MODULE 2: SENSORS AND TRANSDUCERS(Continued)

Structure

2.1 Stain Gages

2.2 Load Cells

2.3 Proximity Sensors, Pneumatic Sensors

2.4 Light Sensors, Tactile Sensors, Fiber Optic Transducers

2.5 Digital Transducers

2.6 Recent Trends– Smart Pressure Transmitters

2.7 Selection of Sensors

2.8 Rotary – Variable Differential Transformer

2.9 Synchros and Resolvers

2.10 Induction Potentiometers

2.11 Micro Electromechanical Systems.

Objectives

- To explain the measurement of pressure using sensors, based nanotechnology, their structure, theory of operation.

2.1 Strain Guages

- Strain Gauge is a passive transducer that converts a mechanical elongation or displacement produced due to a force into its corresponding change in resistance R, inductance L, or capacitance C.
- Similarly, if the metal is subjected to compressive stress, the length will decrease, but the breadth will increase. This will also change the electrical resistance of the conductor.
- If both these stresses are limited within its elastic limit (the maximum limit beyond which the body fails to regain its elasticity), the metal conductor can be used to measure the amount of force given to produce the stress, through its change in resistance.

2.1.1 Strain Gauge Transducer

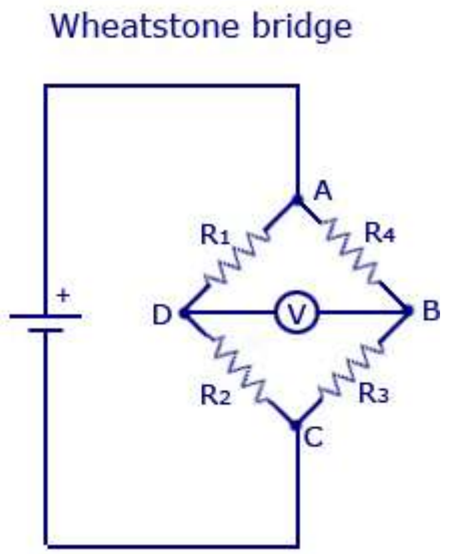
The device finds its wide application as a strain gauge transducer/sensor as it is very accurate in measuring the change in displacement occurred and converting it into its corresponding value of resistance, inductance or capacitance. It must be noted that the metal conductor which is subjected to an unknown force should be of finite length.

Types

- Strain gauge transducers are broadly classified into two. They are

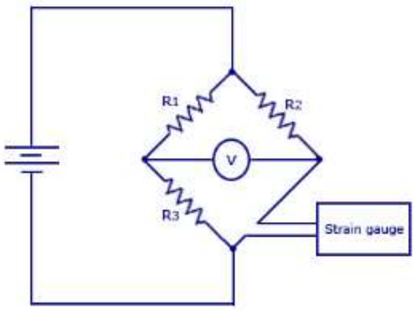
Electrical Resistance Type Strain Gauge

1. In an electrical resistance strain gauge, the device consists of a thin wire placed on a flexible paper tissue and is attached to a variety of materials to measure the strain of the material.
2. In application, the strain gauge will be attached to a structural member with the help of special cement. The gauge position will be in such a manner that the gauge wires are aligned across the direction of the strain to be measured.
3. The wire used for the purpose will have a diameter between 0.009 to 0.0025 centimeters.
4. When a force is applied on the wire, there occurs a strain (consider tensile, within the elastic limit) that increases the length and decreases its area. Thus, the resistance of the wire changes. This change in resistance is proportional to the strain and is measured using a ***Wheatstone bridge.***

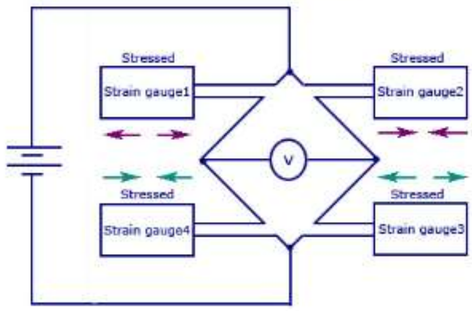


5. A full bridge circuit is used in applications where complimentary pair of strain gauges is to be bounded to the test specimen.

Quarter Bridge Strain Gauge Circuit

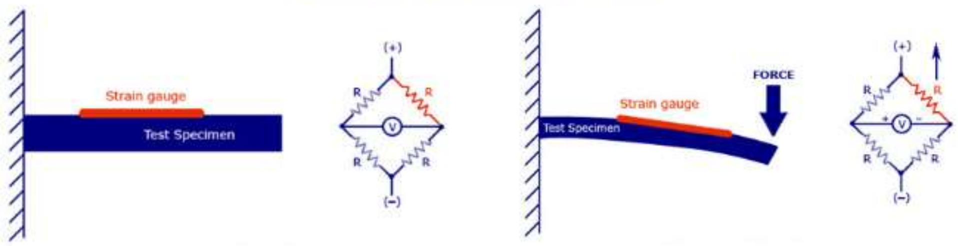


Full Bridge Strain Gauge Circuit



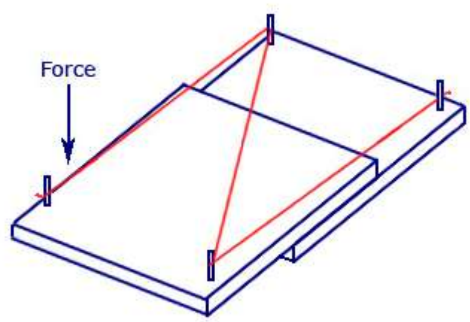
6. A quarter bridge output corresponding to the application of a force is shown below. Initially, the circuit will be balanced without the application of any force. When a downward force is applied, the length of the strain gauge increases and thus a change in resistance occurs. Thus an output is produced in the bridge corresponding to the strain.

