight line / Actual readings

Most instruments are specified to function over a particular range and the instruments can be said to be linear when incremental changes in the input and output are constant over the specified range.
Resolution

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

- Instruments rarely respond to the instantaneous changes in the measured variables. Their response is slow or sluggish due to mass, thermal capacitance, electrical capacitance, inductance etc. Sometimes, even the instrument has to wait for some time till the response occurs.
- These type of instruments are normally used for the measurement of quantities that fluctuate with time.
- The behavior of such a system, where as the input varies from instant to instant, the output also varies from instant to instant is called as **dynamic response** of the system.
- Hence, the dynamic behaviour of the system is also important as the static behaviour.
The dynamic characteristics of a measurement system are:

1) Speed of response
2) Fidelity
3) Lag
4) Dynamic error
Speed of response

• It is defined as the rapidity with which an instrument, responds to the changes in the measured quantity.
• It shows how active and fast the system is.
• Speed measuring instruments:-
Fidelity

- It is defined as the degree to which a measurement system is capable of faithfully reproducing the changes in input, without any dynamic error.
**Lag**

- Every system requires its own time to respond to the changes in input. This time is called as lag.
- It is defined as the retardation or delay, in the response of a system to the changes in the input.
- The lags are of two types:
  1. **Retardation lag:**
     As soon as there is a changes in the measured quantity, the measurement system begins to respond.
  2. **Time delay:**
     The response of the measurement system starts after a dead time, once the input is applied. They cause dynamic error.
EXAMPLE OF DYNAMIC CHARACTERISTICS

Response from a 2\textsuperscript{nd} order instrument:

![Diagram showing response from a 2\textsuperscript{nd} order instrument](image-url)
Response from a 2\textsuperscript{nd} order instrument:

1. **Rise Time (tr)**
   
   • Time taken for the output to rise from 10\% to 90\% of the steady state value.

2. **Settling time (ts)**
   
   • Time taken for output to reach a steady state value.

3. **Response time**
   
   • Time taken to reach first peak of oscillation.
Basic Principle of Sensor / Transduction

Displacement, Temperature, Pressure, etc....

Sensor is a device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.).

Transducer is a device that converts one form of (energy) signal into another form of (energy) signal.
Sensors

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

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

• **Position sensors**
  1) Potentiometer (Rotary and Linear)
  2) LVDT
  3) Encoder
Detail classification of sensors in view of their applications in manufacturing is as follows.

A. Displacement, position and proximity sensors

- Potentiometer
- Strain-gauged element
- Capacitive element
- Differential transformers
- Eddy current proximity sensors
- Inductive proximity switch
- Optical encoders
- Pneumatic sensors
- Proximity switches (magnetic)
- Hall effect sensors
B. Velocity and motion
• Incremental encoder
• Tachogenerator
• Pyroelectric sensors

C. Force
• Strain gauge load cell

D. Fluid pressure
• Diaphragm pressure gauge
• Capsules, bellows, pressure tubes
• Piezoelectric sensors
• Tactile sensor
E. Liquid flow
- Orifice plate
- Turbine meter

F. Liquid level
- Floats
- Differential pressure

G. Temperature
- Bimetallic strips
- Resistance temperature detectors
- Thermistors
- Thermo-diodes and transistors
- Thermocouples
- Light sensors
- Photo diodes
- Photo resistors
Potentiometer

- A rotary potentiometer is a variable resistance device that can be used to measure angular position.
- Through voltage division the change in resistance can be used to create an output voltage that is directly proportional to the input displacement.
• Potentiometers operated by a mechanism can be used as position transducer for example, in a **joystick**

• Potentiometers consist of a resistive element, a sliding contact (wiper) that moves along the element, making good electrical contact with one part of it, electrical terminals at each end of the element, a mechanism that moves the wiper from one end to the other, and a housing containing the element and wiper.
Rotary Potentiometer
Linear Potentiometer

• The linear potentiometer consist of resistance elements with number of turns of wire wound around non conducting bar together with a sliding contact.

• Sliding contact is called as wiper.
Application of Potentiometer

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

• These are typically used in machine-tool controls, elevators, liquid-level assemblies, forklift trucks, automobile throttle controls.

