Unit II
Sensors

Classification of sensors: Sensors, Specifications of sensors, classification of sensors - Displacement, position and proximity sensors – Potentiometers, Velocity and motion sensors – Tacho generator, Pyroelectric sensors, Force - Strain gauge load cell. Fluid pressure - Piezoelectric sensors and Tactile sensor, Elements of data acquisition system, A/D, D/A converters.

1. Introduction

Measurement is a key part of any mechatronics system. Its main role is to collect information about the system and send it to microprocessors for controlling the overall operation. A measurement system typically consists of sensors, transducers, and signal processing devices.

With so many sensors and transducers available today, selecting the right one for a specific application can be challenging. Therefore, it is important to understand the basic working principles of commonly used sensors and transducers. A complete study of all measurement technologies is beyond the scope of this course. For further details, refer to *"Sensors for Mechatronics"* by Paul P.L. Regtien, Elsevier, 2012.

In manufacturing, sensors are used to automate production processes and monitor operations. The main advantages of using sensors in modern manufacturing are:

1. **Early warning of failures:** Sensors alert operators to issues in any subsystem, helping reduce overall downtime through preventive action.
2. **Reduced labor requirement:** Fewer skilled operators are needed as machines handle monitoring and control.
3. **High precision:** Sensors enable ultra-accurate control of product quality.

2. Sensor and transducer

A sensor is a device that produces a signal related to the quantity being measured. According to the Instrument Society of America, a sensor is "a device which provides a usable output in response to a specified measurand." Here, the output is usually an electrical signal, and the measurand is the physical quantity, property, or condition to be measured.

For example, in a variable inductance displacement sensor, the measurand is displacement, and the sensor converts the displacement into a change in inductance.

Transducer

A transducer is a device that converts a physical quantity (measurand) into a usable output signal using a transduction principle. It can also be defined as a device that converts energy from one form to another.

For instance, a Constantan wire (copper-nickel 55-45% alloy) can act as a sensor because its resistance changes when it is stretched or compressed. When combined with electrodes and appropriate input-output circuitry, this wire becomes a transducer. Hence, all sensors are transducers, but not all transducers are necessarily sensors. Transducers may also include actuators that convert electrical energy back to mechanical form.

3. Sensor/Transducer Specifications

No transducer or measurement system is perfect. A mechatronics engineer must understand the capabilities and limitations of a sensor or transducer to evaluate its performance accurately. These performance-related characteristics are called sensor specifications. Sensor specifications indicate how much the sensor's behavior deviates from the ideal or expected response.

Following are the various specifications of a sensor/transducer system.

1. **Range**

   The range is the minimum and maximum values that a sensor can measure.

   Example: A thermocouple might measure temperatures from 25°C to 225°C.

2. **Span**

   The span is the difference between the maximum and minimum values of the sensor.

   Example: For the thermocouple above, the span = 225 − 25 = 200°C.

3. **Error**

   Error is the difference between the measured value and the true value.

   Example: If a sensor reads 29.8 mm but the actual displacement is 30 mm, the error = −0.2 mm.

4. **Accuracy**

   Accuracy is how close the sensor's reading is to the true value.

   Usually expressed as a percentage of full-scale output.

   Example: A piezoelectric sensor measuring pressures from 0.7 kPa to 70 MPa with ±1% full-scale accuracy may vary by ±0.7 MPa.

5. **Sensitivity**

   Sensitivity is the ratio of output change to input change.

   Example: A thermocouple with a sensitivity of 41 µV/°C changes output by 41 µV for each 1°C change in temperature.

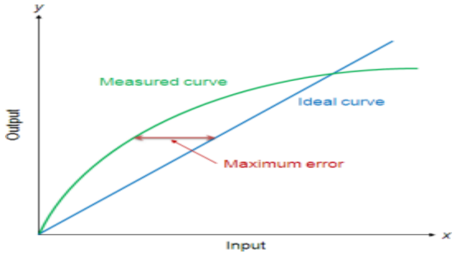
6. **Nonlinearity**

   Nonlinearity is the maximum deviation of the sensor output from a straight-line (ideal) response.

   Often expressed as a percentage:

   $$\text{Nonlinearity (\%)} = \frac{\text{Maximum deviation in input}}{\text{Maximum full-scale input}} \times 100$$

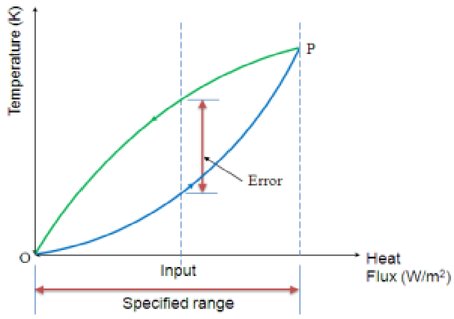
   Environmental factors like temperature and vibration can affect nonlinearity.