Quater-Bridge Strain Gauge Circuit Working

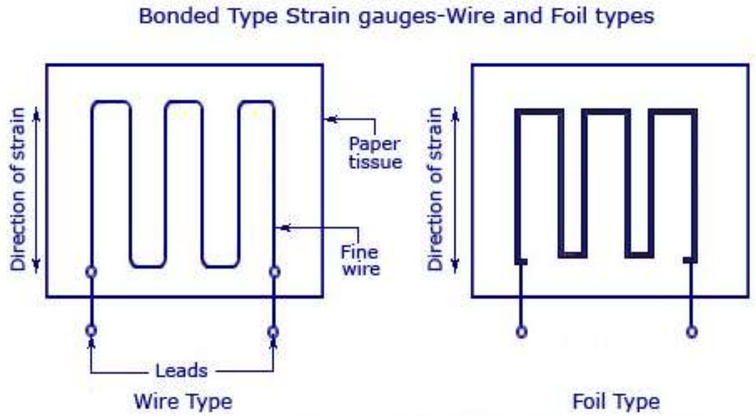


7. The wire strain gauge can be further divided into two. They are bonded and unbonded strain gauge.
8. An unbounded strain gauge has a resistance wire stretched between two frames. The rigid pins of the two frames are insulated. When the wire is stretched due to an applied force, there occurs a relative motion between the two frames and thus a strain is produced, causing a change in resistance value. This change of resistance value will be equal to the strain input.

Unbonded Strain Gauge

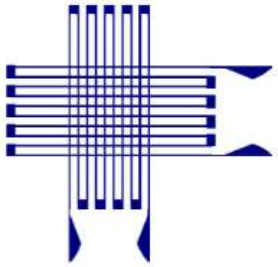


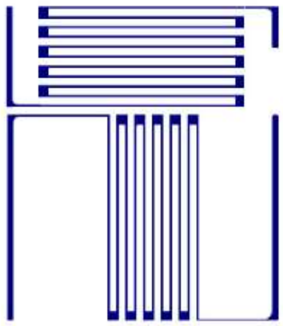
9. A bonded strain gauge will be either a wire type or a foil type as shown in the figure below. It is connected to a paper or a thick plastic film support. The measuring leads are soldered or welded to the gauge wire. The bonded strain gauge with the paper backing is connected to the elastic member whose strain is to be measured.

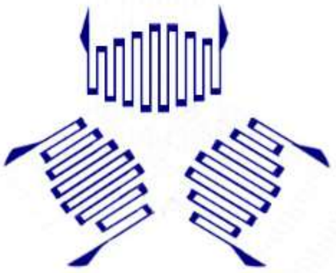


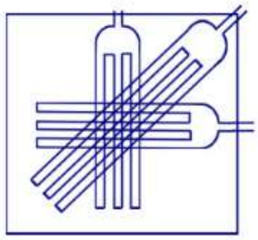
According to the strain to be measured, the gauges can be classified as the following.

- **Uniaxial/Wire Strain Gauge**
  The figure of such a strain gauge is shown above. It mostly uses long and narrow sensing elements so as to maximize the length of the strain sensing material in the desired direction. Gauge length is chosen according to the strain to be calculated.


Two-Element, 90 Degree Planar (Shear) Rosette Strain Gauge


Two-Element 90 Degree Planar Rosette Strain Gauge


Three Element, 60 Degree Delta Rosette strain Gauge


Three Element, 45 Degree Planar Rectangular Rosette Strain Gauge

Biaxial Strain Gauges

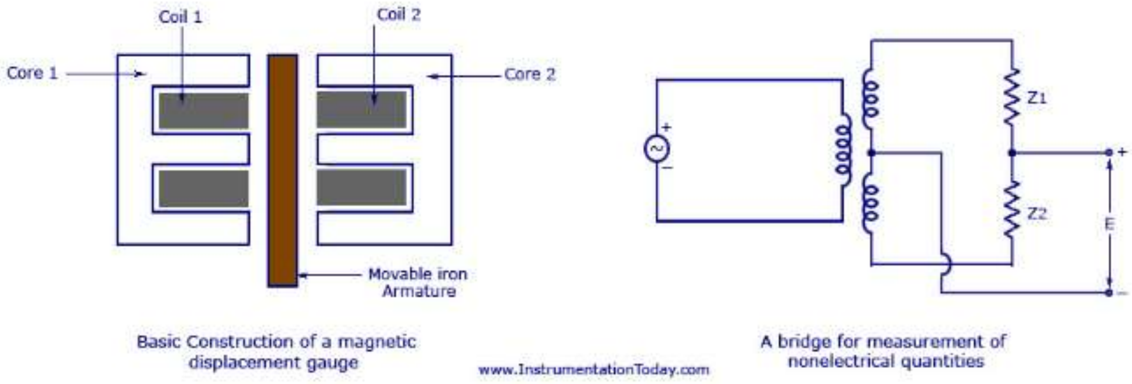
When the measurement of strain is to be done in two directions (mostly at right angles), this method is used. The basic structure for this is the two element 90 planar rosette or the 90 planar shear/stacked foil rosette. The gauges are wired in a Wheatstone bridge circuit to provide maximum output. For stress analysis, the axial and transfers elements have different resistances which can be selected that the combined output is proportional to the stress while the output of the axial element alone is proportional to the strain. The figure is given below.

Three Element Rosettes

It is divided into two types – three element 60delta rosette strain gauge and three element 45planar rectangular rosette. They are used in applications where both the magnitude and direction of the applied strains are to be found out. Both the figures are shown below. The 60 rosette is used when the direction of the principal strain is unknown. The 45 rosette is used to determine a high angular resolution, and when the principal strains are known.

Variable Inductance Type Strain Gauge

1. The basic arrangement of a variable inductance strain gauge is shown below. This type of strain gauge is very sensitive and can be used to measure small changes in length – as small as 1 millionth of an inch.
2. Thus, it is highly applicable as a displacement transducer. The member whose strain is to be measured is connected to one end of a moveable iron armature.
3. The long part of the armature is placed between the two cores with wires coiled in between. If the strain produced makes the armature move towards the left core (core 1), it increases the inductance of the left hand coil, that is, coil 1 and decreases the inductance of coil 2.
4. These two coils produce the impedance Z1 and Z2 in the bridge circuit.
5. This produces an output voltage E, which is proportional to the input displacement and hence proportional to the strain.
6. This type of strain gauge is more accurate and sensitive than a resistive strain gauge. But, it is difficult to install the device as it is bulky and complex in construction.