• In manufacturing, these are used in control of injection molding machines, woodworking machinery, printing, spraying, robotics etc.
LVDT

A reliable and accurate sensing device that converts linear position or motion to a proportional electrical output.

- Primary winding centered between a pair of identically wound secondary windings
- The coils are wound on a one-piece hollow form
- Cylindrical stainless steel housing
- The moving element of an LVDT is a separate tubular armature of magnetically permeable material called the core
Construction of LVDT

- LVDT consists of a cylindrical transformer where it is surrounded by one primary winding in the centre of the former and the two secondary windings at the sides.

- The number of turns in both the secondary windings are equal, but they are opposite to each other.

- The Primary Winding is Connected to an ac source

An movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries.
LVDT Operation

If the core at the center, \( V_1 = V_2, \ V_o = 0 \)

When the core is away from center toward \( S_1 \), \( V_1 \) is greater than \( V_2 \) and the output voltage \( V_o \) will have the polarity \( V_1 \).

When the core is away from center toward \( S_2 \), \( V_2 \) is greater than \( V_1 \) and the output voltage \( V_o \) will have the polarity \( V_2 \).
Fig. 13.21 (a), (b), (c) Various Core Position of LVDT
(d) Variation of Output Voltage vs Displacement
Explain the construction and working of LVDT.

- **Core at Center**
  - \( E_{S1} = E_{S2} \)
  - \( E_0 = E_{S1} - E_{S2} = 0 \)

- **Core at Right**
  - \( E_{S1} < E_{S2} \)
  - \( E_0 = E_{S1} - E_{S2} = -ve \)

- **Core at Left**
  - \( E_{S1} > E_{S2} \)
  - \( E_0 = E_{S1} - E_{S2} = +ve \)

\( E_{S1} > E_{S2} \)

\( E_{S1} = E_{S2} \)
Advantages

- Linearity
- Infinite resolution
- High output
- Ruggedness
- High sensitivity
- Low power consumption
Disadvantages

- Large displacement are required for appreciable differential output.
- They are sensitive to stray magnetic fields.
- It must be selected to operate on AC signals.
- Temperature sensitive.
Applications of LVDT sensors

- Measurement of spool position in a wide range of servo valve applications
- To provide displacement feedback for hydraulic cylinders
- To control weight and thickness of medicinal products viz. tablets or pills
- For automatic inspection of final dimensions of products being packed for dispatch
- To measure distance between the approaching metals during Friction welding process
- To continuously monitor fluid level as part of leak detection system
- To detect the number of currency bills dispensed by an ATM
Rotary variable differential transformer

- It is a type of electrical transformer used for measuring angular displacement.

- It is an electromechanical transducer that provides a variable alternating current (AC) output voltage that is linearly proportional to the angular displacement of its input shaft. When energized with a fixed AC source, the output signal is linear within a specified range over the angular displacement.

- RVDT is used to measure rotational angles and operates under the same principles as the LVDT sensor. Whereas the LVDT uses a cylindrical iron core, the RVDT uses a rotary ferromagnetic core.
Rotary Variable Differential Transformer (RVDT)

Linear for limited rotation \((-40^\circ < \theta_i < +40^\circ)\)

Rotational differential transformer

Voltage level

-40°  40°  Rotation

Linear Range

Measurement

Primary Coil

Secondary Coil

Rotating Ferromagnetic Core

(Measurand)

Secondary Coil

Voltage level

-40°  40°  Rotation

Linear Range
Optical encoders

- Optical encoders provide digital output as a result of linear / angular displacement.
- These are widely used in the Servo motors to measure the rotation of shafts.
- Any transducer that generates a coded reading of a measurement can be termed an encoder.
- Shaft Encoders are digital transducers that are used for measuring angular displacements and velocities.
Shaft Encoders can be classified into two categories depending on the nature and method of interpretation of the output:

1. Incremental Encoders
2. Absolute Encoders
Construction And Working

Figure 2.3.3 Construction and working of optical encoder
Absolute Encoder Simplified Structure

- Rotor plate
- Light emission diode
- Fixed slit
- Photo transistor
- Shaft

(Resolution 8bit type/pure binary code)
Working Principle

• Elements of the Optical Encoder

• The optical encoder uses an opaque disk (code disk) that has one or more circular tracks, with some arrangement of identical transparent windows (slits) in each track.