7. **Hysteresis**

   Hysteresis is the difference in output when the input approaches the same value from increasing vs. decreasing direction.

   Expressed as a percentage of full range.



8. **Resolution**

   Resolution is the smallest input change a sensor can detect.

   Example: An LVDT measuring 20 mm with outputs 1–100 has a resolution of 0.2 mm.

9. **Stability**

   Stability (or drift) is the ability of a sensor to maintain the same output for a constant input over time.

   Expressed as a percentage of full-scale output.

10. **Dead Band / Dead Time**

    Dead band: Range of input where the sensor produces no output.

    Dead time: Delay between applying input and observing sensor output.

11. **Repeatability**

    Ability of a sensor to give the same output for repeated measurements of the same input.

    Expressed as a percentage:

$$\text{Repeatability (\%)} = \frac{\text{Maximum} - \text{Minimum output}}{\text{Full range}} \times 100$$

12. Response Time

Response time is how fast a sensor responds to a step change in input.
Always specified for a particular input step and output range.

4. Classification of Sensors

Sensors can be classified based on factors such as the measurand (what is being measured), application, conversion principle, energy type, and thermodynamic considerations. In manufacturing, sensors are typically grouped according to their applications as follows:

A. Displacement, Position, and Proximity Sensors

Used to measure the movement or position of an object, or to detect its presence within a certain distance:

- Potentiometer
- Strain-gauged element
- Capacitive element
- Differential transformers
- Eddy current proximity sensors
- Inductive proximity switches
- Optical encoders
- Pneumatic sensors
- Magnetic proximity switches
- Hall effect sensors

B. Velocity and Motion Sensors

Used to measure speed or motion of an object:

- Incremental encoder
- Tachogenerator
- Pyroelectric sensors

C. Force Sensors

Used to measure force or load:

- Strain gauge load cell

D. Fluid Pressure Sensor

Used to measure pressure in liquids or gases:

- Diaphragm pressure gauge
- Capsules, bellows, and pressure tubes
- Piezoelectric sensors
- Tactile sensors

E. Liquid Flow Sensors

Used to measure flow rate of liquids:

- Orifice plate
- Turbine meter

F. Liquid Level Sensors

Used to detect or measure liquid levels:

- Floats
- Differential pressure sensors

G. Temperature and Light Sensors

Used to measure temperature or light intensity:

- Bimetallic strips
- Resistance temperature detectors (RTDs)
- Thermistors
- Thermo-diodes and thermotransistors
- Thermocouples
- Photodiodes
- Photoresistors
- Phototransistors

5. Displacement and position sensors

- **Displacement sensors** measure how much an object moves.
- **Position sensors** determine where an object is relative to a reference point.
- **Proximity sensors** detect when an object comes close to the sensor.

5.1) Potentiometer Sensors

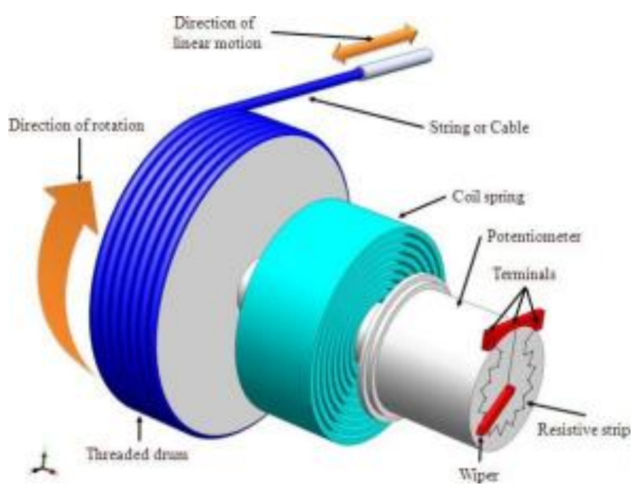
Construction:

A potentiometer sensor can be of linear or rotary (angular) type. It measures displacement by converting mechanical movement into an electrical signal. The main parts are:

- **Resistive element:** Can be a wire-wound track or conductive plastic.
- **Sliding contact (wiper):** Moves along the resistive element, acting as a movable electrical contact.

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

- A rotating shaft (for angular displacement)
- A moving rod (for linear displacement)
- A stretched cable



How it Works:

When a voltage is applied across the resistive element, the slider creates a **voltage divider**. The output voltage changes as the slider moves, which is proportional to the displacement. This output voltage can then be calibrated to measure the actual displacement. The relationship is linear for uniform resistive elements.