Variable Inductance Type Strain Gauge

2.2 Load Cells

1. A load cell is a transducer that converts the mechanical force into readable electrical units, similar to our regular weighing scales.
2. Their main purpose is to weigh or check the amount of load transferred.

3. The load cell sensors are always bonded along with elastic material, known as strain gauges.

Types of Load Cells

Several types of load cells exist for varying applications:

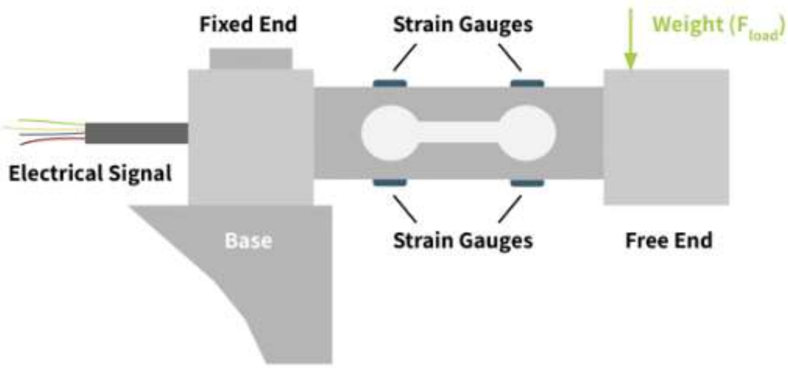
- Strain Gauge Load Cells
- Hydraulic Load Cells
- Pneumatic Load Cells
- Capacitive Load Cells
- Piezoelectric Transducers

Strain Gauge Load Cells

Strain gauge load cells are the most common. Unlike the hydraulic and pneumatic designs described below that convert pressure differentials to measurements, the strain gauge load cell operates through changes in electrical resistance.

Strain gauge load cells consist of:

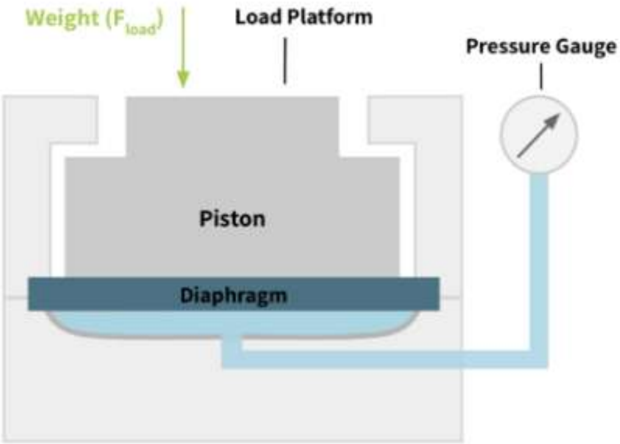
- A loading platform or system to apply the force, F_{load}
- One or more strain gauges
- An excitation voltage source
- Output wires to measure a change in voltage caused by the change in resistance of the strain gauges



Strain gauge load cells are the most popular due to their high accuracy, low price point, and general ease of use. They have a high frequency response for dynamic loads and are not sensitive to temperature variations. Because they can fit into a wide variety of load-mounting configurations, they lend themselves to almost any industrial application.

Hydraulic Load Cells

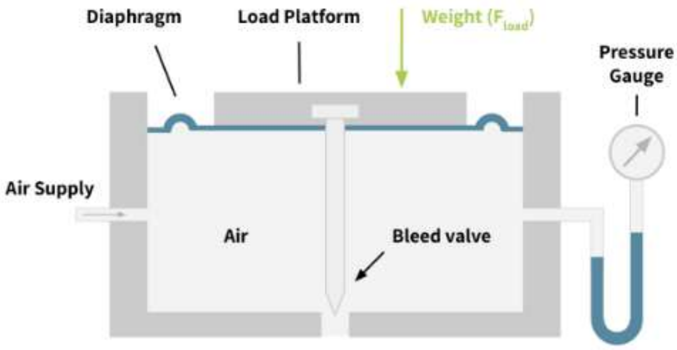
Hydraulic load cells convert a load to hydraulic pressure. The measured load is applied to a load platform attached to a piston. The piston sits in a closed chamber filled with fluid. When a load is applied, the action of the piston on the diaphragm pressurizes the liquid. The change in liquid pressure is directly proportional to the force applied by the load.



Because the hydraulic load cell design contains no electrical components, this type of load cell lends itself to environments where explosion safety is a concern

Pneumatic Load Cells

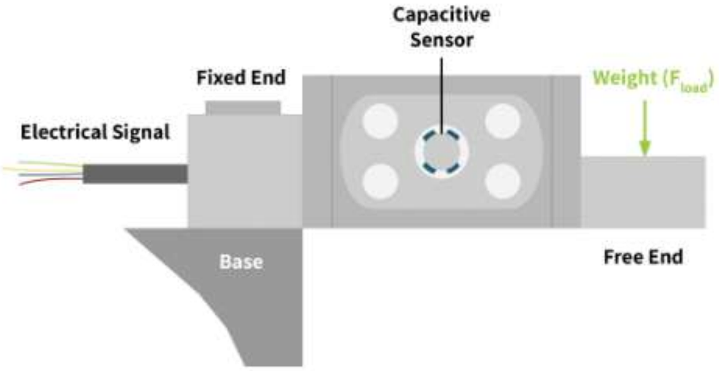
Pneumatic load cells function similarly to their hydraulic counterparts in that they convert fluid pressure into a load measurement. However, the pressurized fluid in a pneumatic load cell is a type of gas, oftentimes air.