• A parallel beam of light (e.g., from a set of light-emitting diodes) is projected to all tracks from one side of the disk.

• The transmitted light is picked off using a bank of photosensors on the other side of the disk that typically has one sensor for each track.

• The light sensor could be a silicon photodiode, a phototransistor, or a photovoltaic cell.
• Since the light from the source is interrupted by the opaque areas of the track, the output signal from the probe is a series of voltage pulses.

• This signal can be interpreted to obtain the angular position and angular velocity of the disk.

• Figure shows the construction of an optical encoder. It comprises of a disc with three concentric tracks of equally spaced holes.

• Three light sensors are employed to detect the light passing thru the holes.

• These sensors produce electric pulses which give the angular displacement of the mechanical element e.g. shaft on which the Optical encoder is mounted.
• The inner track has just one hole which is used to locate the ‘home’ position of the disc.
• The holes on the middle track offset from the holes of the outer track by one-half of the width of the hole. This arrangement provides the direction of rotation to be determined.
Incremental Encoder

• Incremental encoder disk requires only one primary track that has equally spaced and identical window (pick-off) areas.

• The window area is equal to the area of the inter-window gap.

• Usually, a reference track that has just one window is also present in order to generate a pulse (known as the index pulse) to initiate pulse counting for angular position m.

• an incremental encoder requires additional electronics (typically a PLC, counter, or drive) to count pulses and convert the data into speed or motion measurement and to detect complete revolutions.
Construction of Incremental Rotary Encoder

Components inside Incremental Rotary Encoder
Absolute encoder

• absolute encoder disks have several rows of tracks, equal in number to the bit size of the output data word.

• Furthermore, the track windows are not equally spaced but are arranged in a specific pattern on each track so as to obtain a binary code (or gray code) for the output data from the transducer.
Proximity sensors

• A proximity sensor detects an object when the object approaches within the detection range and boundary of the sensor.

• Proximity sensors include all sensors that perform non-contact detection in comparison to sensors such as limit switches, that detect the object by physically contacting them.

• Proximity sensors are used in various processes of manufacturing for detecting the approach of metal and non-metal objects.

• Two types:
  1. Inductive proximity sensors
  2. Capacitive proximity sensors
Inductive proximity sensors

- eddy current proximity sensors are used to detect non-magnetic but conductive materials.
- They comprise of a coil, an oscillator, a detector and a triggering circuit.
• Figure 2.3.1 shows the construction of eddy current proximity switch. When an alternating current is passed thru this coil, an alternative magnetic field is generated.

• If a metal object comes in the close proximity of the coil, then eddy currents are induced in the object due to the magnetic field.

• These eddy currents create their own magnetic field which distorts the magnetic field responsible for their generation.

• As a result, impedance of the coil changes and so the amplitude of alternating current.

• This can be used to trigger a switch at some pre-determined level of change in current.

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

- Automation requiring precise location
- Machine tool monitoring
- Final assembly of precision equipment such as disk drives
- Measuring the dynamics of a continuously moving target, such as a vibrating element,
- Drive shaft monitoring
- Vibration measurements
Capacitive proximity sensor

- Capacitive proximity sensors are similar to inductive proximity sensors.
- The main difference between the two types is that capacitive proximity sensors produce an electrostatic field instead of an electromagnetic field.
- Capacitive proximity switches will sense metal as well as nonmetallic materials such as paper, glass, liquids, and cloth.
Capacitive sensing

As a ferrous or nonferrous target enters the sensing zone, capacitance increases; circuit natural frequency shifts towards the oscillation frequency, causing amplitude gain.

Fig. 5: Working of capacitive proximity sensor
• The sensing surface of a capacitive sensor is formed by two concentrically shaped metal electrodes of an unwound capacitor.

• When an object nears the sensing surface it enters the electrostatic field of the electrodes and changes the capacitance in an oscillator circuit.

• As a result, the oscillator begins oscillating.

• The trigger circuit reads the oscillator’s amplitude and when it reaches a specific level the output state of the sensor changes.