Applications:

Potentiometer sensors are widely used in feedback control systems to ensure components reach the correct position. Typical applications include:

- Machine-tool controls
- Elevators and forklift trucks
- Automobile throttle control
- Injection molding machines, woodworking machinery, and printing equipment
- Robotics and computer-controlled monitoring of sports equipment

5.2) Strain Gauges

Principle:

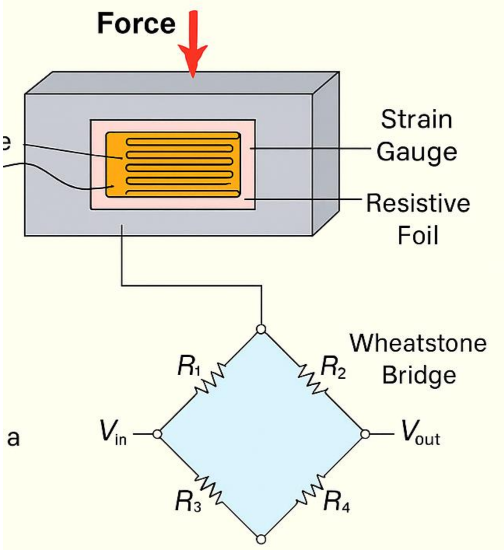
A **strain gauge** measures the deformation (strain) of an object. Strain is the ratio of change in length to the original length of an element. When the object deforms due to an applied force, the resistance of the strain gauge changes. This change in resistance is used to determine the strain.

Construction:

- The strain gauge consists of resistive foils made of Constantan alloy (copper-nickel 55-45%) bonded to a backing material like plastic, epoxy, or glass fiber-reinforced epoxy.
- The gauge is attached to the surface of the object using adhesive like epoxy or cyanoacrylate cement.
- A Wheatstone bridge circuit is commonly used to detect small changes in resistance.

How it Works:

- When the object deforms, the resistance of the strain gauge changes.
- This change unbalances the Wheatstone bridge, producing a voltage that can be measured.
- The measured voltage is calibrated to calculate the amount of deformation or force.



Applications:

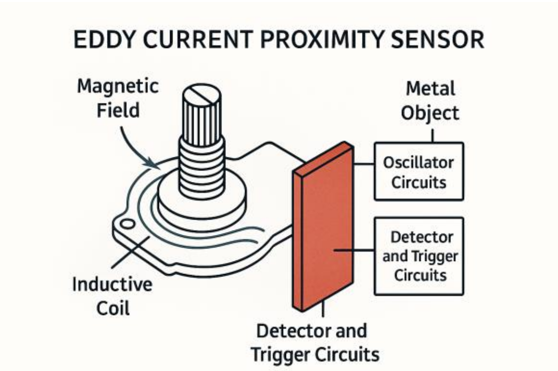
Strain gauges are used for:

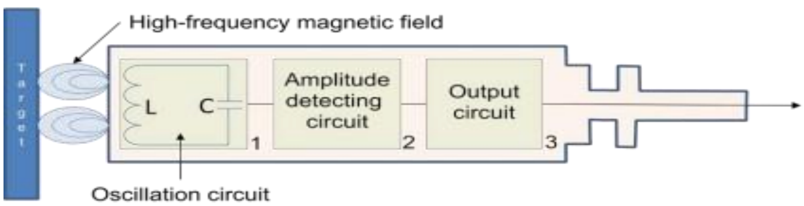
- Experimental stress analysis and machine diagnostics
- Fatigue and proof testing
- Measuring residual stress and vibrations
- Torque, bending, deflection, compression, and tension measurements

Industrial Uses:

- Machine tools for force and torque measurement
- Hydraulic or pneumatic presses
- Automotive safety systems
- Impact sensors in aerospace vehicles

5.3) Eddy current proximity sensors





Schematic of Inductive Proximity Sensor

Eddy Current Proximity Sensors

Eddy current proximity sensors are non-contact type sensors used to detect the presence, position, or displacement of electrically conductive but non-magnetic materials such as aluminum, copper, and brass. These sensors operate on the principle of electromagnetic induction and are commonly used where precise, reliable, and fast detection of metal targets is required.

Construction and Working Principle

An eddy current proximity sensor consists of the following major components:

- **Coil:** A conductive wire wound around a core, which produces an alternating magnetic field when excited by an AC source.
- **Oscillator:** Generates the alternating current that energizes the coil to produce an oscillating magnetic field.
- **Detector (Demodulator):** Detects changes in the amplitude of oscillations caused by variations in coil impedance.
- **Triggering Circuit:** Converts the detected signal changes into a switching output for control or measurement purposes.

When an alternating current passes through the coil, it generates an alternating magnetic field around it. If a metallic object comes within the proximity of this magnetic field, eddy currents are induced within the surface of that object. These circulating currents generate their own opposing magnetic field that interacts with the original field from the coil. This interaction changes the coil's impedance (specifically, the inductive reactance and resistance), thereby altering the amplitude of the oscillator signal.