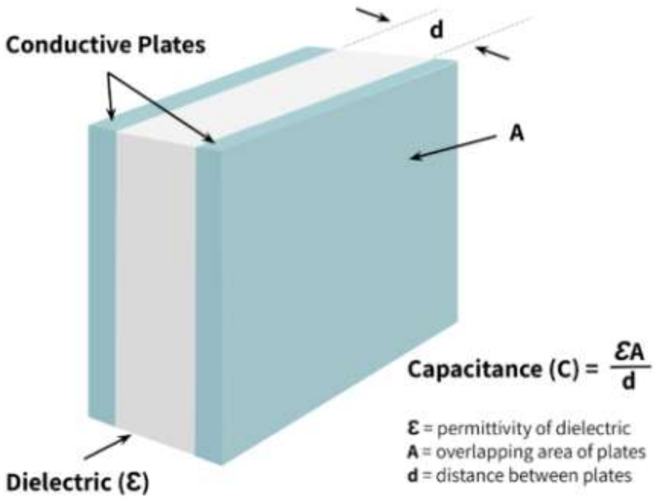


Like their hydraulic counterparts, pneumatic load cells are explosion resistant and are generally used in applications with intrinsic safety concerns. The pneumatic load cell is also tolerant of temperature changes.

Capacitive Load Cells

Capacitive load cells operate on the ability of a material or system to store a charge. They consist of two parallel plates with a gap between them. An electric current is supplied to the plates until a stable charge forms on each: one with a positive charge and the other negative. When a load is applied to one of the plates, the gap narrows causing a stored charge (or capacitance) between the plates. This charge creates the output of the load cell, which is then translated to a load measurement.



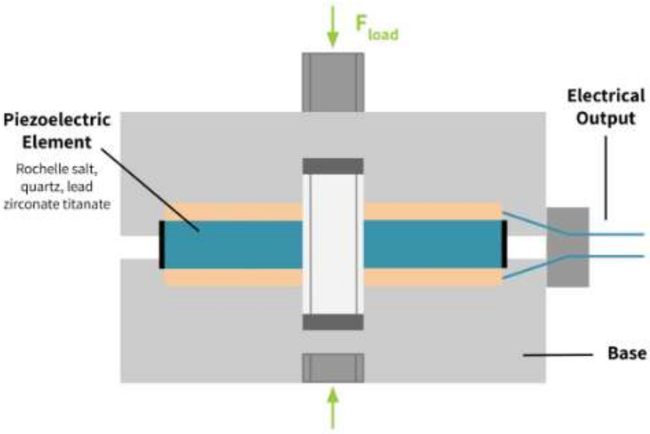


Capacitive load cells are highly sensitive and accurate over a wide range of forces, large and small. They are also rather simple in design, making them more cost-effective than other load cell types.

Piezoelectric Transducers

Piezoelectric sensors operate based on the piezoelectric effect. The piezoelectric effect is a natural property of materials such as quartz crystal and other ceramics.

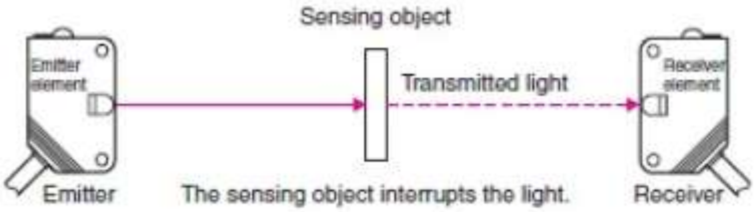
Piezoelectricity is produced when this polarized crystalline material is stressed or deformed. The stress then causes a shift in the orientation of the internal dipoles of the material. It is similar to di-electricity, which occurs when a charge develops from a shift of electrons in an insulator. Piezoelectric sensors can quantify force, pressure, and displacement.



2.3 Proximity Sensors, Pneumatic Sensors

2.3.1 Proximity Sensors

- A proximity sensor is a non-contact sensor that detects the presence of an object (often referred to as the "target") when the target enters the sensor's field.
- Depending on the type of proximity sensor, sound, light, infrared radiation (IR), or electromagnetic fields may be utilized by the sensor to detect a target.
- Proximity sensors are used in phones, recycling plants, self-driving cars, anti-aircraft systems, and assembly lines.
- There are many types of proximity sensors, and they each sense targets in distinct ways. The two most commonly used proximity sensors are the inductive proximity sensor and the capacitive proximity sensor.
- An inductive proximity sensor can only detect metal targets. This is because the sensor utilizes an electromagnetic field.
- When a metal target enters the electromagnetic field, the inductive characteristics of the metal change the field's properties, thereby alerting the proximity sensor of the presence of a metallic target. Depending on how inductive the metal is, the target can be detected at either a greater or shorter distance.
- Capacitive proximity sensors, on the other hand, are not limited to metallic targets. These proximity sensors are capable of detecting anything that can carry an electrical charge. Capacitive sensors are commonly used in liquid-level detection.
- Another type of proximity sensor is called a photoelectric proximity sensor. There are two main types of photoelectric proximity sensors: reflective and through-beam. Reflective proximity sensors detect objects when the light emitted from the sensor is reflected back at the photoelectric receiver. Through-beam sensors detect targets when the target breaks the beam of light between the sensor's emitter and receiver.

