Chapter 9

Mechatronics Systems: Basic Concepts and Applications

9.1. MECHATRONICS: WHAT IS IT?

Mechatronics → Mechanics + Electronics

Mechatronics is a fascinating branch of engineering science which has initially been a combination of mechanics and elecronics. With the advancement of technology, Mechatronics became broad-based covering mechanical, electrical, electronics, software engineering, communication, control and artificial intelligence. Essentially mechatronics is

- a broad term that integrates/unites principles of mechanics, electronics and computing (frequently using micro-controllers to generate a simpler, economical and reliable system.
- the synergistic integration of mechanical engineering with electronics and intelligent control algorithms in the design and manufacture of products process.

The term 'synergistic' implies interaction of two or more disciplines to produce a combined effect greater tham the sum of their separate effects. As such, a mechatronics engineer would study definitive portions of mechanical engineering, electrical/electronics engineering, computer engineering and control engineering.

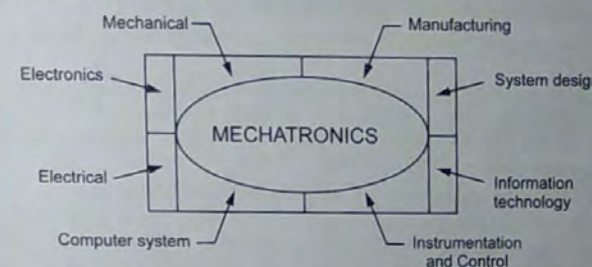


Fig. 9.1. Constituent disciplines of a mechantronics system

The different fields which make up mechatronics have been indicated in Fig. 9.1. Mechatronics is treated as a modern buzzword synonymous with automation, robotics, and electro-mechanical systems.

The noteable examples of mechatronics systems are :

- digitally controlled combustion engines
- machine tools with self-adaptive tools
- contact free magnetic bearings

- automated guided vehicles
- robots

Physically a mechatronics system consists of four prime components viz., sensors, actuators, controllers and mechanical components arranged as shown in Fig. 9.2.

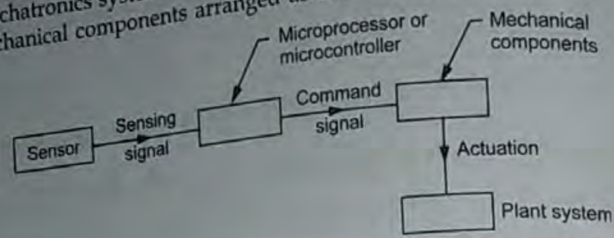


Fig. 9.2. Components of mechantronics system

A typical mechantronic system picks up signals from the environment, processes them to generate output signals, and transforms them into forces, motions and actions.

9.2. ORIGIN AND EVOLUTION

The term 'mechatronics' was coined by Tetsure Mori and was used to describe a philosophy adopted in designing sub-systems of electro-mechanical products. The term was a trade mark of Yasakowa Electric Corporation from 1971 to 1982. Since those early days there have been rapid advances in technology available to manufacturing industries, and the term 'mechatronics' is now firmly established and is being freely used by industries around the world.

The different stages in the evolution of the discipline/field of mechatronics have been :

1. Primary level: The primary stage is the basic control level that covers input/output devices. There is integration of electrical signaling with mechanical action using sensors and actuators, e.g., relay switches and electrically controlled valves.

2. Secondary level: At this stage of development, there has been integration of micro-electronics into electrically controlled devices such as in a cassette tape player.

The auto-focus camers and washing machines too are examples of such systems; often called stand-alone systems.

3. Tertiary level: The tertiary level mechatronics systems, often called smart systems, are of improved quality and sophistication. This results through incorporation of advanced feedback functions into the control strategy that uses micro-electronics, micro-processors and other application specific integrated circuits.

Industrial robots are typical examples of tertiary mechatronics system.

4. Quaternary level: There is an attempt in the quaternary level mechatronics systems to incorporate intelligent and fault detection isolation with the objective of enhancing smartness. There is a linkage of major subsystems such as machining centres, robots for part handling, automated inspection centres, etc., in the large factory systems. Further, intellectual capabilities of the human operator are captured through the concepts of artificial neural network and fuzzy logic. Humanoid robot is one such mechatronics system.

9.3. AVIONICS, BIONICS AND AUTOTRONICS

Avionics is a variant of mechatronics system that is coined from a blend of **aviation** and **electronics**. Every modern aircraft, spacecraft and artificial satellite uses electronic systems of varying types to perform a range of functions pertinent to their purpose and mission. Such systems may include:

- Engine control and flight control systems in order to reduce pilot error and workload at landing or take off.
- Fuel control and monitoring system to report fuel remaining on board.
- Navigation and communication systems. Air navigation is the determination of position and direction on or above the surface of the earth.
- Weather and anti-collision systems. The transport aircraft uses a traffic alert and collision avoidance system which can detect the location of nearby aircraft and provide instructions for avoiding mid-air collision. The weather dectectors give information on lightning and turbulance.
- Flight recorders (black boxes): These store flight information and audio from the cockpit. They provide information on control settings and other parameters when there is any unfortunate incident of crash.
- Display and management of systems fitted to the aircraft to perform individual tasks.

There is also integration of multiple functions to improve performance, simplify maintenance and contain costs.

Bionics is a variant of mechatronics system that has been coined by Jack Steel in 1958 from the subjects of **Bio**logy and Electr**onics**. This biological inspired engineering pertains to the biological methods and systems, and is made use of in the study and design of engineering systems. Bionics studies the mechanical and electronics systems that function like living organism or parts of a living organism both internal and external.

Examples of bionics in engineering include :

- hulls of boat immitating the skin of dolphins
- sonar, radar and medical ultrasound imaging using sound waves and echoes to determine where the objects are in space. This is analogous to sending out of sound waves (from the mouth or nose) by the bats to find food in the dark. When the sound waves hit the target (food), echoes are produced.
- producing artificial neurons, artificial neural networks and swarm intelligence in the field of computer science
- Making of artificial hands with sensors in the finger tips that monitor and adjust the strength of the hand's grip.
- Development of dirt and water repellant paints/coatings from the observation that practically nothing sticks to the surface of lotus flower plant.
- Chaning the shape of aircraft wings according to speed and duration of flight inspitred by different bird species that have differently shaped wings according to the speed at which they fly.
- Creation of new nanosensors to detect explosives inspired by wing structure of butterflies.
- Developoment of smart clothing that adapts to changing temperatures. The smart fabric opens up when the weather is warm and sweating, and shuts tight when cold. This development came from a study of pinecones (a type of plant).
- Application of the ways the animals move in the design of robots.

The above examples clearly indicate that Bionics treats nature itself as a database of solutions that already exist. Further, it will be appropriate to mention how the subjects of Bionics, Cybernetics and Bio-engineering differ from each other.

Bionics explores new ideas for building mechanical and electronics systems. Cybernetics focuses on seeking an explanation of the behaviour of living organisms. Bio-engineering uses living things to perform industrial tasks. For example, using bacteria in paper batteries to supply electrical energy would be an advancement in Bio-engineering, and not Bionics.

Autotronics is a variant of mechatronics system that has been coined by blending automobile and electronics.

automobile + electronics → autotronics

That makes autotronics a flexible engineering that serves to develop and understand conversion principles in design, construction and working of mechanical systems and electronics systems combined with advancement of sensors and microcontrollers. Analysts estimate that more than 80 per cent of all automobile innovatives now stem from electronics. Since 1970, there has progressive changes in motor vehicle technology with many of the functions evolved from mechanical to becoming electronics and controlled by computer. Due to embedding of electronics in automobile operations there has been improvement in :

- fuel injection and engine ignition
- steering, transmission and suspension
- antilock braking
- navigation and general positioning system (GPS)
- audio and video entertainment system
- safety control and security alarms
- collision avoidance systems
- auto-locking system and key-less entry

All this has made driving more comfortable, more secure and more efficient, and has turned driving into a pleasurable experience.

9.4. APPLICATIONS OF MECHATRONICS

Mechatronics is one of the fastest developing fields with wide areas of application in marketing, design and manufacturing. Marketing refers to information analysis related to identification of uses needs and formulation of product specification. The manufacturing domain looks into process development, production planning, material handling, inspection and quality control. The current technological designs are highly complex and that requires integration of knowledge from different interdisciplinary subjects.

Mechatronics finds application in :

- Industries where it is necessary to design and maintain automatic equipment.
- Large manufacturing units involved in high volume production. Automation and industrial robots perform consistently and quickly and that enable manufacturers to keep with demand while reducing costs.
- Many medical applications such as magnetic resonance, ultrasonic probe and arthroscopic devices are mechatronics. Surgical robots have been developed for eye surgery, targeting lung cancer, knee surgery and laparoscopy. Such examinations and treatments are less invasive and that leads to fast recovery and low risk of infection.
- Computer machine tools like CNC milling machines, CNC water jets and CNC plasma cutters.
- Computer aided and integrated manufacturing systems
- Consumer products, industrial goods packaging
- Transportation and vehicular systems, automative engineering equipment in the design of anti-lock brakes and stabilizers, and air-bag inflation. This has made driving safe and less accident prone.
- Home applications such as automatic air-conditioning systems, security systems, washing machines and dish washing, etc.

- Intelligent measuring devices like calibration, measuring and testing of sensors.
- Automatically guided and unmanned aerial vehicles.

In recent times, a greater use of mechatronics is evident in manufacturing, mining, aviation, robotics, defence and transport. Mechatronics engineers may program robots, design telecommunication systems or develop nano-technology.

9.5. ADVANTAGES AND DISADVANTAGES

Mechatronics is basically the application of various technical fields to have reliable product design and manufacturing solutions. The main advantages resulting from mechantronics systems are :

- enhancement of functionality and features
- easy design of processes and products, improved design time and product size
- rapid setting up and cost effective operation of manufacturing facilities
- optimizing performance and quality
- increased effectiveness and productivity
- more user-friendly and more safe to use
- improved and less expensive controls
- little interference from operators
- high level of integration

There is better control of precision, position, speed, flow rate and other variables due to use of micro-controllers, software and artificial intelligence in mechatronics.

However, the mechatronics systems have the following disadvantages too

- high initial cost
- complicated design
- system complex and so difficult repair and maintenance.

9.6. SENSORS AND TRANSDUCERS

A generalized measurement system consists of two components, (*i*) sensing element which responds directly by reacting to the measurand, and (*ii*) transducing element which is responsible for conversion of the measurand into analogus driving signal. The sensing element may also serve to transduce the measurand and put it into a more convenient form. Tie unit is then called ***detector-transducer***.

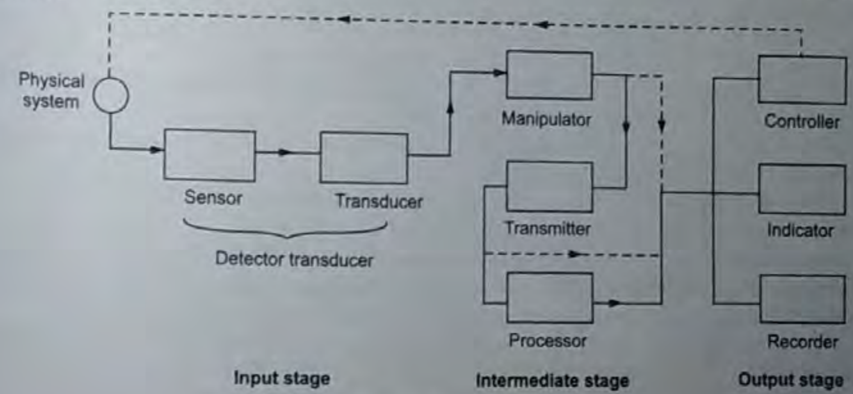


Fig. 9.3. Generalized measurement system

For instance:

• In the ordinary dial indicator the contacting spindle acts as a detector or sensing element for displacement. It simply performs the function of a detector and nothing else.