The sensor's electronics detect this amplitude variation and convert it into a voltage signal, which is then used to trigger a switch or provide an output proportional to the displacement or distance of the object.

Advantages

- Non-contact operation reduces wear and mechanical damage.
- High accuracy and sensitivity for small displacement measurements.
- Compact, robust, and suitable for harsh environments (dust, oil, or moisture).
- Fast response time, ideal for high-speed operations.
- Long operational life and minimal maintenance requirements.

Limitations

- Limited to conductive materials only; cannot detect non-conductive objects.
- Measurement range is relatively small compared to other proximity sensors.
- Output depends on the electrical conductivity and permeability of the target material.
- Temperature variations can slightly affect measurement accuracy.

Applications of Eddy Current Proximity Sensors

- **Automation systems:** For precise part positioning and metal target detection.
- **Machine tool monitoring:** To detect tool wear, tool breakage, or proximity of moving parts.
- **Precision assembly:** Used in final assembly of equipment like hard disk drives and robotic arms.
- **Dynamic measurement:** Monitoring vibrations, shaft run-out, or displacement in rotating machinery.

- **Drive shaft and rotor monitoring:** Detecting eccentricity, imbalance, or shaft deflection.
- **Vibration measurement:** Measuring amplitude and frequency of vibrating components.
- **Quality control:** Ensuring correct placement of metal parts in production lines.

Overall, eddy current proximity sensors offer a highly reliable, contactless, and precise solution for industrial and laboratory applications involving conductive materials.

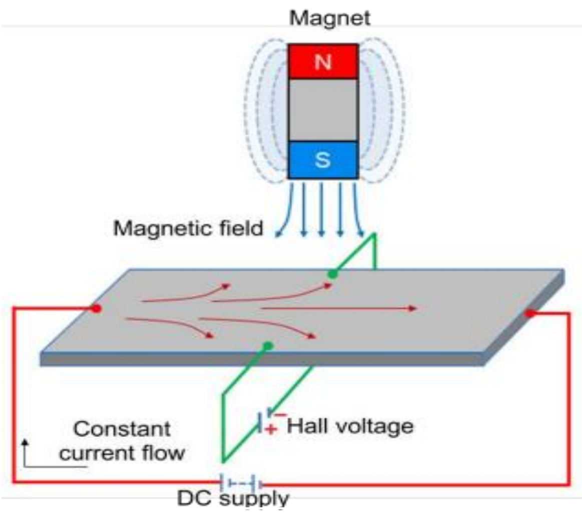
5.4) Hall effect sensor

Principle of Operation

Figure shows the principle of working of a Hall Effect Sensor. When a current-carrying conductor or semiconductor is placed in a magnetic field perpendicular to the direction of current flow, the moving charge carriers experience a Lorentz force.

This force pushes the charge carriers (electrons or holes) to one side of the material, causing:

- One side of the material to become negatively charged
- The opposite side to become positively charged



Principle of working of Hall effect sensor

This charge separation results in a potential difference (VH) across the material, known as the Hall voltage.

The Hall voltage is given by:

$$V_H = \frac{B\, I}{n\, q\, t}$$

Where:

B= Magnetic flux density (in tesla)

I= Current through the conductor (in amperes)

n= Charge carrier density (number of carriers per m^3)

q= Charge of an electron (1.6×10^{-19} C)

t= Thickness of the conducting material (in meters)

From this expression, it is evident that the Hall voltage is directly proportional to the magnetic field strength (B) and the current (I), but inversely proportional to the carrier density (n) and thickness (t).

Construction

A Hall Effect Sensor typically consists of:

1. **Thin semiconductor plate** (such as indium arsenide, indium antimonide, or gallium arsenide) — chosen for its high carrier mobility.
2. **Current source terminals** — to allow current to pass through the plate.
3. **Hall voltage terminals** — placed perpendicular to the current flow.
4. **Magnetic field source** — which interacts with the current-carrying plate.
5. **Signal conditioning circuit** — to amplify and convert the weak Hall voltage into a measurable signal.
6. **Output stage** — that provides a digital or analog output, depending on application.

Working

1. When no magnetic field is present, the charge carriers travel straight, and no voltage is generated across the plate.
2. When a magnetic field is applied perpendicular to the direction of current, charge carriers are deflected to one side due to the Lorentz force.
3. This results in a potential difference (Hall voltage) appearing across the plate, perpendicular to both the magnetic field and the current flow.
4. The magnitude of Hall voltage depends on the strength of the magnetic field, the current, and the material properties.
5. The generated voltage can be used to detect magnetic field strength or proximity of a magnetic object.

Example: Fluid Level Measurement

A typical application of the Hall Effect sensor is in fluid level measurement:

- A float with a permanent magnet is placed inside the container.
- The Hall sensor circuit is mounted externally or inside a protective casing near the float's path.
- As the fluid level rises, the float moves up, bringing the magnet closer to the sensor.
- The magnetic field intensity at the sensor increases, generating a higher Hall voltage.
- When the voltage crosses a preset limit, it triggers a switch to stop fluid inflow, preventing overflow.
- This system provides accurate, contactless fluid level control.