• As the target moves away from the sensor the oscillator’s amplitude decreases, switching the sensor output back to its original state.
Capacitive proximity sensor

- Capacitive sensors depend on the dielectric constant of the target.
- The larger the dielectric number of a material the easier it is to detect.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Sensing range</th>
<th>Applications</th>
<th>Target materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductive</td>
<td>&lt;4-40 mm</td>
<td>Any close-range detection of ferrous material</td>
<td>Iron, Steel, Aluminum, Copper etc.</td>
</tr>
<tr>
<td>Capacitative</td>
<td>&lt;3-60 mm</td>
<td>Close-range detection of non-ferrous material</td>
<td>Liquids, Wood, Granulates, Plastic, Glass etc.</td>
</tr>
<tr>
<td>Photoelectric</td>
<td>&lt;1mm- 60 mm</td>
<td>Long-range, small/large target detection</td>
<td>Silicon, Plastic, Paper, Metal etc.</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>&lt;30 mm- 3 mm</td>
<td>Long-range detection of targets with difficult surface properties, Color/reflectivity insensitive.</td>
<td>Cellophane, Foam, Glass, Liquid, Powder etc.</td>
</tr>
</tbody>
</table>
Temperature measurement

• 3 basic types
1. Thermocouple
2. RTD (resistance temperature detector)
3. Thermistor
Thermocouple

• Thermocouple is a device used for the measurement of temperature.
• It can be even considered as a sensor for the measurement of temperature.
Working Principle

• The junction of two dissimilar metals forms a thermocouple.

• When the two junctions are at different temperatures, a voltage is developed across the junction.

• By measuring the voltage difference between the two junctions, the difference in temperature between the two can be calculated.

• If the temperature of one junction is known and the voltage difference is measured, then the temperature of the second junction can be calculated.
• The working principle of thermocouple is based on three effects, discovered by Seebeck, Peltier and Thomson. They are as follows:

• 1) **Seebeck effect:** The Seebeck effect states that when two different or unlike metals are joined together at two junctions, an electromotive force (emf) is generated at the two junctions. The amount of emf generated is different for different combinations of the metals.

• 2) **Peltier effect:**

• When a electric current crosses a junction between two dissimilar metals, one junction get heated up and another will evolved the heat(cold junction)
Thermocouple grade wire, type 'J'
Stainless steel sheath minimizes corrosion

Stainless steel armor. Stainless steel braid or plain lead wire also available
Adjustable compression fitting

THERMOCOUPLE (COMPRESSION STYLE)
Types of thermocouples

1. Type E
2. Type J
3. Type K
4. Type M
5. Type N
6. Type T
7. Type B
8. Type R
9. Type S
<table>
<thead>
<tr>
<th>Type</th>
<th>Material</th>
<th>Color Code</th>
<th>Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermocouple Grade</td>
<td>Positive Wire</td>
<td>Negative Wire</td>
<td>Minimum</td>
</tr>
<tr>
<td>J</td>
<td>Iron</td>
<td>Constantan</td>
<td>0</td>
</tr>
<tr>
<td>K</td>
<td>Chromel</td>
<td>Alumel</td>
<td>-200</td>
</tr>
<tr>
<td>T</td>
<td>Copper</td>
<td>Constantan</td>
<td>-200</td>
</tr>
<tr>
<td>E</td>
<td>Chromel</td>
<td>Constantan</td>
<td>-200</td>
</tr>
<tr>
<td>TYPE</td>
<td>Temperature</td>
<td>Positive Leg</td>
<td>Negative Leg</td>
</tr>
<tr>
<td>------</td>
<td>-----------------</td>
<td>--------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>TYPE B</td>
<td>0 to 1700°C</td>
<td>Platinum-30% Rhodium</td>
<td>Platinum-6% Rhodium</td>
</tr>
<tr>
<td>TYPE E</td>
<td>-100 to 1000°C</td>
<td>Chromel</td>
<td>Constantan</td>
</tr>
<tr>
<td>TYPE J</td>
<td>0 to 750°C</td>
<td>Iron</td>
<td>Constantan</td>
</tr>
<tr>
<td>TYPE K</td>
<td>-100 to 1300°C</td>
<td>Chromel</td>
<td>Alumel</td>
</tr>
<tr>
<td>TYPE N</td>
<td>-230 to 1300°C</td>
<td>Nicrosil</td>
<td>Nisil</td>
</tr>
<tr>
<td>TYPE R</td>
<td>0 to 1600°C</td>
<td>Platinum-13% Rhodium</td>
<td>Platinum</td>
</tr>
<tr>
<td>TYPE S</td>
<td>0 to 1600°C</td>
<td>Platinum-10% Rhodium</td>
<td>Platinum</td>
</tr>
<tr>
<td>TYPE T</td>
<td>-200 to 350°C</td>
<td>Copper</td>
<td>Constantan</td>
</tr>
</tbody>
</table>
Characteristics