• The function of the bourdon tube of a pressure gauge is two-fold: firstly to sense the pressure and secondly to give the resulting effect or the output in the form of displacement The tube then works as a detector-transducer.

• In a compressive load cell, the platform detects the force and gives an output in the form of deflection. This deflection may be further converted into an electrical output by-strain gauges mounted on the load cell. The strain gauge is called secondary transducer because of second translation.

Different types of sensors and transducers are available for the measurement of one particular quantity and the choice of a suitable unit depends upon the static and dynamic performance characteristics.

9.7. MECHANICAL DETECTOR-TRANSDUCER ELEMENTS

Transducers make use of different principles to convert the various quantities being measured into their analogs. Table 9.1 provides a list of the mechanical detector-transducers, together with the functions they perform.

Table 9.1 Mechanical detector-transducer elements

Detector-Transducer	Operation
Contacting spindle	Displacement to displacement
Elastic member	
• Bourdon tube (circumferential and twisted) • Bellows • Diaphragms (flat, dished and corrugated)	Fluid pressure to displacement
• Springs • Proving ring	Force to displacement
Concentrated mass	
• Seismic mass	Acceleration and vibration amplitude to displacement
• Pendulum	Force to displacement
• Manometric liquid	Fluid pressure to displacement
Thermal	
• Liquid-in-glass and filled system thermometers • Bimetallic rods	Temperature to displacement
• Temperature sticks	Temperature to phase change
• Thermocouples and thermopiles	Temperature to electric voltage
• Thermistors and resistance thermometers	Temperature to resistance change

(Contd.)

Hydropneumatic	
(*a*) Static	
• Float	Liquid level to displacement
• Hydrometer	Specific gravity of liquid to displacement
(*b*) Dynamic	
• Orifice plate, venturi and nozzle • Pitottube	Velocity to pressure
• Vanes	Velocity to force
• Turbines	Linear to angular velocity

9.7.1. Elastic elements

These units are frequently employed to furnish an indication of the magnitude of applied pressure/force through a displacement measurement. Operation of the elastic elements is based on one or a combination of the following three acts:

(*i*) compression that tends to force the molecules of the solid together

(*ii*) tension that tends to force the molecules farther apart

(*iii*) torsion that tends to twist the solids

A force may be determined by applying it to an elastic element and measuring the resulting elastic deformation. The devices commonly used include springs, the proving ring and the torsion rods.

• In a spring type indicating scale, unknown weight applied to the free end of the spriing causes displacement which is indicated by the pointer. A tape-and-drum movement can be employed to operate the pointer.

• The proving ring (stress ring) is a ring of known physical dimensions and mechanical properties. An external tensile or compressive force applied across the ring diameter causes distortion which is proportional to that force. The distortion is measured by means of a dial gauge, a sensitive micrometer, or a strain gauge. The proving ring is widely used as a calibration standard for large tensile testing machines.

• A torsion bar would twist in proportion to the applied torque and the resulting angular deformation can be used as a measure of the torque.

• Most pressure measuring devices use either a bourdon tube, a bellow or a diaphragm. The action of these elements is based on elastic deformation brought about by the force resulting from pressure summation.

9.7.2. Mass sensing elements

The inertia of a concentrated mass provides another mechanical detector transducer. The principle is employed in vibration pickups and accelerometers, and serves to measure the characteristics of dynamic motion (displacement velocity, acceleration, and frequency) through application of Newton's second law of motion.

• Any simple mechanical vibrating member such as a pendulum would serve as a time or frequency transducer, chopping the passage of time into discrete bits.

• The pressure measurement by manometers is also based on the principle of mass displacement.

9.7.3. Thermal detectors

These units sense the temperature of a system by indicating some change in the property of a material which varies with temperature; properties which are so used include :

(i) Expansion of solids and liquids: bimetallic thermometers, liquid-in-glass and the filled system thermometers

(ii) Thermo-electric property of metals and alloys: thermocouple and thermopiles

(iii) Electrical resistance of metals and semiconductors: resistance thermometers and thermistors.

(iv) Radiating ability : total radiation and optical pyrometers

9.7.4. Hydro-pneumatic elements

A simple float and a hydrometer are the two common examples of the hydro-pneumatic sensors applied to static conditions.

• The float converts the fluid level into displacement but makes no allowance for change of the density of the supporting liquid.

• A hydrometer senses specific gravity and uses the depth of immersion as a means for detecting variations in the specific gravity of the supporting liquid.

• The obstruction head flow meters (orifice plate, venturi and nozzle) provide a flow information in the form of pressure change as a result of energy transformation. The obstruction placed in the path of the fluid results in a change of fluid pressure which is dependent on the rate of flow. The difference in pressure before and after the obstruction is measured by means of a differential pressure gauge and is correlated to flow rate,

• Aero-or-hydrodynamic principles are also applied to determine the fluid velocity. A point tube measures the pressures resulting from total-flow rate rather than the change of rate. Flow rate is also sensed by vanes in the form of airfoil and turbine wheels. Flow rate a inferred from the vane displacement or the angular velocity of turbine wheel.

9.8. ELECTRICAL TRANSDUCERS

Nowadays electrical/electronic techniques of measurement are being increasingly applied to measurements in many fields other than in electrical engineering. The advantages of such methods over others are :

- more compact instrumentation
- good frequency and transient response
- feasibility of remote indication and recording
- possibility of mathematical processing of signals like summation, integration etc.
- minimum of friction and mass-inertia effects
- possibility of non-contact measurements
- less power consumption and less loading on the system to be measured
- amplification greater than that produced by a mechanical contrivance

The different electrical phenomena employed in transduction elements of electrical transducers are listed in Table 9.2 along with their typical applications.

An examination of Tables 9.1 and 9.2 would reveal that whereas displacement is output from the mechanical and hydro-pneumatic devices, it is input to the electrical devices. This aspect results in a very workable combination with the mechanical device serving as detector-transducer and an electrical device serving as the electro-mechanical transducer (more often as transducer only) with the sole object of converting the linear or rotary displacement of the mechanical system into an electrical output. Transducers are also known as gauges, kpickups and signal generators. Most of the pickups have two basic elements in essential, viz., an actuating device and the transducing element. Some of the typical transducer actuating mechanisms are shown in Fig. 9.4.

Table 9.2 Electrical transducers

Operating	Principle	Applications
	Externally Powered (Passive) Transducers	
Resistance		
• Potentiometric device	Resistance in a potentiometric or a bridge circuit varies with change in the position of a slider by an externally applied load	Displacement and pressure
• Resistance strain gauge	Resistance of a wire or semi-conductor is changed by elongation or compression due to an external load	Force, torque and displacement
• Resistance thermometer	Resistance of a pure metal wire (with positive temperature coefficient of resistance) varies with temperature	Temperature and radiation heat
• Thermistor	Resistance of certain metal oxides (with negative tempera-true coefficient of resistance) varies with temperature	Temperature
• Pirani gauge	Resistance of a heating element changes due to convection cooling by the stream of gas flow	Gas flow and gas temperature
• Resistance hygrometer	Resistance of a conductive strip changes with moisture content	Relative humidity
• Photo-conductive cell	Resistance of the cell as a circuit element varies with incident light	Photosensitive relay
Capacitive		
• Variable capacitance pressure gauge	Variation in capacitance due to change in distance between two parallel plates by an externally applied force	Displacement and pressure
• Dielectric gauge	Variation in capacitance by change in the dielectric between the plates	Liquid level, and thickness
• Capacitor microphone	Variation in capacitance between a fixed plate and a movable diaphragm due to sound pressure	Speech, music and noise
Inductive		
• Magnetic circuit transducer	Variation in self-inductance or mutual inductance of an ac	Pressure and displacement

	excited coil by changes in the magnetic circuit	
• Reluctance pick-up	Variation in reluctance of the magnetic circuit by changing the position of the iron core of a coil	Pressure, displacement, vibration and position
• Diffferential transformer	Variation in the differential voltage of two secondary windings by positioning the magnetic core through an externally applied force	Pressure, force, displacement and position
• Eddy current gauge	Variation in inductance of a coil by the proximity of an eddy current plate	Displacement and thickness
• Magnetostriction gauge	Variation in magnetic properties by the measurand	Force, pressure and sound
Voltage and current		
• Photo emissive cell	Electron emission due to incident radiation upon the photo emissive surface	Light and radiation
• Photo multiplier tube	Secondary electron emission due to incident radiation on photosensitive cathode	Light and radiation, photosensitive relays
• Ionization chamber	Electron flow induced by ionization of gas due to radioactive radiation	Particle counting, and radiation
• Hall effect pick up	Setting up of potential difference across a semi-conductor plate when there is interaction of magnetic flux with an applied current	Magnetic flux, and current
	Self-generating (Active) Transducers (No External Power)	
• Thermocouple and thermopile	Generation of an emf across the junction of two dissimilar metals of semiconductors when one junction is heated	Temperature, heat flow and radiation
• Piezoelectric pick up	Generation of an emf when an external force is applied to certain crystalline materials (e.g., quartz)	Pressure changes acceleration, vibration and sound
• Photo-voltaic cell	Generation of voltage in a semi-conductor junction device when the cell is stimulated by the radiant energy	Solar cell and light meter
• Moving coil generation	Generation of voltage due to motion of a coil in a magnetic field	Velocity and vibration

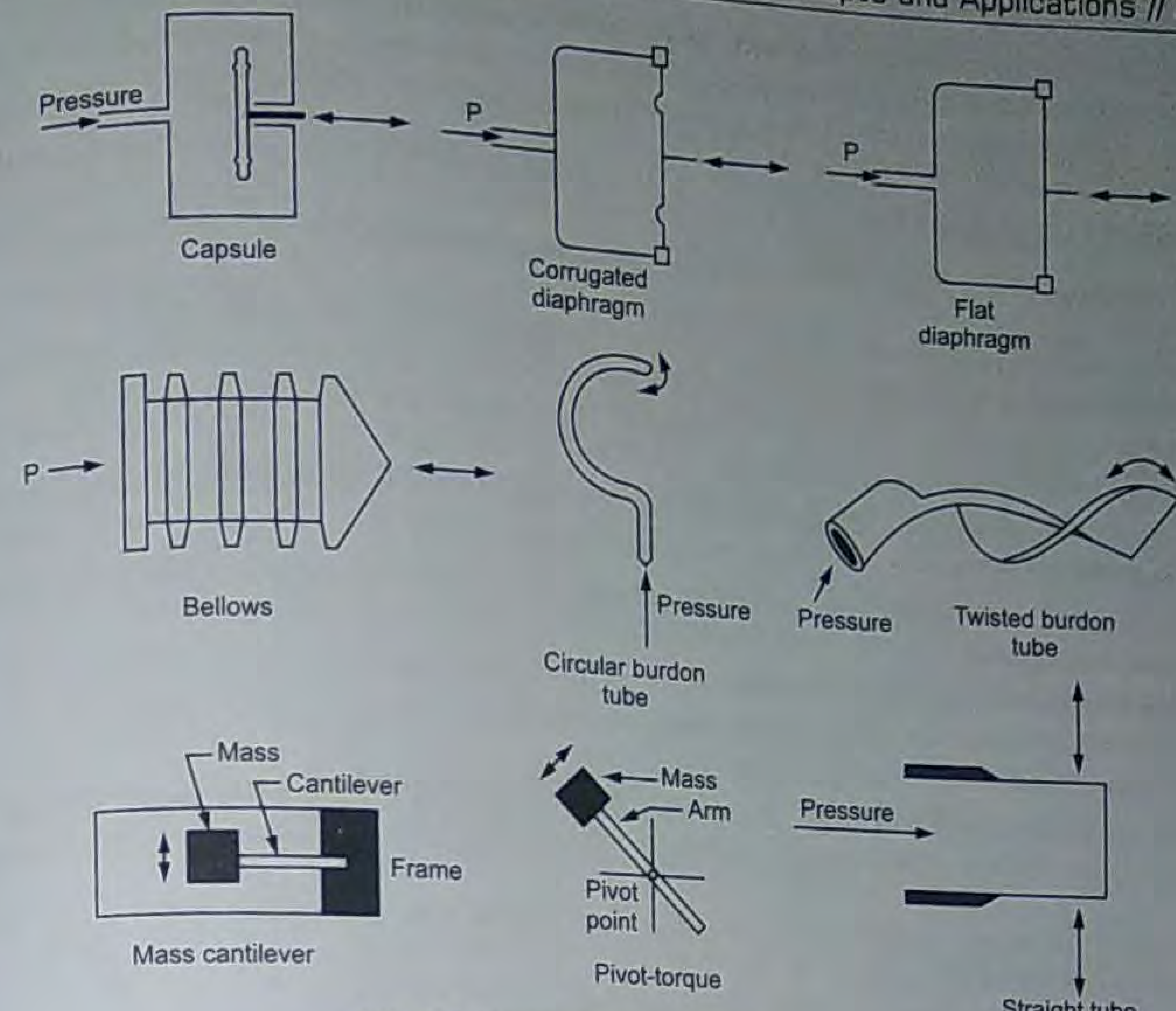


Fig. 9.4. Transducer actuating mechanisms

9.9. TRANSDUCER CLASSIFICATION AND DESCRIPTION

The transducers may be classified on the basis of their application (type and nature of measurand), method of energy conversion, nature of signal output, kind of sensing element mechanical or non-mechanical, and according to whether they are self-generating (active or externally powered (passive).