Advantages

i. Non-contact measurement — no physical wear or friction
ii. Fast response and capable of operation up to 100 kHz
iii. High reliability and repeatability
iv. Insensitive to dust, dirt, oil, and vibration
v. Works in harsh industrial environments
vi. Can detect both DC and AC magnetic fields

Applications

i. Measurement of linear and angular displacement
ii. Speed sensing in automotive wheel and crankshaft systems
iii. Proximity detection and limit switches in automation
iv. Fluid level monitoring in tanks
v. Current sensing in electrical systems
vi. Brushless DC motor control (commutation sensing)
vii. Position sensing in robotics and CNC machines

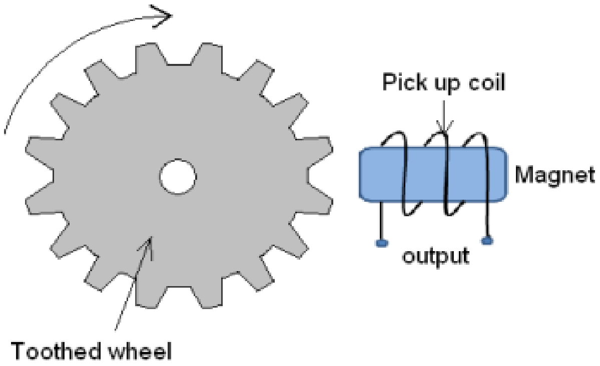
6. Velocity, motion, force and pressure sensors

6.1) Tachogenerator

A tachogenerator is a device used to measure the angular velocity or rotational speed of a shaft or rotating element by converting mechanical motion into an electrical signal. It operates on the principle of electromagnetic induction or variable reluctance, depending on the construction type.

Principle of Working (Variable Reluctance Type)

Tachogenerator works on the principle of variable reluctance. It consists of an assembly of a toothed wheel and a magnetic circuit, as shown in *Figure*. The toothed wheel is mounted on the shaft or element whose angular motion is to be measured. The magnetic circuit consists of a coil wound on a ferromagnetic core.

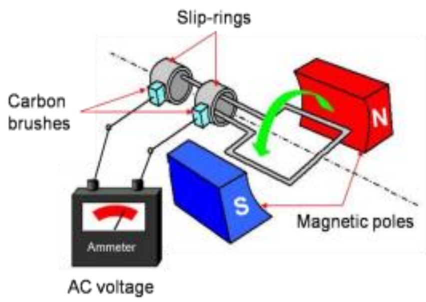


Principle of working of Tachogenerator

As the wheel rotates, the air gap between the wheel tooth and the magnetic core changes periodically. This variation in air gap causes a cyclic change in the magnetic flux linked with the coil. According to Faraday's law of electromagnetic induction, this varying magnetic flux induces an alternating emf in the coil. The frequency of this emf corresponds to the rotational speed of the shaft, while its amplitude depends on the magnetic field strength and rate of rotation.
The alternating emf generated is therefore a measure of angular motion. The output signal is generally passed through a pulse shaping or signal conditioning circuit to convert it into a series of uniform pulses. These pulses are then counted by a counter or electronic display, giving a precise indication of rotational speed.

AC Tachogenerator

An alternating current (AC) generator can also function as a tachogenerator. It comprises a rotor coil that rotates with the shaft inside a stationary magnetic field produced by a permanent magnet or electromagnet, as illustrated in *Figure*
When the rotor turns, an alternating emf is induced in the coil. The magnitude of this emf is directly proportional to the angular velocity of the rotor. Thus, by measuring the output voltage, the rotational speed of the shaft can be accurately determined.



Construction and working of AC generator

AC tachogenerators generally exhibit nonlinearity errors of about ±0.15% and are suitable for rotational speeds up to 10,000 revolutions per minute (rev/min). They are widely used in applications requiring smooth and continuous measurement of rotational speed.

Advantages

- Provides a direct electrical output proportional to speed.
- Simple and robust construction.
- Suitable for real-time monitoring and control systems.
- Can be used for both speed and direction sensing (especially DC type).
- Reliable operation even under harsh industrial conditions.