![Characteristics Graph]

- **Thermocouple Output Voltage (mV)**
- **Temperature (°C)**

Legend:
- E
- K
- J
- C
- T
- R
- S

Graph shows the relationship between thermocouple output voltage and temperature for different thermocouple types.
Thermistors

• Thermistor or thermal resistor is a hard, ceramic-like electronic semiconductor, commonly made from a mixture of metallic oxide materials.

• Have a very large negative resistance coefficient (i.e., an increase in $T$ by 1°C yields a decrease of 5% in resistance).
RTD: Resistance Temperature Detectors

- Platinum is most commonly used for precision resistance thermometers because it is stable, resists corrosion, is easily workable, has a high temp melting point, and can be obtained to a high degree of purity.
- Simple and stable resistance-temperature relationship.
- Platinum is sensitive to strain; bending the sensor can change the resistance.
• The RTD wire is a pure material, typically platinum, nickel, or copper. The material has an accurate resistance/temperature relationship which is used to provide an indication of temperature.

• As RTD elements are fragile, they are often housed in protective probes.

• RTDs, which have higher accuracy and repeatability, are slowly replacing thermocouples in industrial applications below 600 °C.
**Thermocouple**
- Self-powered
- Simple
- Rugged
- Inexpensive
- Wide variety
- Wide temperature range

**Advantages**
- Most stable
- Most accurate
- More linear than thermocouple

**Disadvantages**
- Non-linear
- Low voltage
- Reference required
- Least stable
- Least sensitive

**RTD**
- High output
- Fast
- Two-wire ohms measurement

**Thermistor**
- Expensive
- Current source required
- Small Δ R
- Low absolute resistance
- Self-heating

**Advantages**
- Non-linear
- Limited temperature range
- Fragile
- Current source required
- Self-heating
<table>
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<tbody>
<tr>
<td>Typical measurement range</td>
<td>-267°C to 2316°C</td>
<td>-240°C to 649°C</td>
</tr>
<tr>
<td>Characteristic</td>
<td>Linear</td>
<td>Nonlinear</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Speed of response</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Type of transducer</td>
<td>Active</td>
<td>Passive</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Size</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Material Used</td>
<td>Copper-constantan, Iron-constantan etc.</td>
<td>Nickel, Copper, Platinum etc.</td>
</tr>
<tr>
<td>Compensation</td>
<td>Cold junction compensation required</td>
<td>Not required</td>
</tr>
<tr>
<td>Applications</td>
<td>Suitable for applications which require wide temperature range</td>
<td>Suitable where speed of response and accuracy are more important</td>
</tr>
</tbody>
</table>
Load Cells

• A load cell is a transducer that is used to convert a force into electrical signal.
• The most common type is a strain gauge load cell.
Strain Gauge

What Is It?

• A Strain Gauge is a device used to measure the strain of an object.
  – The most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern.
Strain Gauge

Resistance

\[ R = \rho \frac{l}{A} \]

1. Strain Gauge under tension. Resistance goes up.

Tension causes resistance increase

Bonded Strain Gauge

Gauge insensitive to lateral forces

Resistance measured between two points

Compression causes resistance increase
**Strain Gage**

**Glenn Research Center**

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**F = applied load**

- \( A = \text{wire area} \)
- \( i = \text{current} \)
- \( l = \text{wire length} \)
- \( V = \text{voltage} \)
- \( \rho = \text{resistivity} \)
- \( R = \text{resistance} \)

**Ohm's Law**

\[ i = \frac{V}{R} \]

\[ R = \frac{\rho l}{A} \]

**As Load F increases**

- \( A \) decreases
- \( R \) increases
- \( l \) increases
- \( i \) decreases

\[ i \sim \frac{1}{F} \]

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**22/02/2017**

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Strain Gauge

How Does It Work?

• The gauge is attached to the object by a suitable adhesive.