Self-generating and externally powered units

Self-generating transducers develop their own voltage or current. The energy required for this is absorbed from the physical quantity being measured. Examples are: thermocouples and thermopiles, piezo-electric pick up, photo-voltaic cell, etc.

Externally powered transducers derive the power required for energy conversion from an external power source. They may also absorb a little energy from the process variable being measured. Examples are : resistance thermometers and thermistors, potentiometric devices, differential transformer, photo-emissive cell, etc.

Input and output transducers

Input transducers convert a non-electrical quantity into an electrical signal (a strain gauge or photo electric cell) and the output transducers convert the electrical signal back injto a non-electrical quantity (movement of pointer against a graduated scale). In between the input and output transducers, there is usually a signal conditioning equipment (amplifier, filter, etc.).

With the fast developing technology, there has been a rapid increase in the development and application of various types of transducers to convert all the measured quantities into their electrical analogs. The output electrical signal may be amplified, recorded and processed in the instrumentation system.

Transducer Description

Information must be available about the following aspects while describing a particular transducer:

- the physical quantity or variable which is to be measured, i.e., the measurand
- the principle of operation of the transducer and where the output of the transducer originates
- the sensing element which responds directly to the measurand
- the built-in special features (if any)
- the useful range, i.e., the minimum and maximum values of the physical quantity the transducer can measure.

With regard to a DC tachometer (an instrument for measuring angular speed), the above mentioned aspects are:

- angular speed in rpm is the measurand
- principle of operation is electromagnetic
- AC generator is the sensing element
- commutator is the special built-in feature ; it transforms AC voltage into DC voltage output
- minimum and maximum values of speed are 0 and 2000 rpm, i.e., the useful range is 0-2000 rpm

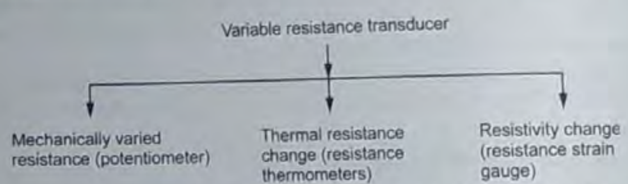
The DC tachometer would then be specified as : "0-2000 rpm, DC output, commutator type electromagnetic speed transducer".

9.10. VARIABLE RESISTANCE TRANSDUCERS

In terms of physical quantities, the equation for electrical resistance of a metal conductor is

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

where R is the resistance (ohms), ρ is the conductor resistivity or specific resistance (ohm cm), l is the physical length (cm) and A is the uniform cross-sectional area of the resistor (cm^2). Any method of varying one of these quantities can be the design basis of an electrical transducer. In the variable resistance transducer, an indication of measured physical quantity is given by a change in the resistance.



Further, with some devices, resistance changes with light intensity (photo conductive effect) while with others, resistance changes on exposure to magnetic field (magneto-resistive effect).

The variable resistance transducers are passive and they rely on an external excitation voltage for their operation. However, they are straight-forward in design, simple and easy to use.

9.10.1. Linear and Angular Motion Potentiometers

These potentiometers convert the linear motion (or the angular motion of a rotating shaft) into changes in resistance. Basically a resistive potentiometer (or 'pot') is a variable resistor whose resistance is varied by the movement of a slider over a resistance element. (Fig. 9.5 *a*, *b*). Translatory devices have strokes from 2 mm to 50 cm, while rotational ones have a full scale ranging from 10° to as much 60 full turns.

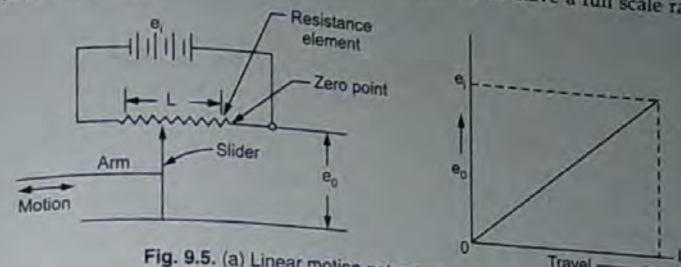


Fig. 9.5. (a) Linear motion potentiometer schematics

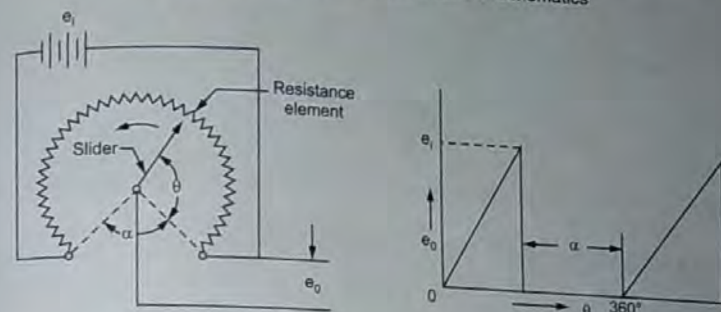


Fig. 9.5. (b) Rotary motion potentiometer schematics

The resistance elements in common use are wire wound because that gives sufficiently high resistance value in small space. The characteristics of the resistance wire are :

- precision drawn wire with a diameter of about 25 to 50 microns, and wound over a cylindrical or a flat mandrel of ceramic, glass, anodized aluminium.
- resistivity of wire ranges from 0.4 μΩ-m to 1-3 μΩ-m, and temperature coefficient varies from 0.002% per °C to 0.001 % per °C. With these values, the device operates with appreciable constant sensitivity over a wide temperature range.
- the wire is strong, ductile, and protected from surface corrosion by enamelling or oxidation.

The materials commonly employed are the alloys of copper-nickel, nickel-chromium, and silver-palladium.

9.10.2. Resistance thermometers and thermistors

Metals such as platinum, copper, tungsten and nickel become more resistant to the passage of electric current as they become hotter. Their resistance increases with growth in temperature, *i.e.*, they have a positive temperature coefficient of resistance. For many practical purposes and within a narrow temperature range, the metal resistance thermometers depend upon the following relationship between metal resistance and temperature

$$R_1 = R_0 [1 + \alpha (t_1 - t_0)]$$

where R_0 is the resistance in ohms at the reference temperature (usually 0°C) and α is the temperature coefficient of resistance in $°C^{-1}$. For precise temperature measurements, platinnum is preferred because it is physically stable and has high electrical resistance characteristics Because of accuracy, stability and sensitivity, the platinum resistance thermometer has been used to define the international practical temperature scale from the boiling point of oxyger (–182.9 °C) to the freezing point of antimony (630.5°C).

Thermistors are essentially semi-conductors (sintered mixture of metallic oxides such as manganese, copper, iron and uranium) which exhibit large non-linear resistance changes with temperature variation, i.e., they have a high negative temperature coefficient. Thermistors are normally made in the form of beads, disks, washers, rods and can be made as small as 1 mm. Thermistors have the advantages of high sensitivity, very small size, fast thermal response, fairly low cost and, easy adaptability to electrical readout devices.

Thermistors and metal resistance thermometers find extensive application as temperature detecting elements for the purpose of measurement and control.

9.10.3. Resistance strain gauges

Operation of these gauges is based on the principle that the electrical resistance of a conductor changes when the resistance element is strained by an external force. Under no load conditions, the gauge is bonded or cemented directly onto the surface of the body or structure which is being examined. The different forms of bonded strain gauges are :

(*i*) fine wire gauges cemented to a paper backing

(*ii*) photo-etched grids of conducting foil on an epoxy resin backing

(*iii*) a single semi-conductor filament mounted on an epoxy-resin backing with copper or nickel leads

The wire grid participates in the subsequent deformations both in the specimen and the resistance element. A tensile or positive strain increases the resistance while compressive or negative strain decreases resistance. Resistance gauges made up as single elements measure strain in one direction only. A combination of elements, *i.e.*, rosettes will however permit simultaneous measurements in more than one direction.

The strain gauge is a versatile device and finds application in the measurement of different variables such as load, force, thrust, pressure, torque and displacement, etc.

9.11. THERMO-ELECTRIC TRANSDUCERS

When two dissimilar metal conductors are joined at the ends and the two junctions are kept at different temperatures, a small emf is produced in the circuit. The magnitude of this voltage depends upon the material of conductors and the temperature difference between the two junctions. This thermo-electric effect is used in thermo-couples for the measurement of temperature. Any number of combination of metals may be used. Two commonly employed combinations are iron and constantan (an alloy of copper and nickel), and chromel (an alloy of chromium and nickle) and alumel (an alloy of aluminium and nickel.

9.12. VARIABLE INDUCTANCE TRANSDUCERS

These transducers are based on a change in the magnetic characteristics of an electrical circuit in response to a measurand which may be displacement, velocity, acceleration, etc. Before discussing these transducers, it is pertinent to become familiar with the following terms and definitions:

– *Inductance or self-inductance* : When a varying current is made to pass through a coil, an induced counter emf results due to magnetic flux intersecting the turns of the coil. This effect causes resistance to flow of current and is called inductance or self-inductance.

– *Mutual inductance* : The term refers to the set up of an emf in a coil or in a circuit element due to varying flux field in neighbouring coil or circuit element

– *Reluctance* : The term refers to that characteristic of a magnetic circuit which determines the total magnetic flux when a given magneto-motive force is applied. Reciprocal of reluctance is termed permeance.

– *Permeability*: It is defined as the ratio of the number of flux lines set up in a coil under given conditions to the number of magnetic flux lines that would occur if the path were air (other conditions remaining unchanged).

Variable inductance transducers have the advantages of freedom from mechanical hysteresis, good response to both static and dynamic measurements, continuous resolution and high output. The performance is, however, adversely affected by the external magnetic fields. Variable inductance transducers can be classified into self-generating (active) and externally powered (passive) units.

9.12.1. Active units

Active units in which the output signal is generated because of the relative motion between a conductor and magnetic field, and without the supply of an energy from an external source.

The operation of self-generating inductance transducers depends upon the following well-known principles:

(*i*) When a conductor is caused to move with a velocity through a magnetic field in a plane perpendicular to the magnetic field, an emf is generated along the conductor [Fig. 9.6 (*a*)].