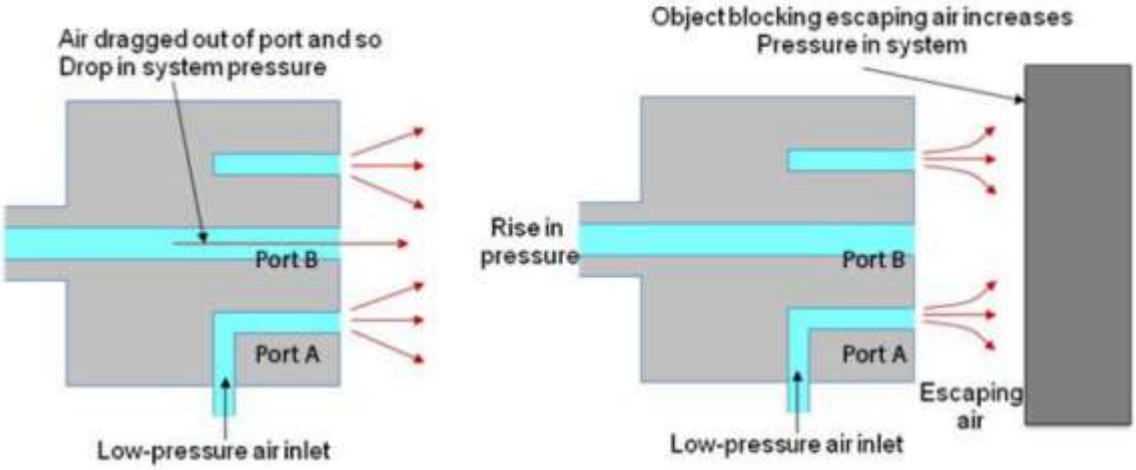


- Two other commonly used proximity sensors are the magnetic proximity sensors and ultrasonic proximity sensors.
- Magnetic proximity sensors are only used to detect permanent magnets.
- Ultrasonic proximity sensors emit a high pitch sound. The distance between the sensor and the target is determined by how long the sound takes to reflect back to the sensor.

2.3.2 Pneumatic Sensors

A pneumatic pressure sensor is used to measure the compressed air/ gas pressure levels in a system by allowing them to be measured and monitored through a range of electronic devices. These pressure sensors are transducers, whereby generating the electrical signal in proportion to the output pressure being measured.

Pneumatic sensors are used to measure the displacement as well as to sense the proximity of an object close to it. The displacement and proximity are transformed into change in air pressure.



In the absence of any obstacle / object, this low pressure air escapes and in doing so, reduces the pressure in the port B.

However when an object obstructs the low pressure air (Port A), there is rise in pressure in output port B. This rise in pressure is calibrated to measure the displacement or to trigger a switch.

These sensors are used in robotics, pneumatics and for tooling in CNC machine tools.

2.4 Light Sensors, Tactile Sensors, Fiber Optic Transducers

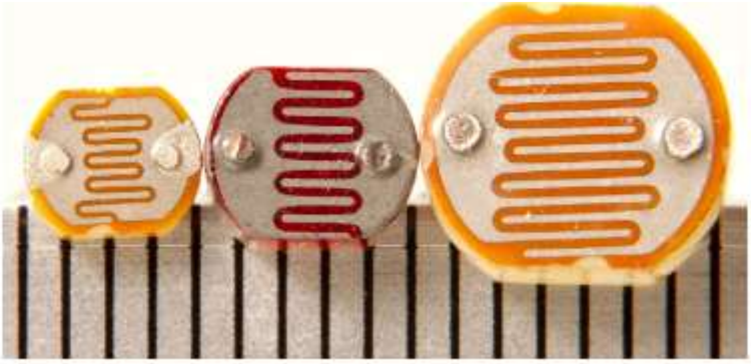
2.4.1 Light Sensors

A light sensor is a photoelectric device that converts light energy (photons) detected to electrical energy (electrons).

Different types of light sensors are available, mainly **Photoresistors, Photodiodes, and Phototransistors**

1. Photoresistors

The most common light sensor type used in a light sensor circuit are photoresistors, also known as Light-Dependent Resistors (LDR). Photoresistors detect whether a light is on or off and compare the relative light levels throughout the day.

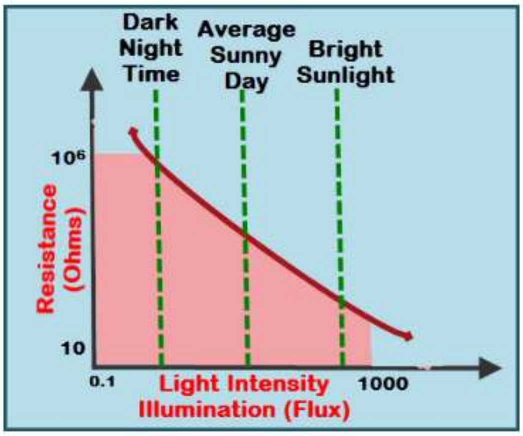


Photoresistors b

Photoresistors are made of highly-resistance semiconductor material called cadmium sulfide cell, which is highly sensitive to visible and near-infrared light.

Photoresistor Working Principle

As its name suggests, photoresistors work similarly to your regular resistors, but the resistance change depends on the amount of light it is exposed to. High light intensity will cause a lower resistance between the cadmium sulfide cell, while low light intensity results in a higher resistance between the cadmium sulfide cells.



Photoresistor Working Principle

This working principle can be seen in applications such as street lamps, wherein during the day, the high light intensity results in lower resistance, and thus they are not lit up when the sun is still shining brightly.

2. Photodiodes

Photodiodes are another type of light sensor. But instead of using the change in resistance like LDR, it's more complex to light, easily changing light into a flow of electric currents. It is also commonly known as a photodetector or photo sensor.

Phototransistors

Photodiodes are mainly made from silicon and germanium materials and comprise optical filters, built-in lenses, and surface areas.

Here are some of the applications of photodiode:

1. Compact disc players
2. Smoke detectors
3. Remote control devices
4. Solar panels
5. Medical applications

3. Phototransistors

The last light sensor type we'll be exploring today is the phototransistor. The phototransistor light sensor can be described as a photodiode + amplifier. With the added amplification, light sensitivity is far better on the phototransistors. However, it does not fair better in low-light detection than in photodiodes.

2.4.2 Tactile Sensors

1. A tactile sensor is a device. It measures the coming information in response to the physical interaction with the environment.
2. The sense of touch in humans is generally modeled, i.e. cutaneous sense and the kinesthetic sense.
3. Cutaneous touch has the capability of detecting the stimuli resulting from the mechanical stimulation, pain, and temperature.
4. The kinesthetic touch receives sensor inputs from the receptors present inside the muscles, tendons, and joints.