Limitations

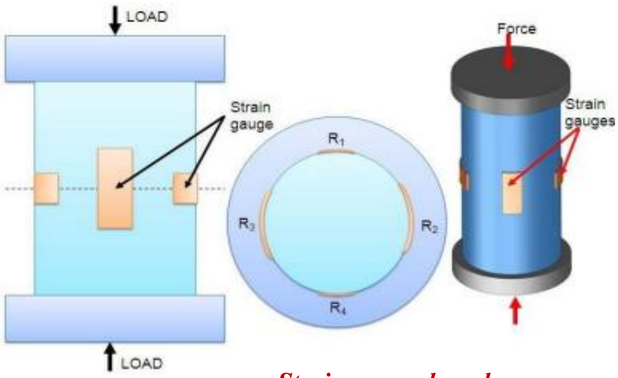
- Output signal may require filtering or conditioning for precision applications.
- Subject to wear and tear due to moving parts.
- Accuracy can be affected by temperature variations and magnetic interference.
- Limited speed range compared to modern optical or Hall-effect tachometers.

Applications

- Speed feedback in closed-loop control systems (e.g., servomechanisms, motors).
- Automobile industry for engine RPM measurement.
- Machine tools and industrial drives to maintain constant speed.
- Turbomachinery and generators for performance monitoring.
- Test benches and research laboratories for rotational analysis.

6.2) Strain Gauge as force Sensor

A strain gauge can be effectively used as a force sensor by converting the mechanical deformation of a structural element into a corresponding change in electrical resistance. The working principle is based on the piezoresistive effect, where the electrical resistance of a conductor or semiconductor changes when it is stretched (tension) or compressed.



Strain gauge-based Load cell

Principle of Operation

When a mechanical element is subjected to **tensile or compressive stress**, its length and cross-sectional area change slightly. This causes a proportional change in the **resistance (R)** of the strain gauge element, which is given by:

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

Where

ρ= resistivity of the material, L= length, and A= cross-sectional area.

A change in the applied load leads to a change in strain (ε), which in turn alters the resistance of the strain gauge. This change in resistance is then converted into a voltage signal using a Wheatstone bridge circuit, which can be calibrated to represent the applied force or load.

Construction and Working

Figure shows a strain gauge-based load cell, which is one of the most common types of force sensors. It consists of a cylindrical tube or elastic element to which one or more strain gauges are bonded at specific locations where the strain is maximum.

When a load is applied on the top collar of the cylindrical body, it causes deformation (either compression or tension) in the structure. The strain experienced by the surface of the cylinder is transmitted to the strain gauges, resulting in a change in their electrical resistance.

This resistance variation is processed through a signal-conditioning circuit, which provides a calibrated output proportional to the applied force. By arranging multiple strain gauges in a full-bridge configuration, temperature effects can be minimized and sensitivity can be enhanced.

Performance Characteristics

- Measuring Range: Up to 10 MN (Mega Newtons) of force.
- Non-linearity Error: ±0.03% of full scale.
- Repeatability Error: ±0.02% of full scale.
- Response Time: Very fast (suitable for dynamic force measurements).
- Sensitivity: Depends on the gauge factor and bridge excitation voltage.

Advantages

- High accuracy and excellent linearity within the operating range.
- Compact and adaptable for both static and dynamic force measurements.
- Can be easily integrated with electronic instrumentation.
- Suitable for a wide range of forces, from a few newtons to several meganewtons.
- Excellent long-term stability and repeatability.

Applications

- Industrial weighing systems and load testing machines.
- Material testing and structural monitoring in mechanical and civil engineering.
- Robotics and automation systems for force feedback control.
- Aerospace and automotive industries for component stress analysis.
- Process control and press force measurement in manufacturing operations.

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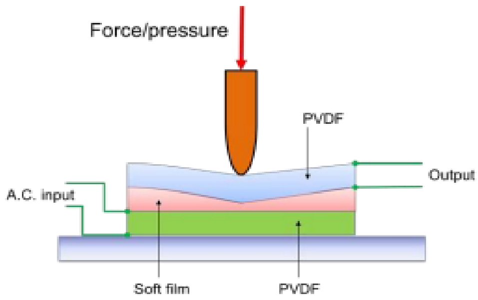
6.3) Fluid pressure Tactile sensors

Tactile sensors are devices designed to detect physical contact, pressure, or touch, often used in robotics and human-machine interfaces. They enable machines to sense contact with objects, similar to how human skin detects touch.



Schematic of a tactile sensor

Construction and Working Principle (PVDF-Based Tactile Sensor)

Figure shows a piezoelectric polyvinylidene fluoride (PVDF) based tactile sensor. The sensor typically consists of:

- Two PVDF layers separated by a soft elastic film, which transmits mechanical vibrations.
- The lower PVDF layer is excited by an alternating current, generating vibrations due to the reverse piezoelectric effect.
- Vibrations pass through the soft film to the upper PVDF layer, inducing an alternating voltage across it.

When pressure is applied on the upper PVDF layer (e.g., a robot fingertip contacting an object or a human finger pressing a touch screen), the vibration pattern changes, which alters the output voltage. This voltage change can be processed to trigger switches, control actions, or detect touch location in robotic grippers, CNC machine touch panels, or touchscreen displays.