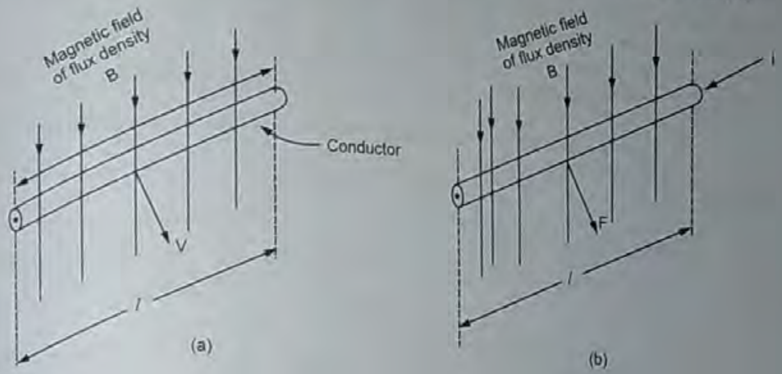


Fig. 9.6. Flux cutting : operating principle of self-generating inductive transducers

The relationship between the emf generated and the velocity is given by : $e = BlV$ where e is the generated emf, B is the flux density of the magnetic field, l is the conductor length and V is the conductor velocity. Evidently when B and l are maintained constant $e \propto V$. The emf generated along the conductor is then a measure of the velocity of the conductor. Transducers based upon this principle can be used for measuring velocities and are frequently used in measurement of angular speed, vibration and fluid flow.

(*ii*) When a conductor is placed in a magnetic field with its longitudinal axis at right angles to the lines of flux and a current is allowed to flow through the conductor, a mechanical force is generated. This force acts on the conductor in a direction perpendicular to the lines of flux and to the conductor (Fig. 9.6 *b*). The relationship between the force generated and the current is given by

$$F = Bli \qquad \text{...(9.1)}$$

where F is the generated force, B is the flux density of the magnetic field, l is the conductor length and i is the conductor current. Evidently when B and l are maintained constant, then $F \alpha i$. The force generated is then a measure of the current flowing through the conductor. This aspect forms the basis for the working of most of the moving-coil and moving-magnet type measuring instruments.

Some examples of the self-generating inductive transducers are shown in Fig. 9.7.

In the ***electromagnetic type***, a coil is wound direct on a permanent core. When a plate of iron or other ferromagnetic material is moved with respect to the magnet, the flux field expands or collapses and a voltage is induced in the coil. Practical application of the device lies in the angular speed indication. When the pickup is placed near the teeth of a rotating gear, speed measurements can be made with great accuracy.

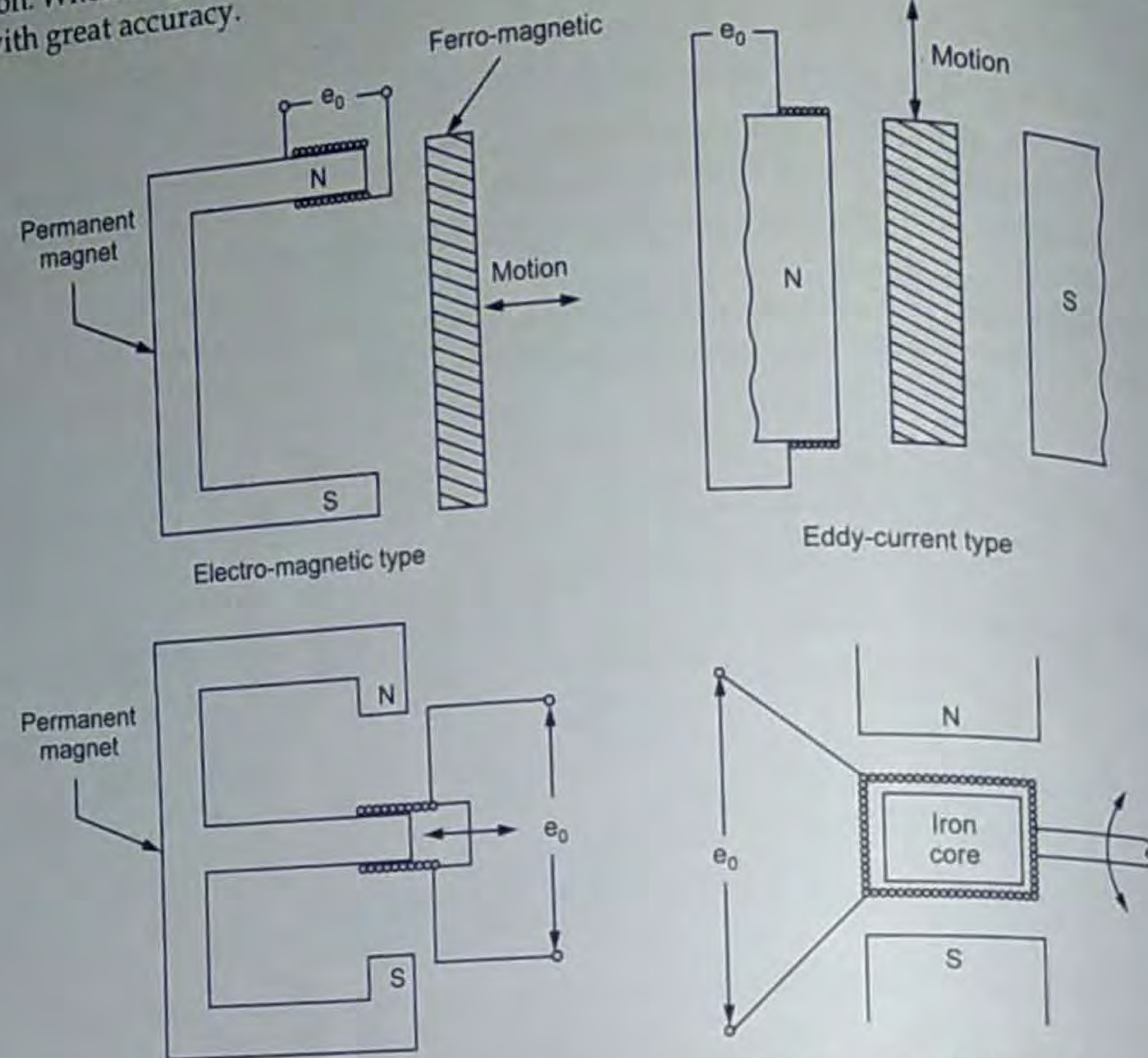


Fig. 9.7. Self-generating variable inductance transducers

In the ***electrodynamic type***, there is a movement of the coil or conductor within the field of a permanent magnet. The turns of the coil are perpendicular to the intersecting lines of force. The movement of the coil induces a voltage which at any moment is proportional to the velocity of the coil. The principle of electrodynamic transducers is used in the magnetic flow meters.

9.12.2. Passive units

Passive units in which the motion of an object results in a change in the inductance of the coils of the transducer; energy is required to be supplied from an external source.

Passive type inductance transducers operate on the following aspects of flux linkage

(*i*) When a current i (amperes) passes through a coil having N turns and an air core (Fig. 9.8), a magnetic flux ϕ (Weber) is generated

$$\phi \, \alpha \, Ni \text{ or } Ni = S\phi \qquad \text{...(9.2)}$$

where S is called the reluctance of the coil. The reluctance is also prescribed by relation

$$S = \frac{1}{\mu_0 \mu_r A}$$

where,
A = cross-sectional area of magnetic circuit (m^2)
l = length of magnetic circuit (m)
μ_0 = permeability of free space = $4\pi \times 10^{-7}$ H/m
μ_r = relatively permeability of the core of the coil. The value of μ_r depends upon the core material, and for air $\mu_r = 1$.

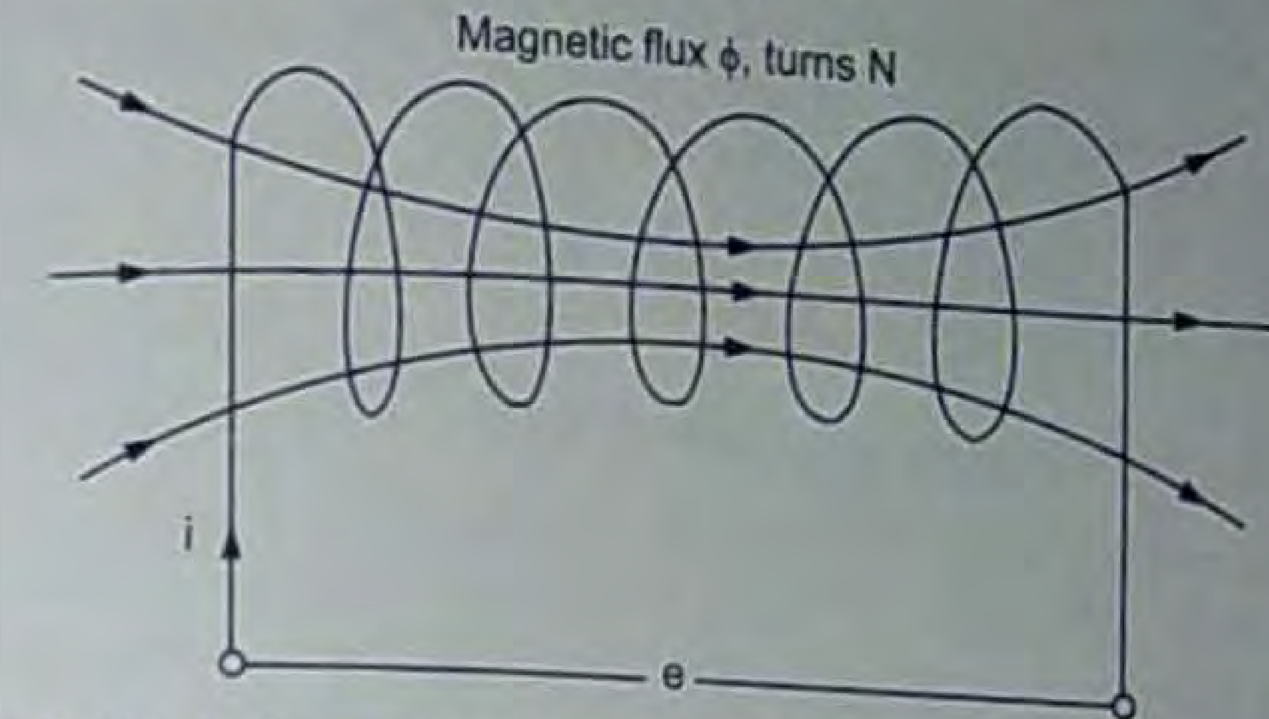


Fig. 9.8. Flux linking: operating principle of passive inductive transducers

(*ii*) The coil inductance is a measure of the magnitude of magnetic flux and is defined as

$$L = \frac{N\phi}{i} \qquad \text{...(9.3)}$$

where ϕ is the magnetic flux density.

Combining equations 9.1, 9.2 and 9.3, we obtain

$$L = \frac{N^2 A \mu_0 \mu_r}{l} \text{ henrys} \qquad \text{...(9.4)}$$

Evidently the self-inductance of the coil is dependent upon the number of turns of coil, the geometrical configuration of the circuit and the permeability of the core.

Variable inductance/reluctance transducers are constituted of magnetic field and core such that a gap exists between the core and the fixed coils. A change in the reluctance of the magnetic circuit by a mechanical input results in a similar change both in the inuctance and inductive reactance of the coils. The change in inductance is then measured by suitable circuitry related and to the value of mechanical input

Reluctance of the magnetic circuit may be altered by affecting a change either in the air gap or in the amount/type of the core material. Transducers that make use of an air gap change are known as ***reluctance type*** and the transducers utilizing a variable core permeability change are referred to as ***permeance type***.

Variable reluctance transducer : Figure 9.9 shows the variable reluctance transducer in which the variable air gap serves to alter the inductance of a single coil. The change in inductance may be calibrated in terms of the armature movement. The variable reluctance principle is particularly applicable to measurement of dynamic quantities such as pressure, acceleration, force, displacement and angular position, etc.