Tactile Sensor

Types of Tactile Sensors
There are different types of tactile sensors which are given below

- Force/ torque sensor
- Dynamic sensor
- Thermal sensor

Force/ Torque Sensor
Force/ torque sensors are used in combination with a tactile array to give the information for force control. These types of sensors can sense load anywhere like the distal link of a manipulator and in constrains as a skin sensor. The skin sensor generally provides more accurate force measurement at higher bandwidths

Force or Torque Sensor

Dynamic Sensor

Dynamic sensors are smaller accelerometers at the finger strips or at the skin of the robotic finger. The general function like Pacinian corpuscles in humans and have equally large respective fields; thus one or two skins accelerometer are sufficient for entire finger. These sensors effectively detect the making and breaking of contact, the vibrations linked with the sliding over textured surfaces.

Dynamic Sensor

A stress rate sensor is the second type of dynamic tactile sensor. If the fingertip is sliding at the speed of a few cm/s overall small bumps or pits on a surface, the temporary changes in the skin became important. A piezoelectric polymer such as PVDF produces a charge in response to damage that can be applied to produce a current, which is directly proportional to the range of change.

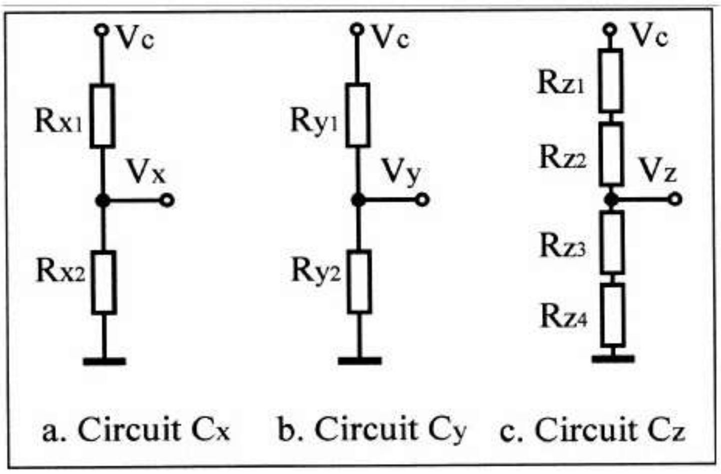
Thermal Sensor

Thermal sensors are important to the human ability to identify the materials of the objects made, but some are used in robotics as well. The thermal sensing involves detecting thermal gradients in the skin, which are correspondent to both the temperature and the thermal conductivity of an object. Robotic thermal sensors are involved in the Peltier junctions in combination with the Thermistors.

Thermal Sensor

Working principle and Circuit Diagram of the Tactile Sensor

The tactile sensors are developed to provide tactile sensing abilities for tele-operational manipulators and intelligent robots. Tactile sensors can identify a normal force applied to the tactile pixels for mesmerizing the force control and the tactile images and to generate object recognition. However, to obtain tactile images and normal forces, the information of tangential is critical for force control and slide prevention, which is mesmerizing to task success – thus the three-dimensional tactile sensors are required.

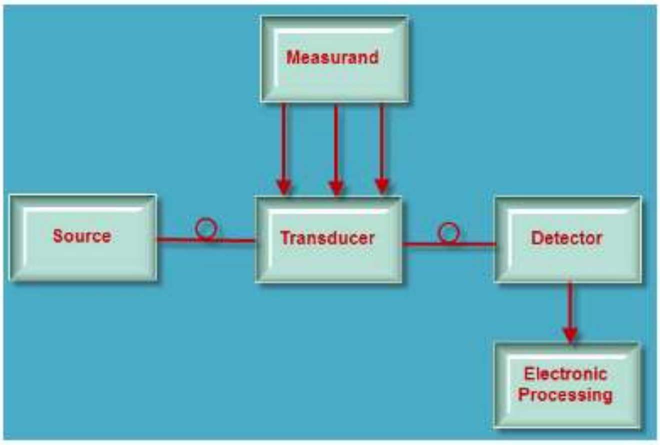


Circuit Diagram of Tactile Sensor

2.4.3 Fiber Optic Sensors

The fiber optic sensors also called as optical fiber sensors use optical fiber or sensing element. These sensors are used to sense some quantities like temperature, pressure, vibrations, displacements, rotations or concentration of chemical species.

1. Fiber optic sensors are supreme for insensitive conditions, including noise, high vibration, extreme heat, wet and unstable environments.
2. These sensors can easily fit in small areas and can be positioned correctly wherever flexible fibers are needed.
3. The wavelength shift can be calculated using a device, optical frequency-domain reflectrometry.
4. The time-delay of the fiber optic sensors can be decided using a device such as an optical time-domain Reflectometer.



Block Diagram Of Fiber Optic Sensor

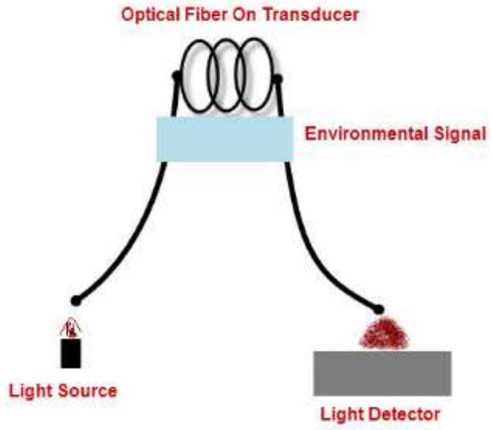
Types of Fiber-Optic Sensor Systems

These sensors can be classified and explained in the following manner:

Based on the sensor location, the fiber optic sensors are classified into two types:

1. Intrinsic Fiber-Optic Sensors

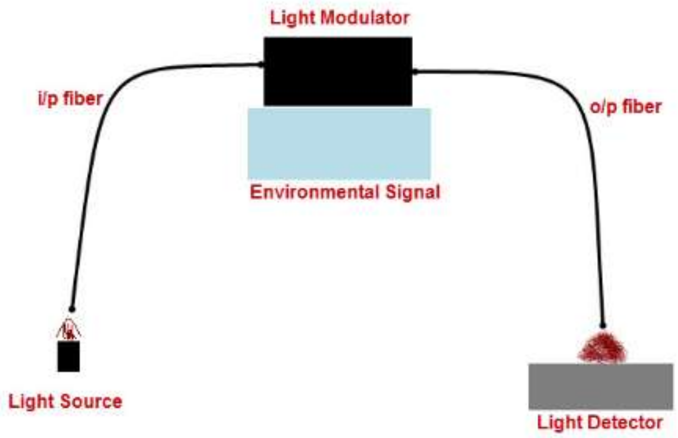
In this type of sensors, sensing takes place within the fiber itself. The sensors depend on the properties of the optical fiber itself to convert an environmental action into a modulation of the light beam passing through it.