Applications

- Robotic fingertips for object manipulation and grasping.
- Touch-sensitive screens in CNC machines, industrial panels, and consumer electronics.
- Human-machine interfaces for detecting applied force or pressure.
- Safety sensors in automated systems to detect contact and avoid collisions.

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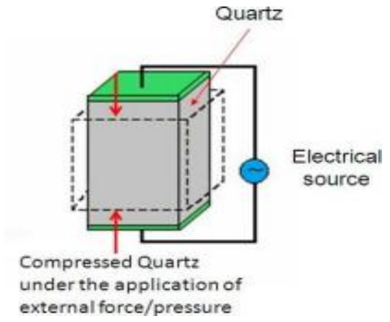
6.4) Piezoelectric sensor



Principle of working of Piezoelectric sensor

Piezoelectric sensors measure pressure, acceleration, or dynamic forces, including oscillations, impacts, or high-speed compression/tension. They exploit the piezoelectric effect, where mechanical stress generates an electric charge in certain crystalline materials.

Construction and Working Principle

- The sensor contains piezoelectric crystals, such as quartz, which produce a charge when subjected to mechanical stress (Figure 2.4.10).
- When a force or pressure is applied, the crystals are compressed or stretched, causing a redistribution of charge.
- One surface of the crystal becomes positively charged, while the opposite surface becomes negatively charged.

The net charge $q$on the crystal surface is proportional to the displacement $x$of the charges, which in turn is proportional to the applied force F:

$$q = kx = SF$$

Where:

- $k$is a constant related to the crystal material,
- $S$is the charge sensitivity, defining how much charge is generated per unit force.

Applications

- Measuring dynamic forces in machinery, engines, and impact testing.
- Monitoring vibrations and accelerations in structural health monitoring systems.
- Pressure sensing in industrial processes, automotive sensors, and aerospace instrumentation.
- Integration into robotics and tactile sensing systems for force feedback.

Tactile and piezoelectric sensors are critical in automation, robotics, and instrumentation, converting mechanical interactions such as pressure, touch, or vibration into measurable electrical signals. PVDF-based tactile sensors are ideal for touch detection, while piezoelectric sensors excel in dynamic force, vibration, and acceleration measurement.

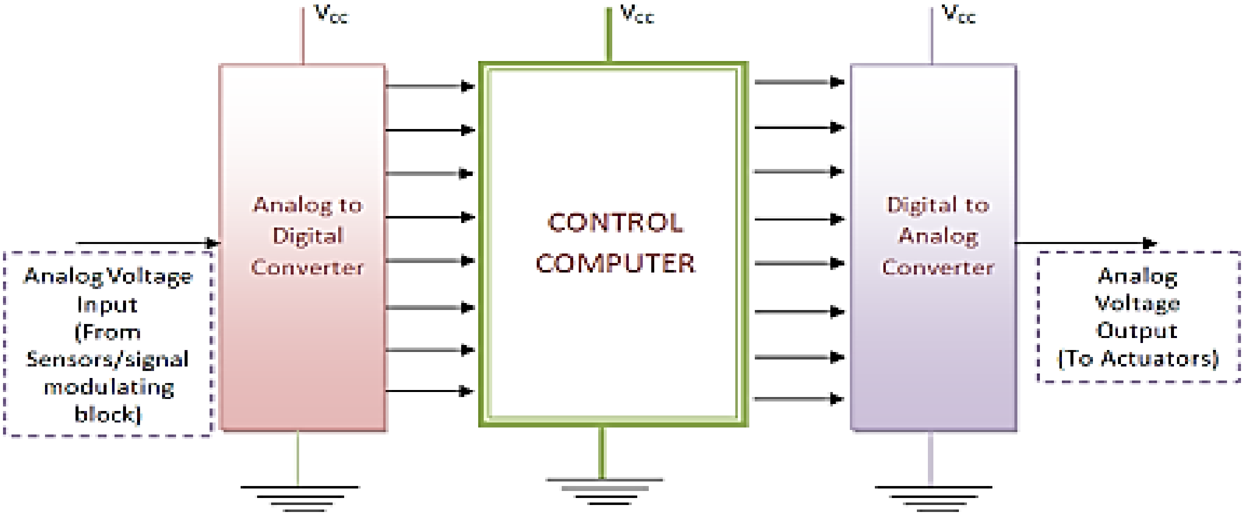
7. Data Acquisition Systems

7.1 Introduction

Data Conversion Devices are essential components of a Machine Control Unit (MCU). MCUs are typically controlled by computers or microcontrollers, which process signals only in digital form (0s and 1s). However, signals obtained from sensors or signal conditioning modules are usually analog (continuous) in nature. Therefore, a mechanism is required to convert analog signals into digital form and vice versa. This is accomplished using an Analog-to-Digital Converter (ADC).