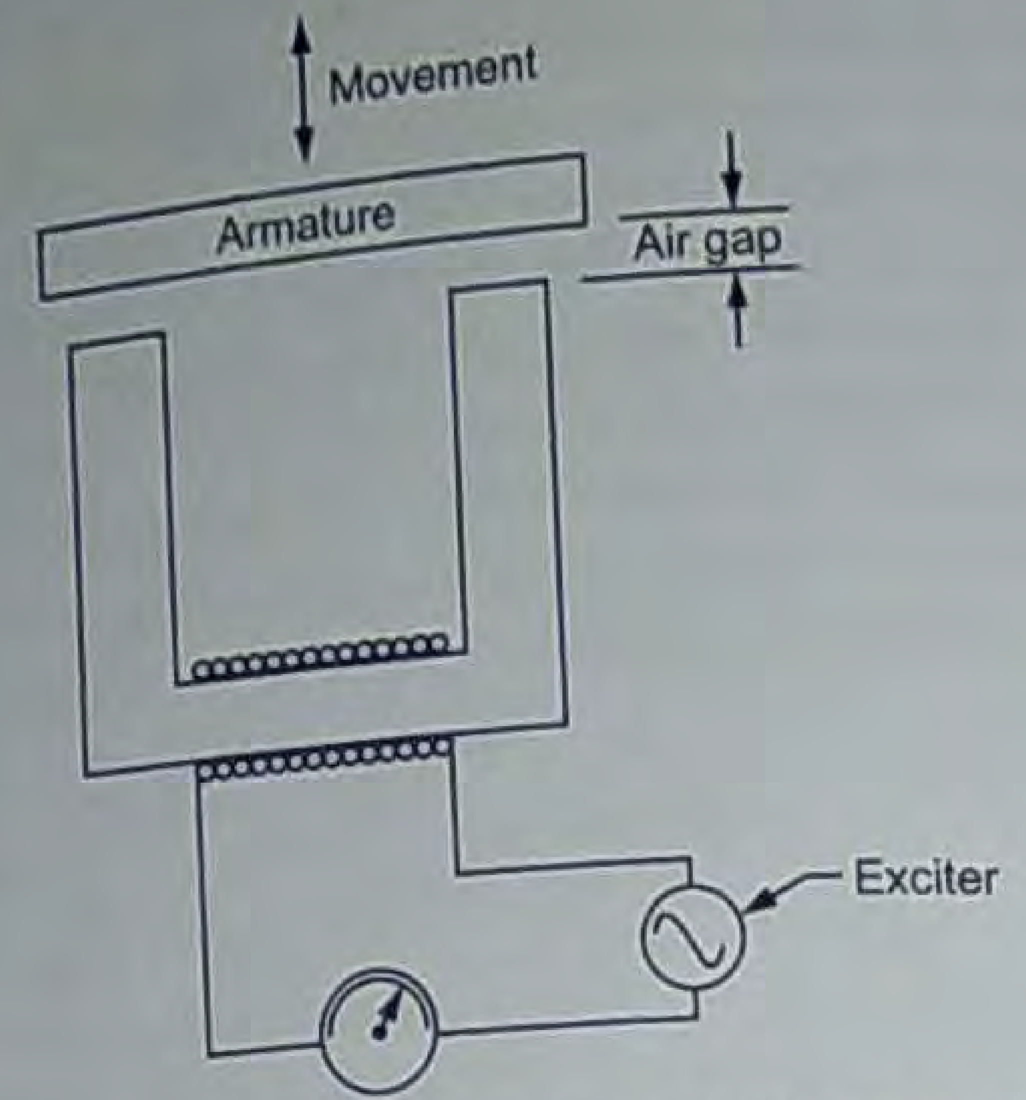


Fig. 9.9. Self inductance variable reluctance transducer

Variable permeance transducer: Figure 9.10 illustrates the variable permeance transducer where the inductance of the coil is changed by varying the amount of core material. The arrangement consists of a coil of many turns of wire wound on a tube of insulating material with a movable core of magnetic material.

As the coil is energized and the core enters the solenoid cell, the inductance of the coil increases in proportion to the amount of metal within the coil. A pickup of this type is used primarily for displacement, strain and force measurement.

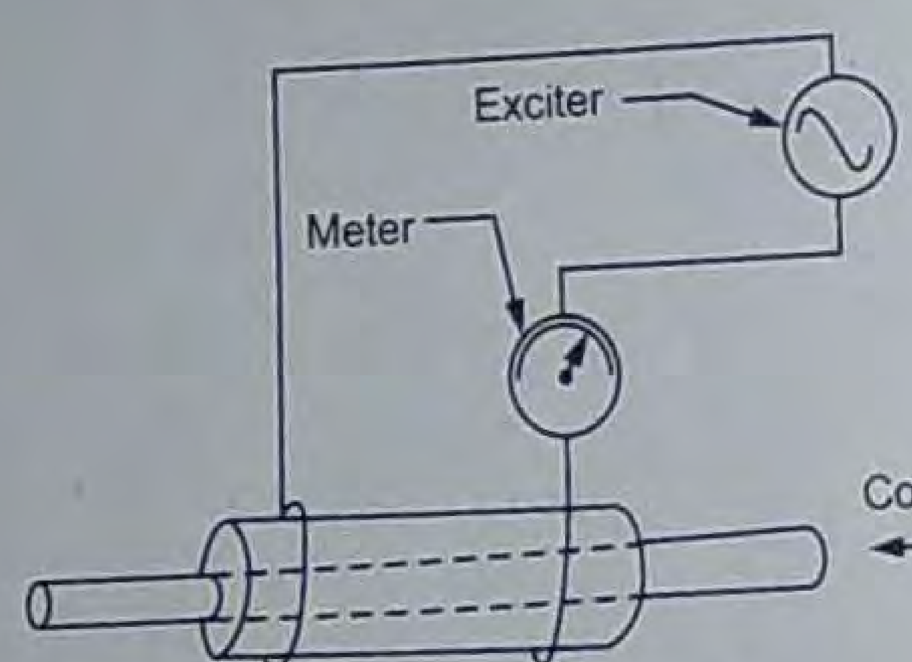


Fig. 9.10. Self-inductance variable permeance transducer

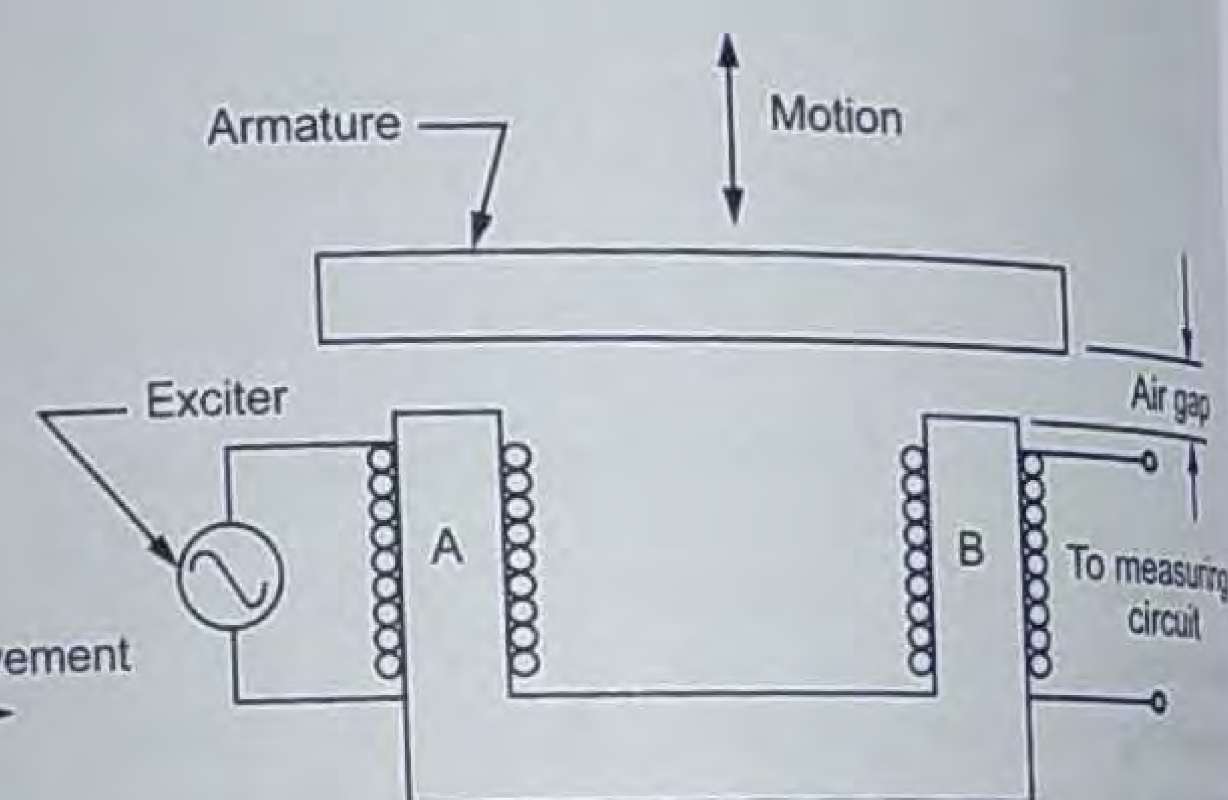


Fig. 9.11. Mutual-inductance arrangement

Figure 9.11 illustrates a form of two-coil mutual inductance transducer. Coil A is the energizing coil and B is the pickup coil. A change in the position of the armature by a mechanical input alters the air gap. This causes a change in the output from coil B which may be used as a measure of the armature displacement, *i.e.*, the mechanical input.

9.12.3. Linear-variable differential transformer (LVDT)

One of the most useful variable inductance transducers is the linear variable differential transformer shown schematically in Fig. 9.12. The device has one primary and two secondary windings with the magnetic core free to move inside the coils. The core is attached to the moving part on which the displacement measurements are to be made. When ac current is supplied to the primary winding, the magnetic flux generated by this coil is disturbed by the armature so that voltages are induced in the secondary coils. The secondary windings are symmetrically placed, are identical and are connected in phase opposition so that emfs induced in them are opposite to each other. The net output from the transformer is then the difference between the voltages of the two secondary windings. The position of the magnetic core determines the flux linkages with each winding. When the core is placed centrally, equal but opposite emfs are induced in the secondary windings and zero output is recorded. This is termed as the balance point or null position.