Intrinsic Type Fiber Optic Sensors

2. Extrinsic Fiber-Optic Sensor

In extrinsic type fiber optic sensors, the fiber may be used as information carriers that show the way to a black box. It generates a light signal depending on the information arrived at the black box. The black box may be made of mirrors,gas or any other mechanisms that generates an optical signal.



Extrinsic Type Fiber optic Sensors

2.5 Digital Transducers

A transducer measures physical quantities and transmits the information as coded digital signals rather than as continuously varying currents or voltages.

- Any transducer that presents information as discrete samples and that does not introduce a quantization error when the reading is represented in the digital form may be classified as a digital transducer.
- Most transducers used in digital systems are primarily analogue in nature and incorporate some form of conversion to provide the digital output. Many special

techniques have been developed to avoid the necessity to use a conventional analogue - to-digital conversion technique to produce the digital signal

2.6 Recent Trends– Smart Pressure Transmitters

- Smart pressure transmitters have the sensor converting pressure into an electric signal, amplified and passed to the built-in converter, as opposed to usual setups where the signal goes to a central controller.
- The converter processes the data on the fly and actively regulates measurements. The output of smart pressure transmitters are analog electrical signal and digital signal that can go through HART, Modbus, FieldBus and other protocols.
- Microprocessor on board of the transmitters allows increasing its accuracy and expanding the list of its functions.

2.7 Selection of Sensors

1. Accuracy & Precision –

1. These two terms do not mean the same thing, though they are often related. Accuracy has to do with how close the sensor reading is to the true value while Precision refers to the ability of the sensor to detect small changes.
2. As an example, a temperature sensor that measures boiling water at 97.53°C has high precision but low accuracy.
3. Both the accuracy and precision of a given instrumentation system must be appropriate for the requirements of the system. Too high of precision can give a false impression that the reading is also accurate or can result in the system detecting noise rather than the actual desired data.
4. A sensor with more accuracy than necessary will be more expensive and more difficult to use properly than one more appropriate to the measurement required.
5. Additionally, both accuracy and precision are affected by errors incurred throughout the system. Transducer error, wiring, signal conditioners, and the gauges or converters used to read the value each add their own errors into the system that must be understood in order to select the appropriate sensors.

2. Environment –

1. The selection of the proper sensor requires a good understanding of the environment in which the instrument will be operated.
2. Many sensors can be affected by the non-ideal conditions of a production floor (such as temperature variation, vibration, humidity, chemicals, etc.)
3. It is important to take the environment into account when selecting the sensor and its packaging, mounting, and other options.

3. Excitation – Many transducers require power to produce an output signal and it is important to provide a power source that will not introduce additional errors.

4. Signal Conditioning – The world is full of non-ideal realities in sensors. Electrical noise is always present, often more so on production floors, and can cause erroneous readings. Signal conditioners and other protection circuits can provide some protection from these effects before conversion. Sometimes these are useful, but other times it is possible or preferred to process the signals after conversion, so the use of conditioners must be evaluated during the instrumentation design process.

5. Conversion – In modern systems, it is often preferred that the instrumentation system provides digital data (rather than analog gauges or chart recorders). The analog to digital converters must be evaluated and matched appropriately to the sensors or errors can be introduced, or money wasted by overpaying for precision in one that is not present in the other. Make sure to properly handle ratiometric and non-ratiometric sensors by properly matching with converters that are the same.

6. Processing – Even if signal conditioning is performed, the sensor and conversion process is full of various sources of error. Some of these errors are linear (consistent effect across the measurement range), while others are non-linear. There are various methods and algorithms that can be used to compensate for these errors or to extract the best possible signal from the system.

The following factors are considered while selecting sensors.

1. Accuracy required
2. Precision
3. Sensitivity
4. Operating range
5. Resolution
6. Speed response
7. Reliability
8. Maintenance should also be easy and frequency of maintenance required should be less over the period.

2.8 RVDT

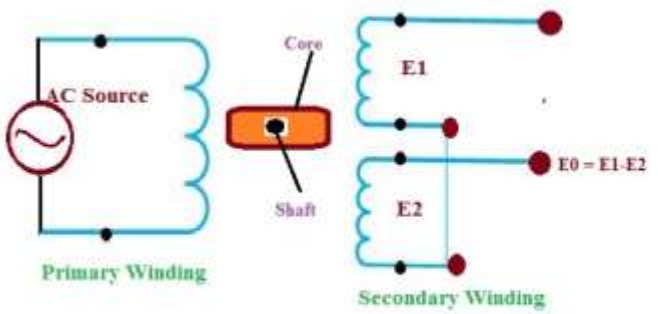
The RVDT stands for Rotary Variable Differential Transformer. It is one kind of electromechanical transducer used to give the linear o/p which is proportional to the i/p angular displacement.

1. The main function of RVDT is to detect the angular displacement and converts it into an electrical signal.
2. The both the RVDT and LVDT workings are similar, but LVDT employs the flexible iron core for displacement measurement whereas in RVDT employs a cam type core.
3. This core will turn among the two windings of the transformer using the shaft.

Rotary Variable Differential Transformer

RVDT Construction and Its Working

1. RVDT transducer has two windings similar to a normal transformer such as primary winding and two secondary windings shown in the following RVDT diagram.
2. The two windings of the transformer wounded, where the two secondary windings have an equivalent number of windings.
3. These are located on both sides of the primary winding of the transformer. A cam formed a magnetic core which is made with a soft iron is coupled to a shaft.
4. Thus, this core can be twisted among the windings. The construction of both the RVDT and LVDT are similar but the main difference is the shape of the core in transformer windings. This core will turn between the two windings of the transformer due to the shaft.