• As the object is deformed, the foil is deformed, causing its electrical resistance to change.

• The resistance change is commonly measured using a Wheatstone bridge.
Wheatstone Bridge

- A Wheatstone Bridge is an electrical circuit.
  - Used in a load cell to measure an overall change in resistance.
  - Increases sensitivity and reduces the affects of temperature.
Load Cells Applications

• Scales
  – Weighbridge
• Force Gauges
• Torque Gauges
Load Cells Types

- **S Type**
- **Button**
- **Canister**
- **Shear**
- **Beam**
Electro magnetic flow sensor

\[ E = \frac{1}{C} B D V \]
where \( C = a \) constant

**Figure 14-8.**—Schematic view of a magnetic flowmeter.
Electromagnetic Flowmeter
Working Principle

• The operation of a magnetic flowmeter or magmeter is based upon Faraday's Law, which states that the voltage induced across any conductor as it moves at right angles through a magnetic field is proportional to the velocity of that conductor.

• This law states that

\[ e = B l v \]

• In electromagnetic flowmeters, the conductor is the liquid flowing through the pipe,

\[ e = B D v \]
• In Magmeter magnetic field is generated using Electromagnets.
• The magnetic field has to permeate the process liquid through the tube wall, and for that reason the measuring tube should not have ferromagnetic properties.
• The electrodes are in direct contact with the process liquid. Their material needs to be adequately resistant to corrosion and must allow good electrical contact with the process liquid.
• The most commonly used electrode materials are stainless steel grades, Cr-Ni alloys, platinum, tantalum, titanium zirconium.
Stepper Motor

- Brushless DC electric motor.
- Division of full rotation.
- Divided to equal steps.
- Motor position commanded to move.
- Hold at any of steps without an open loop controller.
Working principle

• A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements.

• The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence.

• The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation.

• The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.
**Terminology**

- **Step Angle** – the angle by which the rotor of a stepper motor rotates for each command pulse.
  
  Step angle, \( \beta = \frac{(N_s - N_r) \times 360^\circ}{N_s \times N_r} \), where ‘Ns’ is no. of stator teeth & ‘Nr’ is no. of rotor teeth

- **Resolution** – the number of steps needed to complete one revolution of shaft.
  
  Resolution = \( \frac{360^\circ}{\beta} \)

- The speed of the motor shaft is, \( n = \frac{\beta \times f}{360} \) rps , where ‘f’ is stepping frequency(or pulse rate).

- **Detent torque** – the torque required to hold the rotor stationary while power is switched off.

- **Holding torque** – the torque required to deflect the rotor one full step at standstill.
The 3 Types Of Motors?

1. Variable Reluctance Stepper
2. Permanent Magnet Stepper
3. Hybrid Synchronous Stepper
Types

• **Permanent magnet stepper motor** – uses a permanent magnet in the rotor.

• **Variable reluctance stepper motor** – have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles.

• **Hybrid stepper motor** – use a combination of PM and VR techniques to achieve maximum power in a small package size.
Permanent magnet stepper

- Permanent magnet (PM) in the rotor operate on the attraction or repulsion b/w the rotor PM and the stator electromagnets.
- The rotor is made of a permanent-magnet material like magnetically hard ferrite.
- The stator has projecting poles but the rotor is cylindrical and has radially magnetized permanent magnet.

![Diagram of Permanent Magnet Stepper](image-url)
PM Stepper Motor Working

• When a particular stator phase is energised, the rotor magnetic poles move into alignment with the excited stator poles.
• The stator windings 1 and 2 can be excited with either polarity current.
• When phase 1 is excited with positive current, the rotor aligns itself in a vertical position.
• If excitation is now switched to phase 2 the rotor rotates by full step of 90° in clockwise direction.
• Next, when phase 1 is excited with negative current, the rotor turns through another 90° degree in CW direction.
Working of a Permanent Magnet Stepper Motor