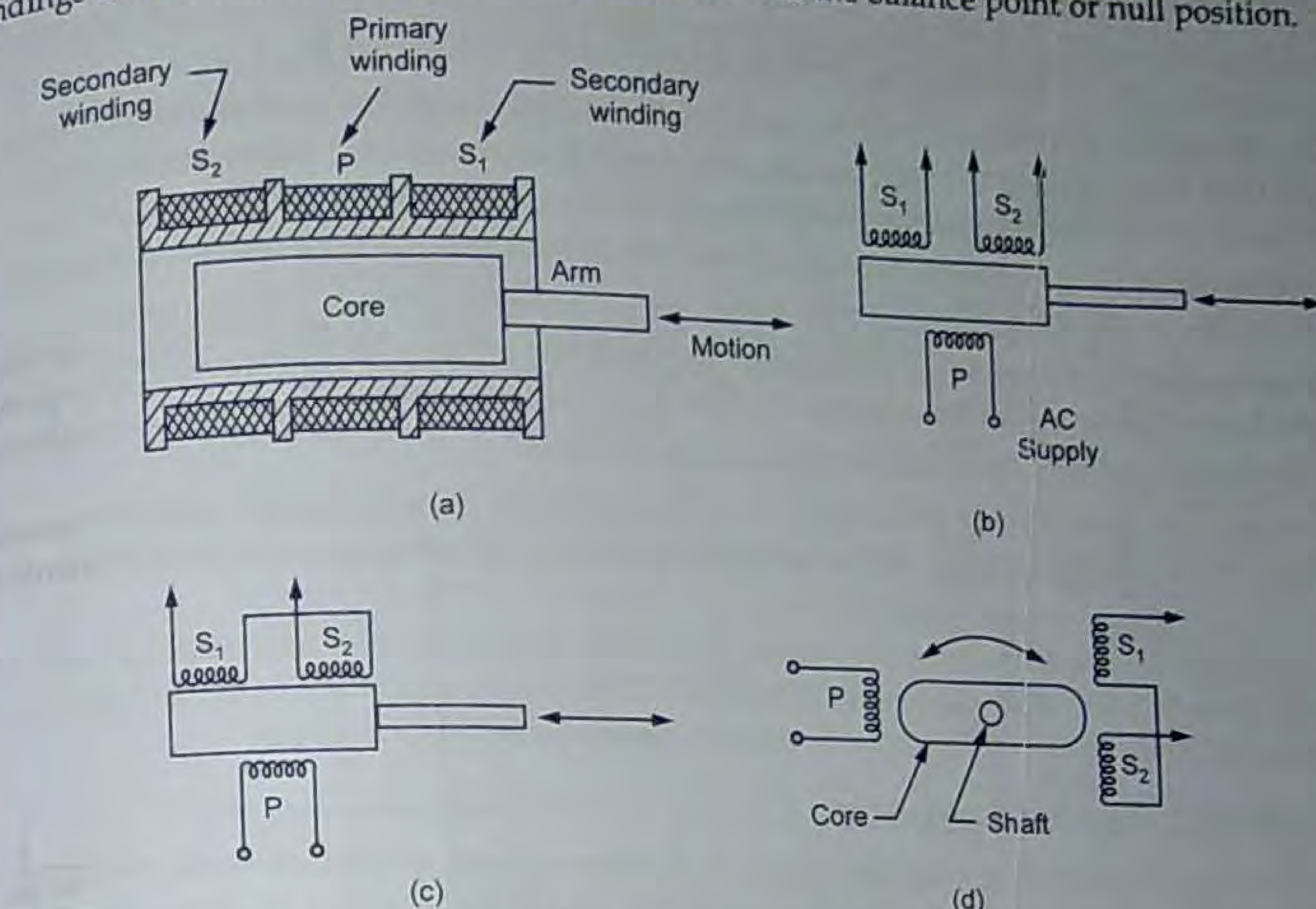


Fig. 9.12. Variable differential transformer

A variation in the position of the core from its null position produces an unbalance in the reactance of secondary windings to the primary windings. The voltage induced in the secondary winding towards which the core is displaced increases. A simultaneous decreased induced voltage results from the secondary coil. Thus, upon displacement of the armature, the result will be a voltage rise in one secondary and a decrease in the other. The asymmetry in the core position thus produces a differential voltage E_0 which varies linearly with change in the core position (Fig. 9.13). Small residual voltages resulting from certain stray magnetic and capacitance effects may, however, not cancel and the output voltage may not necessarily become zero at the null position. Figure 9.13 (*b*) represents an enlarged view of the residual voltage when the core is at the null position.

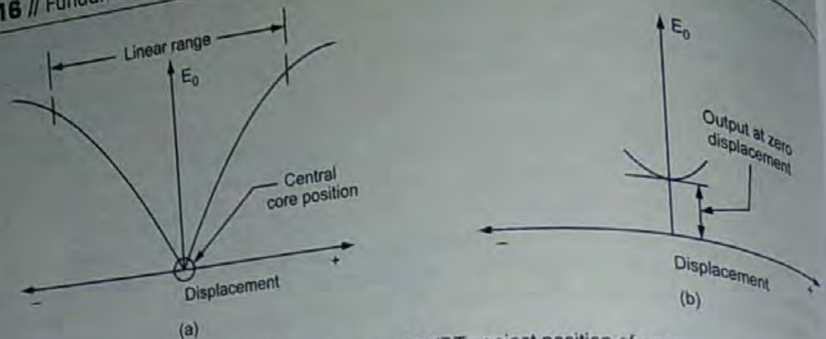


Fig. 9.13. Output voltage of LVDT against position of core

The differential transformers are available in a broad range of sizes and are widely used for displacement measurement in variety of applications. Some important characterstics and features of the LVDT type of displacement sensors are :

- simplicity of design, ease of fabrication and installation, rugged and durable construction
- wide range of displacement; displacement ranges available from 2×10^{-4} m to 0.5 m
- high output, low hysteresis, continuous (infinite) resolution and linear electrical response (linearity better than 0.5%) when actuated by linear mechanical motion
- negligible operating force and no wear of moving parts

The device, however, is not particularly sensitive and must be excited with ac only; excitation frequency 50 Hz to 20 kHz. Input voltage is limited by the current carrying capacity of the primary coil.

Typical measurements are any quantities which can be transduced into displacement, e.g. pressure, acceleration, vibration, force and liquid level. The disadvantage lies in the area of dynamic measurements as its core is of appreciable mass in comparison to strain gauge.

9.13. CAPACITIVE TRANSDUCERS

A capacitor comprises two or more metal plate conductors separated by an insulator. As voltage is applied across the plates, equal and opposite electric charges are generated on the plates. Capacitance is defined as the ratio of the charges to the applied voltage and for a parallel plate capacitor is given by :

$$C = \epsilon_0 \epsilon_r \frac{A}{t} (N - 1) \text{ farads}$$

where A = overlapping or effective area between plates (m^2)

t = distance between plates (m)

N = number of capacitor plates

ϵ_0 = permittivity of free space = 8.854×10^{12} F/m

ϵ_r = relative permittivity (or dielectric constant) of the material between the plates

The value of ϵ_r depends upon the insulator material and for air $\epsilon_r = 1$

For a cylindrical capacitor, the capacitor is

$$C = \epsilon_0 \epsilon_r \frac{2\pi l}{\log_e\left(\frac{r_2}{r_1}\right)} \text{ farads} \quad ...(9.5)$$

where l = length of overlapping part of cylinders (m)

r_1 = radius of inner cylindrical conductor (m)

r_2 = radius of outer cylindrical conductor (m)

A capacitive pick up operates on the principle of a variation in capacitance produced by the physical quantity being measured. The capacitance can be made to vary by changing either the relative permittivity (dielectric constant) ϵ_r, the effective area A, or the distance between the plates t. The mechanical displacement is generally measured by noting the change in capacitance brought about by either change in area or by change in distance between the plates. The change in dielectric is used to measure changes in liquid or gas levels.

Figure 9.14 represents the elementary diagram of the two arrangements of a capacitance transducer where capacitance change occurs because of change in the area of plates. Since capacitance is directly proportional to the effective area of the plates, response of such a system is linear.

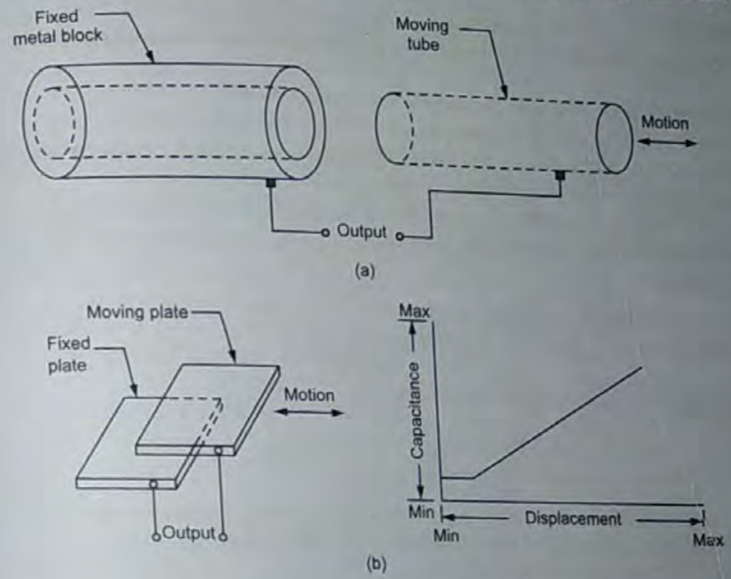


Fig. 9.14. Capacitance transducer: area change

Figure 9.15 represents the basic form of a capacitance transducer utilizing the effect of change of capacitance with changes in distance between the two plates. One is a fixed plate and the displacement to be measured is applied to the other plate which is moving. Since capacitance varies inversely as the distance between the plates, the response of this transducer is not linear.

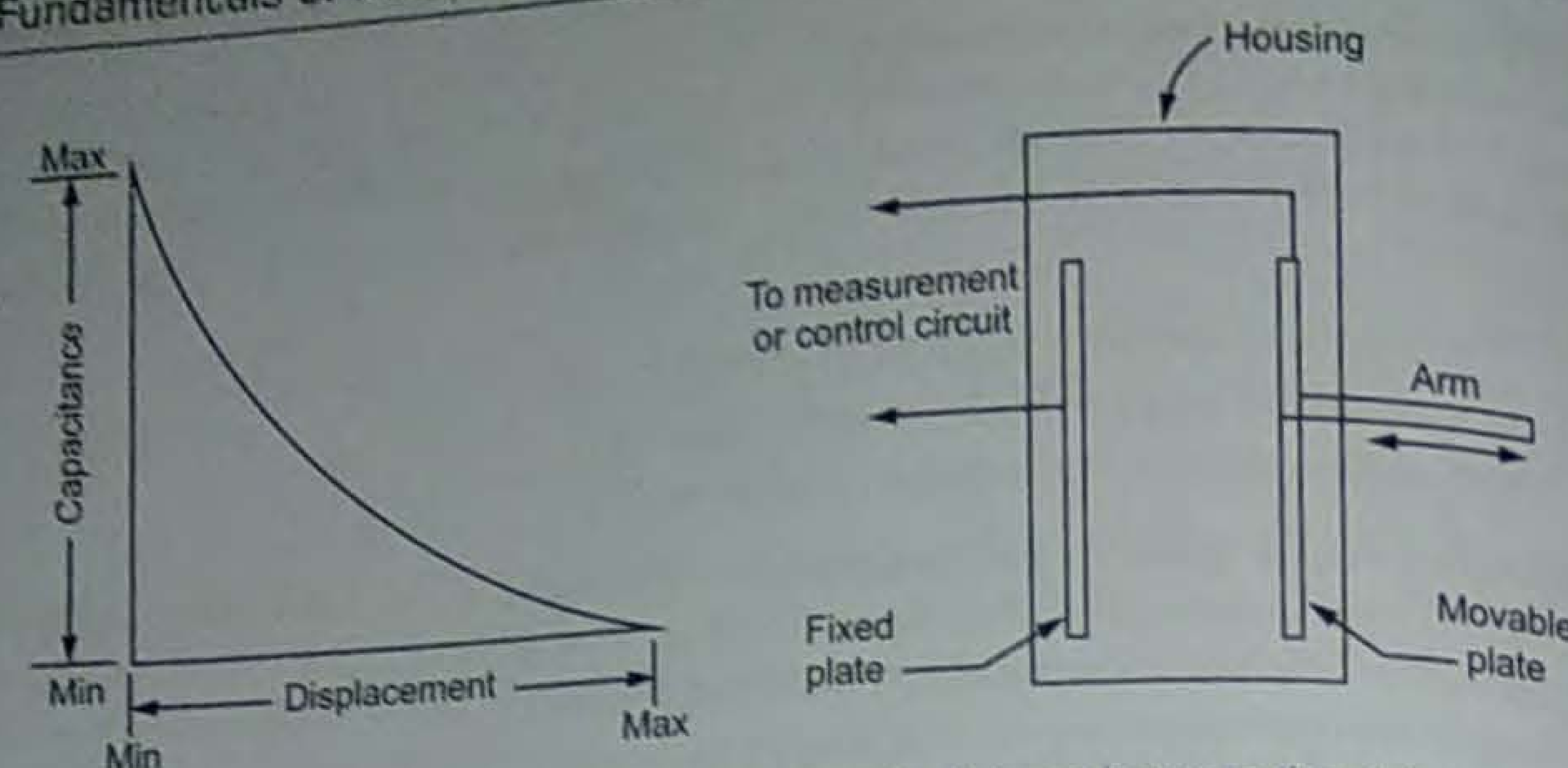


Fig. 9.15. Capacitance transducer: change in distance between the plates

Capacitance transducers can detect displacements as small as 2.5×10^{-6} m and produce a measurable signal. Parallel plate capacitance transducers have the advantages of :

(*i*) easy fabrication (*ii*) excellent high frequency response (*iii*) good linearity output (*iv*) ability to measure static and dynamic quantities, and (*v*) a relatively low initial and maintenance cost.