RVDT Construction

The typical RVDTs are linear over a +40 or -40 degrees, Sensitivity is about 2mV to 3mV per degree of rotation and the input voltage range is 3V RMS at frequency ranges from 400Hz to 20kHz. Based on the movement of the shaft in the transformer, the three conditions will be produced such as:

1. When the Core is at Null Position
2. When the Core Rotates in Clockwise Direction
3. When the Core Rotates in Anticlockwise Direction

When the Core is at Null Position

In the first condition, when the shaft is placed at the null position then the induced e.m.f in the secondary windings are similar although reverse in phase. Thus, the differential o/p potential will be zero, and the condition will be E1 = E2, where E0 = E1-E2 =0

When the Core Rotates in Clockwise Direction

In the second condition, when the shaft rotates in the direction of clockwise; more section of the core will enter across the primary winding. Therefore, the induced e.m.f across the primary winding is higher than secondary winding. Hence, the differential o/p potential is positive, and the condition will be E1 > E2, where E0 = E1-E2 = positive.

When the Core Rotates in Anticlockwise Direction
In the third condition, when the shaft rotates in the direction of anticlockwise, more section of the core will be entered across the secondary winding. Thus, the induced e.m.f across the secondary coil is higher than the primary coil. Hence, the differential o/p potential is negative that means 1800 phase shift, and the condition will be E1 < E2, where E0 = E1-E2 = negative.

RVDT Advantages and Disadvantages
The advantages of RVDT include the following.

- The consistency of RVDT is high
- The exactness of RVDT is high
- The lifespan is long
- The performance is repeatable
- The construction is compact and strong
- Durability
- Low cost
- Easy to handle electronic components
- Resolution is infinite
- Linearity is Excellent
- A wide range of dimension ranges

The disadvantages of RVDT mainly include the following

- The contact among the measuring exterior as well as the nozzle is not possible for all time.
- The output of the RVDT is linear (about +40 or -40 degrees), so it restricts the usability.

2.9 Synchros and Resolvers

Converting angular rotation to an electrical signal is the job of an AC transducer. Types of transducers include synchros, resolvers, and linear/rotary variable differential transformers (LVDTs/RVDTs). They can be used in a variety of applications, such as an inertial navigation reference unit (gyro or compass), an automatic direction finder (ADF), an omnirange system, distance measurement equipment, cockpit indicators, and landing-gear positioning and control.
Synchros have been used in a variety of military and commercial systems for many years. Traditionally, they have been the transducer of choice where reliability is important and difficult environment conditions exist. The simplicity of their connection and today’s synchro-to-digital and digital-to-synchro converter boards make the synchro a very attractive component.

Synchros and resolvers are very similar; however, there are some differences. A synchro has one primary winding and three secondary windings, with each secondary winding mechanically oriented 120º apart. In contrast, a resolver has two primary windings and two secondary windings oriented at 90º to each other.

While a synchro and a resolver are electrically very similar to a transformer, they are mechanically more like a motor. The primary winding in a synchro or a resolver can be physically rotated with respect to the secondary windings. For this reason, the primary winding is called the rotor. The secondary windings, which are fixed, are called stators.

Synchros are often used to track the rotary output angle of a closed-loop system, which uses feedback to achieve accuracy and repeatability. A synchro can be turned continuously and, since its secondary winding outputs are analog signals, provide infinite resolution output.

As the shaft of a synchro turns, the angular position of its rotor winding changes with respect to its secondary (stator) windings. The relative amplitude of the resulting AC output signals from the secondary windings indicates the rotary position of the synchro's shaft.

2.10 Induction Potentiometers

The potentiometer is constituted by a synchro-resolver and two associated circuits, an a.c. voltage supply circuit of one stator winding incorporating an oscillator whose amplitude is controlled by the supply voltage and an output circuit connected to the rotor which incorporates a demodulator stage.
Types:

1. Rotary potentiometers. (a) Concentric potentiometer. (b) Single-turn potentiometer. (c) Servo potentiometer.
2. Linear potentiometers. (a) Multi-turn slide potentiometers. (b) Slide potentiometers. (c) Dual-slide potentiometers.

2.11 Micro Electromechanical Systems.

Micro-electromechanical systems (MEMS) is a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimetres. These devices (or systems) have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale.
In the most general form, MEMS consist of mechanical microstructures, microsensors, microactuators and microelectronics, all integrated onto the same silicon chip.
A sensor is a device that measures information from a surrounding environment and provides an electrical output signal in response to the parameter it measured. Over the years, this information (or phenomenon) has been categorized in terms of the type of energy domains but MEMS devices generally overlap several domains or do not even belong in any one category.
These energy domains include:
• Mechanical - force, pressure, velocity, acceleration, position
• Thermal - temperature, entropy, heat, heat flow
• Chemical - concentration, composition, reaction rate
• Radiant - electromagnetic wave intensity, phase, wavelength, polarization

reflectance, refractive index, transmittance
• Magnetic - field intensity, flux density, magnetic moment, permeability
• Electrical - voltage, current, charge, resistance, capacitance, polarization

Outcomes

At the end of the module, students will be able to:

CO-2: Outline the applications of Ultrahigh Sensitivity, motion, acceleration, Gas sensors and construct its fabrication based on nanotechnology [L3] M-2

TEXT BOOKS:

1. Micro- and Nano-Scale Sensors and Transducers, By Ezzat G. Bakhoum, CRC Press, 1st Edition,2015.

Reference Books

1. Electrical and Electronic Measurements, R.K Rajput, S. Chand, 3rd Edition, 2013
2. A Course in Electronics and ElectricaL, J.B. Gupta, Katson Books, 13th Edition, 2008
3. A Course in Electrical and Electronic Measurements and Instrumentation, A. K. Sawheny, DhanpatRai,
4. https://onlinecourses.nptel.ac.in/noc21_ee26/preview
5. https://nptel.ac.in/courses/108108147