A typical control system with data conversion devices is shown in the figure. The MCU processes the digital signals received from sensors and generates digital actuating signals. Many actuators, such as DC servo motors, operate only on analog signals. Hence, the digital signals from the MCU must be converted back to analog form using a Digital-to-Analog Converter (DAC).

Various types of ADCs and DACs exist, each with distinct working principles and circuitry.

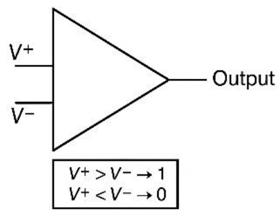


A control system with ADC and DAC devices

7.2 Basic Components of ADCs and DACs

7.2.1 Comparators

In general ADCs and DACs comprise of Comparators. Comparator is a combination of diodes and Operational Amplifiers. A comparator is a device which compares the voltage input or current input at its two terminals and gives output in form of digital signal i.e. in form of 0s and 1s indicating which voltage is higher. If V+ and V- be input voltages at two terminals of comparator then output of comparator will be as



7.2.2 Encoders

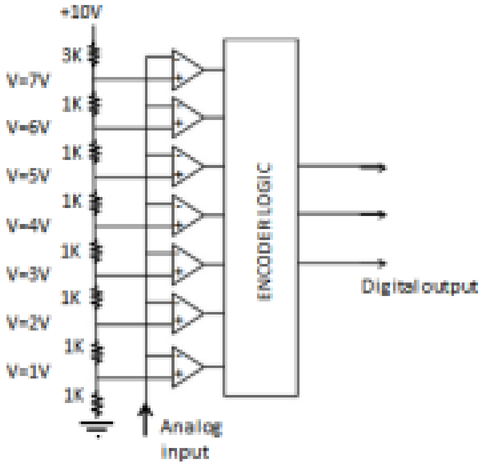
The output from comparators consists of 0s and 1s but cannot be considered a true binary output. To convert this sequence into a proper binary form, a circuit called an **encoder** is used. A simple encoder converts 2^n input lines into n output lines, with the output lines following binary algebra."

7.3 Analog to Digital Converter (ADC)

As discussed in previous section ADCs are used to convert analog signals into Digital Signals. There are various techniques of converting Analog Signals into Digital signals which are enlisted as follows. However we will be discussing only Direct Conversion ADC, detail study of other techniques is out of the scope of the present course.

1. Direct Conversion ADC or Flash ADC
2. Successive Approximation ADC
3. A ramp-compare ADC
4. Wilkinson ADC
5. Integrating ADC
6. Delta-encoded ADC or counter-ramp
7. Pipeline ADC (also called subranging quantizer)
8. Sigma-delta ADC (also known as a delta-sigma ADC)
9. Time-interleaved ADC

7.4 Direct Conversion ADC or Flash ADC



Circuit of Flash ADC

The figure shows the circuit of a Direct Conversion, also known as a Flash ADC. To convert an analog signal into an *N-bit* digital signal, a Flash ADC requires (2^n – 1) comparators and 2^n resistors. The resistor network provides reference voltages to all the comparators.

Each comparator produces an output of 1 when the input analog voltage is higher than its corresponding reference voltage; otherwise, the output is 0.

In this circuit, the reference voltages for the comparators are obtained through a resistor ladder network. The circuit shown in Figure functions as a 3-bit ADC. Let us assume this ADC operates over a range of 0–10 V. It therefore requires 7 comparators and 8 resistors.

The resistors are connected in such a way that they form a voltage ladder, producing voltage drops of 1 V each using 1 kΩ resistors. Hence, the reference voltages across the comparators are 1 V, 2 V, 3 V, 4 V, 5 V, 6 V, and 7 V.

Now, consider an input voltage of 2.5 V to be converted into its digital equivalent. Since 2.5 V is greater than 1 V and 2 V, the first two comparators will produce outputs of 1 and 1, respectively. However, as 2.5 V is less than 3 V, 4 V, 5 V, 6 V, and 7 V, the remaining comparators will produce 0s. Therefore, the comparator outputs (from top) will be 0000011.

This output is applied to an encoder logic circuit, which first converts the thermometer code into a single high-line format, and then into a 3-bit binary code using binary logic. The resulting digital output from the ADC can then be used by microcontrollers or computers for further processing or control actions.

7.5 Digital to Analog Converters

DACs are used to convert digital signals into Analog Signals. There are various techniques of converting Digital Signals into Analog signals.

Common DAC Techniques

1. Pulse-width modulator
2. Oversampling DACs or interpolating DACs
3. The binary-weighted DAC
4. Switched resistor DAC
5. Switched current source DAC
6. Switched capacitor DAC
7. The R-2R ladder
8. The Successive-Approximation or Cyclic DAC,
9. The thermometer-coded DAC