EXAMPLE 9.1

The 3 cm region between the two plates of a parallel plate capacitor is filled by two dielectric layers :

(*i*) 1 cm thick with dielectric constant 5, and

(*ii*) 2 cm thick with dielectric constant 10,

What would be the relative permittivity (dielectric constant) of a material which gives the same capacitance if it completely fills the region between the plates?

Solution: For a multiple parallel plate capacitor with space between adjacent plates filled with different materials having dielectric constants $\epsilon_{r1}, \epsilon_{r2} \ldots \epsilon_{r3}$ and having respective distances $t_1, t_2, t_3 \ldots$, we have :

$$C = \frac{\epsilon_0 A}{\frac{t_1}{\epsilon_{r1}} + \frac{t_2}{\epsilon_{r2}} + \frac{t_3}{\epsilon_{r3}}}$$

Substituting the values from the given data,

$$C = \frac{\epsilon_0 A}{\frac{0.01}{5} + \frac{0.02}{10}} = \frac{\epsilon_0 A}{0.004} \quad \ldots(i)$$

Let ϵ_r be the dielectric constant of the single medium which completely fills the gap of 3 cm between the two parallel plates of area A and gives the same capacitance. Then

$$C = \epsilon_0 \epsilon_r \frac{A}{t} = \epsilon_0 \epsilon_r \frac{A}{0.03} \quad \ldots(ii)$$

Equating the capacitance values given by expressions (*i*) and (*ii*)

$$\frac{\epsilon_0 A}{0.004} = \epsilon_0 \epsilon_r \frac{A}{0.03}$$

That gives:

$$\epsilon_r = \frac{0.03}{0.004} = 7.5$$

EXAMPLE 9.2

A capacitive transducer using two quartz diaphragms of area 800 mm² and separated by a distance of 4 mm has a capacitance of 350 uF. When a pressure of 1 MN/m² is applied to one of the diaphragms, a deflection of 0,75 mm is produced. Workout the change in the capacitance of the system.

Solution: Before application of pressure : $C_1 = \epsilon_0 \epsilon_r \frac{A}{t_1}$

After application of pressure : $C_2 = \epsilon_0 \epsilon_r \frac{A}{t_2}$

Given : $C_2 = 350\ \mu F$; $t_1 = 4$ mm and $t_2 = 4 - 0.75 = 3.25$ mm

$$\therefore \quad C_2 = 350 \times \frac{4}{3.25} = 430.77\ \mu F$$

$\therefore$ Change in capacitance

$$\Delta C = C_2 - C_1 = 430.77 - 350 = 80.77\ uF$$

9.14. PIEZO-ELECTRIC TRANSDUCERS

Piezo-electricity represents the property of a number of crystalline materials that cause the crystal to develop an electric charge or potential difference when subjected to mechanical forces or stresses along specific planes. Conversely, the crystal would undergo change in thickness (and thus produce mechanical forces) when charged electrically by a potential difference applied to its proper axis. Elements exhibiting piezo-electric qualities are sometimes known as electro restrictive elements.

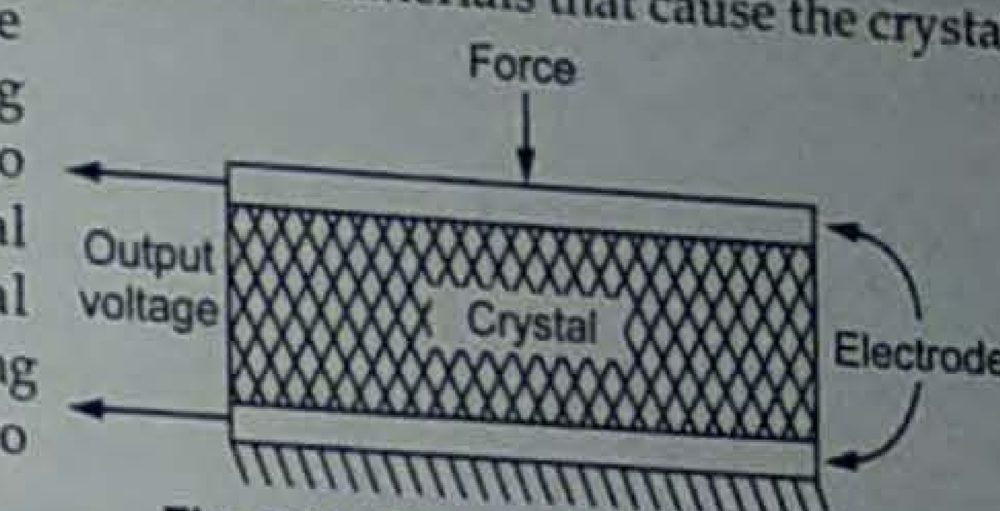


Fig. 9.16. Piezo-electric transducer

A typical mode of operation of a piezo-electric device for measuring varying force applied in a simple plate is shown in Fig. 9.16. Metal electrodes are attached to the selected faces of a crystal in order to detect the electrical charge developed. The magnitude and polarity in the induced charge on the crystal surface is proportional to the magnitude and direction of the applied force and is given by :

$$Q = KF \quad \ldots(9.6)$$

where Q is the charge in coulomb, F is the impressed force in newtons and K is the crystal sensitivity in C/N; it is constant for particular crystals and the manner in which they are out. The relationship between the force F and the change δt in the crystal thickness t is given by the stress-strain relationship.

$$\text{Young's modulus} = \frac{\text{stress}}{\text{strain}}; = Y = \frac{F/A}{\delta t / t} \quad \ldots(9.7)$$

$$F = AY\frac{\delta t}{t} \quad \ldots(9.8)$$

The charge at electrode gives rise to voltage, such that

$$V_0 = \frac{Q}{C}$$

where C is the capacitance between electrodes. Furthermore

$$C = \epsilon_0 \epsilon_r \frac{A}{t} \text{ farads}$$

Combining the above equations, we obtain :

$$V_0 = \frac{K}{\epsilon_0 \epsilon_r} t \frac{F}{A} = g\,t\,P \qquad ...(9.9)$$

where g is the crystal voltage sensitivity in Vm/N and P is the applied pressure in N/m^2.

There are two main groups of piezo-electric crystals: (i) natural crystals such as quartz and tourmaline, (ii) synthetic crystals such as Rochelle salts, lithium sulphate (LS), ammonia dihydrogen phosphate (ADP), ethylene diamine tartrate (EOT), dipotassium tartrate (DKT) etc. The advantages vary from crytal to crystal and one is chosen on the basis of a particular application. Tourmaline is the least active chemically while tartaric acid is most active electrically.

- *Natural crystals* have a very low electrical leakage when used with very high input impedance amplifiers and permit the measurement of a slowly varying parameter. They are, therefore, capable of withstanding higher temperatures; operating at low frequencies and sustaining shocks.
- *Synthetic crystals* exhibit a much high output for an applied stress and are about thousand times more sensitive than natural crystals. However, they are usually unable, to withstand high mechanical strain without fracture. Further, the synthetic crystals have an accelerated rate of deterioration over the natural ones.

The major advantages of piezoelectric transducers are:

- high frequency response
- high output
- rugged construction
- negligible phase shift and
- small size. The small size of the transducer is especially useful for accelerometers where added mass will mechanically load a system.

The piezo-electric unit, has the disadvantage in that it cannot measure static conditions and that its output is affected by changes in temperature. When an instrument is electrically connected to measure the electrical charge generated, it is slowly dissipated through the internal resistance of the crystal , *i.e.*, the charge decreases over a period of time. Because of this characteristic, the piezo-electric transducers have a poor steady state response and as such are used mainly for measuring dynamic quantities (parameters varying rapidly with time). Special amplifiers with very high input impedance (10^{12} to 10^{14} ohms) can however, be used to measure the static or quasi-static quantities, but that makes the measuring system increasingly expensive.

Applications: Piezo-electric transducers are most often used for accelerometers, pressure cells and force cells in that order.

EXAMPLE 9.3

A quartz crystal having a thickness of 2 mm and a voltage sensitivity of 0.05 Volt-m/ newton is subjected to a pressure of 15×10^5 N/m^2. Calculate the voltage developed by the piezo-electric pick up and the charge sensitivity of the crystals. Take the permitivity of the quartz as 40.5×10^{-12} F/m.

Solution : The output voltage for a piezo-electric pick up is given by

$$= 0.05 \times 0.002 \times (15 \times 10^5) = \mathbf{150\ V}$$

(*b*) Charge sensitivity $= \epsilon_0 \epsilon_r g = \epsilon_g$

$$= (40.5 \times 10^{-12}) \times 0.05$$

$$= 2.025 \times 10^{-12}\ \text{C/N} = 2.025\ \text{pc/N}$$

9.15. PHOTO-ELECTRIC TRANSDUCERS

These tranducers operate on the principle that when light strikes special combination of materials, a voltage may be generated, a resistance change may take place, or electrons may flow. Photo-electric cells are used for a wide variety of purposes in control engineering for precision measuring devices, in exposure meters used in photography. They are also used in solar batteries as sources of electrical power for rockets and satellites used in space research. Photo-electric transducers offer the advantage that they do not involve any contact being made with the system being measured ; just interruption of a beam of light. Further, the light does not have to be visible; they can be selected to operate with infrared radiation Photo-electric transducers can be grouped into : photo-emissive (photo tube), photo-conductive and photo-voltaic cells.

9.15.1. Photo-emissive cell

These transducers (Fig. 9.17) operate on the photo-emissive effect, *i.e.*, when certain types of materials are exposed to light, electrons are emitted and a current flow is produced.

light information ⟶ current information

The light sensitive photo-cathode may consist of a very thin filmof cesium deposited by vaporization onto an oxidized silver base. Light strikes the cathode, causing the emission of electrons which are attracted towards the anode. This phenomenon produces flow of electric current in the external circuit; the current being a function of radiant energy striking the cathode.

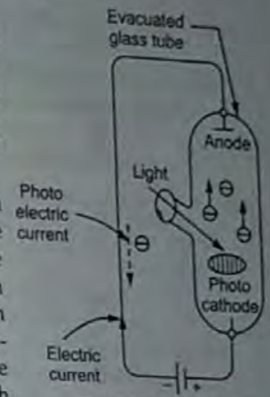


Fig. 9.17. Photo tube

There exist three separate types of photo-emissive cells; the high vacuum single cathode, the gas filled and the multiplier tubes. The high vacuum and the gas filled tubes are both diodes where the cathode and anode are enclosed in a glass or quartz envelope which is either evacuated or filled with an inert gas. The difference lies in the extent of the vacuum and the kind of inert gas. The photo-multiplier tubes use the principle of secondary emission. The device consists of a series of reflecting electrodes, called dynodes, which amplify the original output current. The dynodes are so arranged that the electrons making a dynode produce further electron emission from the dynode. The number of emitted electrons can be increased and high gains made possible by photo-multipliers.

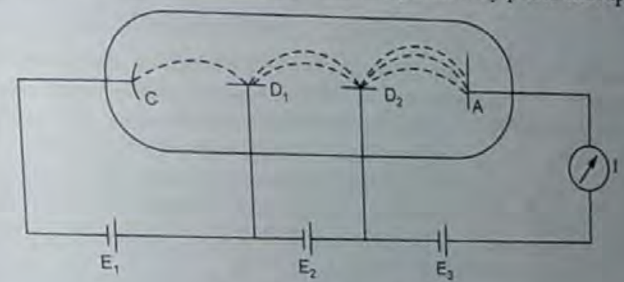


Fig. 9.18. Photo-multiplier tube

With reference to Fig. 9.18, voltage E_1 accelerates the electrons emitted by cathode C and these are focussed onto the dynode D_1. Each incident electron causes emission of secondary electrons which subsequently get focussed upon dynode D_3. Finally these are attracted by the anode A leading to generation of current I.