North Polarity  South Polarity
Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Permanent Magnet</th>
<th>Variable Reluctance</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>COST</td>
<td>Cheapest</td>
<td>Moderate</td>
<td>Most Expensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>More expensive due to manufacturing processes</td>
</tr>
<tr>
<td>Design</td>
<td>Moderately Complex</td>
<td>Simple</td>
<td>Complex</td>
</tr>
<tr>
<td>Resolution</td>
<td>30° - 3°/step</td>
<td>1.8°/step and smaller</td>
<td></td>
</tr>
<tr>
<td>Torque vs. Speed</td>
<td></td>
<td>Less pronounced torque drop at higher speeds</td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>QUIET</td>
<td>Noisy no matter what type of excitation</td>
<td>QUIET</td>
</tr>
<tr>
<td>Stepping</td>
<td>Full, Half and Microstepping</td>
<td>Typically run in Full-Step only</td>
<td>Full, Half and Microstepping</td>
</tr>
</tbody>
</table>
Applications

- They are commonly used in watches and old electric meters
- They are used in a wide variety
  1. In Industry
     As - Drilling Machine,
     - Grinder,
     - Laser Cutting,
     - Conveyor;
     - Assembly Lines.
  2. In computer Peripherals
     As - Printer,
     - Plotter,
     - Tape Reader,
     - Card Reader;
     - Copy Machines.
  3. In Business
     As - Banking systems;
     - Automatic typewriters.
  4. In Motion Control and Robotics
     As - Silicon Processing;
     - I.C. Bonding.
What is servo motor?

• A servomotor is a rotary actuator that allows for precise control of angular position, velocity and acceleration.
• It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors.

• Servomotors are not a specific class of motor although the term servomotor is often used to refer to a motor suitable for use in a closed-loop control system.

• Servomotors are used in applications such as robotics, CNC machinery or automated manufacturing.
• Motors can be either AC or DC
• Can be of 1 phase or 3 phase.
• DC motors can be brushed or brushless.
• Brushless DC motors are more expensive, drives are more complex, but are more reliable and maintenance free.
• Feedback device for servomotors is typically an encoder or resolver built into the motor frame.
• Control circuitry is a motion controller (generates motion) and a drive to supply power to the motor
Figure 3-44. Typical servo system block diagram
• There are mainly two types of servo-motors,

  1) AC Servo-motor  
  2) DC Servo-motor

• AC servo-motors are generally preferred for low power use and for high-power use DC servomotors are preferred because they operate more efficiently than comparable to AC servo-motors

• DC Servo-motor:

• Unlike large industrial motors, dc servomotors are not used for continuous energy conversion. The basic operating principle is same as other electromagnetic motors.
Types of servo motors

- AC servo motor
- Dc servo motor
- Continuous rotation servo motor
- Linear servo motor
Layout of servo mechanism
Stator
From the position of the rotor, a rotating magnetic field is created to efficiently generate torque.

Winding
Current flows in the winding to create a rotating magnetic field.

Bearing
Ball Bearing

Encoder
The optical encoder always watches the number of rotations and the position of the shaft.

Shaft
This part transmits the motor output power. The load is driven through the transfer mechanism (such as the coupling).

Rotor
A high-function rare earth or other permanent magnet is positioned externally to the shaft.
Working principle of DC servomotor

In DC operation, servomotors are usually responds to error signal abruptly and accelerate the load quickly. A DC servo motor is actually an assembly of four separate components, namely:

1. DC motor
2. Gear assembly
3. Position-sensing device
• The motors which are utilized as DC servo motors, generally have separate DC source for field winding and armature winding.

• The control can be archived either by controlling the field current or armature current.

• Field control has some specific advantages over armature control and on the other hand armature control has also some specific advantages over field control.

• Which type of control should be applied to the DC servo motor, is being decided depending upon its specific applications.
Solenoid valves

• Turning Electrical Power into Mechanical Work
• How solenoid works
1. Apply Current
2. Magnetic Field Builds
3. Stop and Plunger Become Attracting Magnets
4. Magnetic Force Drives Plunger to Stop
Solenoid Valve…
working

• It is a valve which is used to control the action of the air movement.

• Solenoid valve is used to mix and distribute the air by the valve that generates the air.

• The valve is controlled by using the electric current with the help of solenoid.

• There are two port valves, three port valves and multi port valve.
Components

- Magnetic Coil
- Valve Stem
- Valve Sheet
- Inlet
- Outlet
- Plunger
- Breakaway Pin.
Application

• These are applicable in controlling the hydraulic action.

• These are used for mixing and distributing the air.

• These are applicable in RO purifier.

• These are applicable in the dust collectors.