9.15.2. Photo-conductive Cell

These are the variable resistance transducers. They operate on the principle of photo conductive effect, i.e., some special type of semi-conductor materials change their resistance when exposed to light.

light information ⟶ resistance information

Figure 9.19 shows schematically the construction and electrical circuit of a photo-conductive cell. The sensitive material usually employed is cadmium sulphide, cadmium selenide, germanium, etc., in the form of thin coating between the two electrodes on a glass plate. Further, the cells are used in the circuit as a variable resistance and are put in series with an ammeter and a voltage source. When the light strikes the semi-conductor material, these is a decrease in the cell resistance thereby producing an increase in the current indicated by the ammeter.

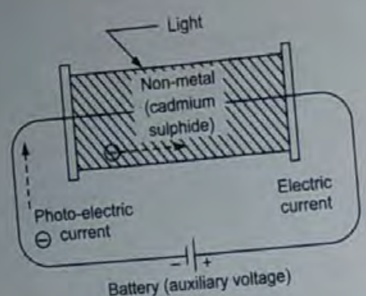


Fig. 9.19. Photo-conductive cell

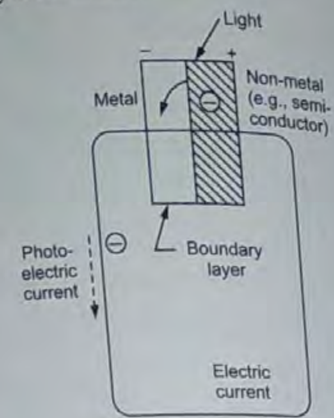


Fig. 9.20. Photo-voltaic cell

9.15.3. Photo-voltaic cell

These transducers operate on the photo-voltaic effect, i.e., when light strikes a junction of certain dissimilar metals, a potential difference is built up

light information ⟶ emf information

The cell consists of a metal base plate, a non-metal semi-conductor and a thin transparent metallic layer (Fig. 9.20). Typical examples of the layers are the copper oxide on copper and iron oxide on iron combination. The transparent layer may be in the form of a sprayed conducting lacquer. Light strikes the coating and generates an electric potential. The output is, however, low and is non-linear function of the light intensity. In contrast to photo-tube and photo-conductive cells, the photo-voltaic unit is self-generated and requires no voltage source to operate it. Further, it need not be operated in vacuum or gas rilled envelope. The most common application of photo-voltaic cell is in light exposure meter in photographic work.

9.16. HALL EFFECT

The Hall effect relates to the generation of transverse voltage difference on a conductor which carries current and is subjected to magnetic field in perpendicular direction. The current may be due to the movement of holes or that of face electrons.

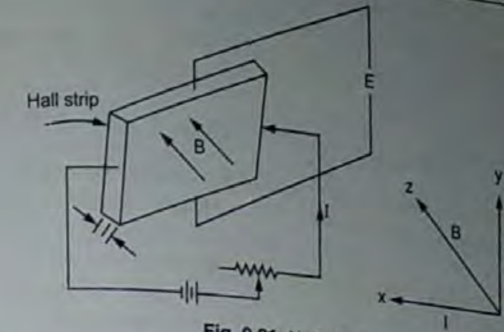


Fig. 9.21. Hall effect

Refer Fig. 9.21 which shows the schematic of a circuit which produces the Hall effect. Here

(i) the Hall strip carries a current/ in the x-direction and is subjected to magnetic field B in the z-direction.

(ii) the thickness f of the strip is very small as compared to its length and width.

(iii) the voltage E is setup in the transverse or y-direction. This voltage is directly proportional to the current I, field strength B and inversely proportional to thickness t of the strip. That is

$$E = K\frac{BI}{t}$$

The proportionality constant K is called the Hall effect coefficient. Taking the current in ampere, flux density in W_b/m^2 and the thickness of strip in meter, the units of K work out as $\frac{Vm^3}{AW_b}$

The notable aspects of transducers operating on Hall effect are:

(i) The Hall effect is present in metals and semi-conductors in varying amounts depending upon the densities or mobiles of carriers. However, the Hall effect is more pronounced in semi-conductors than in metals,

(ii) The magnitude of current flow in the circuit is limited by heat dissipation and permissible temperature rise.

(iii) The Hall effect transducers are of non-contact type, and have small size and high resolution.

The Hall effect transducers are used :

(a) to determine whether a semi-conductor is of N-type or P-type.

(b) to measure either the current or the strength of magnetic field.

(c) to measure the displacement where it is possible to change the magnetic field strength by variation in the geometry of the magnetic structure.

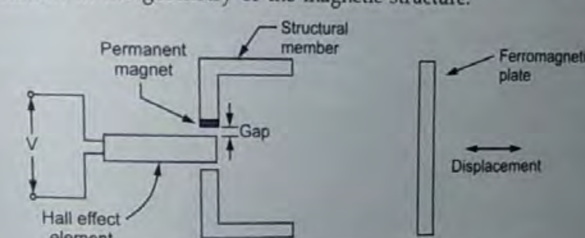


Fig. 9.22. Hall effect displacement transducer

Figure 9.22 shows the arrangement of Hall effect transducer as used for the measurement of linear displacement. This proximity pick up requires a ferrous target whose approach changes the reluctance of an internal magnetic circuit. The Hall effect element is located in the gap adjacent to the permanent magnet. When a plate of iron or other ferromagnetic material is moved with respect to the structure, the magnetic field in the gap due to the permanent magnet changes. That produces the output voltage which is a measure of the displacement of the ferromagnetic plate with respect to the structure.

This arrangement has been successfully employed for measuring displacement as small as 0.025 mm.

REVIEW QUESTIONS

A. Conceptual and conventional questions :

1. What is mechatronics? List the main technical areas under its domain.
2. Give a brief account of the different stages in the evolution of the discipline of mechatronics.
3. (*a*) How does a mechatronics system operate?
   (*b*) Give a few examples of mechatronics systems.
4. Mention a few industrial applications of mechatronics.
5. "Mechatronics is a multi-disciplinary subject." Comment on the validity of this statement.
6. Define and explain the terms autotronics, bionics, and avionics.
7. Mention a few domains where the mechatronics-based design concept is considered fundamental to engineers.
8. Differentiate between a sensor and a transducer.
9. Distinguish between:
   (*i*) active and passive transducers,
   (*ii*) input and output transducers.
   Illustrate your answer with suitable examples.
10. What is meant by transduction? List a few effects to which the principle of transduction can be attributed.
11. List the advantages and disadvantage of mechantronics systems.
12. Draw the schematic arrangement of the key elements of a typical mechatronics system.
13. What are transducers and how are they classified? Explain their importance in an instrumentation process. Give some examples of mechanical transducers where there is a transduction from (*i*) force to displacement (*ii*) velocity to pressure (*iii*) temperature to displacement (*iv*) fluid pressure to displacement.
14. In modern measurement systems, there is more reliance on electrical/electronic techniques of measurement. List some advantages of electrical transducers over mechanical transducers.
    Suggest a suitable transducer to convert each of the following variables into electrical signals :
    (*i*) pressure (*ii*) force
    (*iii*) acceleration (*iv*) angular speed of a shaft, and
    (*v*) liquid level.
    Indicate in each case the measurements involved.
15. (*a*) Distinguish between:
    (*i*) active and passive transducers and
    (*ii*) input and output transduceer. Illustrate your answer with suitable examples.
    (*b*) What information is needed to describe a transducer for a particular measurement?
    (*c*) Explain the major considerations which govern the selection of an instrument transducer.
16. Explain the use of wire wound potentiometers for the measurement of linear and rotary motions. Point out the advantages and limitations of such transducers.

17. (*a*) Explain the various physical principles involved in the operation of various categories of inductive transducers.
    (*b*) Give the essential features of inductive and capacitive transducers when used for the measurement of displacement.
18. (*a*) Describe the principle of operation of linear variable differential transformer. Why it is necessary to connect the secondaries in a differential mode? Identify the input and output of the system and sketch the typical input-output graph.
    (*b*) Explain the use of a linear variable differential transformer LVDT for the measurement of pressure differential across an obstruction meter placed in fluid flow through a pipe line.
19. (*a*) Describe the principle of operation of a piezo-electric transducer. Identify the input and output of the system.
    (*b*) Mention some natural and synthetic materials that exhibit piezo-electric effect.
20. Explain the difference in the principle of operation of a photo-emissive cell, a photo-conductive cell and a photo-voltaic cell. Give the applications of each of these cells.
21. Mention the different parameters of a parallel plate capacitor that may vary to bring about a change in the capacitance of the device. Point out the physical variable that is usually measured by employing a particular variation.

B. Fill in the blanks with appropriate word/words

(*i*) A transducer is a device that converts the measurand into an ________.
(*ii*) The energy conversion process that takes place in a transducer is referred to as ________.
(*iii*) A spring is a mechanical transducer converting force to ________.
(*iv*) Passive transducers rely on an ________ for their operation.
(*v*) The capacitance of a parallel plate capacitor can be varied by changing either the ________ or the ________ or the ________.
(*vi*) Piezo-electric transducers are made from natural crystals such as ________ or synthetic crystals such as ________.
(*vii*) Photo-electric transducers produce electrical signals in response to changes in the ________.

Answers:

(*i*) optical, mechanical or electrical signal; (*ii*) transduction; (*iii*) displacement; (*iv*) external excitation voltage; (*v*) relative permittivity, overlapping (effective area), distance between the plates; (*vi*) quartz and Rochelle salt, lithium sulphate; (*vii*) intensity of incident light.

C. Indicate true or false in respect of the following statement. If false, into the correct statement:

(*i*) High value of pot resistance leads to high sensitivity.
(*ii*) Capacitive transducers used for the measurement of liquid level operate or the principle of capacitance changes with change of distance between plates.
(*iii*) Linear variable differential transformer (LVDT) is an active transducer working on the principle of variable resistance.
(*iv*) When a static force is applied to a piezo-electric transducer, there occur oscillations in the generated electric change.
(*v*) Piezo-electric transducers produce an emf when external magnetic field is applied across them.
(*vi*) The abbreviation LVDT stands for linear voltage differential transformer.
(*vii*) Piezo-electric crystals are used for the measurement of static as well as dynamic changes.
(*viii*) Hall effect transducers are highly sensitive to temperature variations.
(*ix*) Photo-conductive transducer is a light controlled variable resistor.
(*x*) The photo-voltaic cell converts the light information to resistance change of the electric circuit.

Answers:

(i) True,
(ii) False ; change of dielectric strength
(iii) False ; principle of mutual inductances
(iv) True ; the generated electric charge decreases over a period of time.
(v) False ; when external mechanical force is applied
(vi) False ; linear variable differential transformer
(vii) False ; the piezo-electric transducers have a poor steady state response and as such are used mainly for measuring dynamic quantities
(viii) True
(ix) True
(x) False ; in a photovoltaic cell, the light strikes the junction of certain dissimilar metals and a potential difference is built up in the electric circuit.

D. Multiple choice questions :

1. Printout the device/devices that refer to self-generating transducers
   (a) resistive
   (b) capacitive
   (c) piezo-electric
   (d) thermo-electric
2. The active transducer which can be used for linear or angular velocity measurements depends upon
   (a) generation of force by allowing current to flow through the conductor
   (b) variation in mutual inductance of the coils
   (c) movement of conductor through a magnetic field
   (d) variation in a capacitance of a capacitor
3. The LVDT is an inductive transducer which functions due to
   (a) change in the air gap
   (b) change in the amount of core material
   (c) mutual inductance
   (d) variation in the position of the core
4. Specify the photo-electric device which converts the light information to resistance information
   (a) photo-emissive cell
   (b) photo-conductive cell
   (c) photo-voltaic cell
5. When certain natural or artificial crystals are deformed, an electric charge is generated. This characteristic is referred to as
   (a) thermo-electric effect
   (b) capacitive effect
   (c) electro-magnetic effect
   (d) piezo-electric effect
6. Specify the variable in a capacitive transducer that does not necessitate a physical contact between the transducer and the measurand
   (a) effective or overlapping area of plates
   (b) distance between plates
   (c) dielectric constant of the insulator

7. Specify the transducer which is generally used for dynamic rather than for static measurements.
   (a) capacitive
   (b) resistive
   (c) piezo-electric
   (d) inductive transducer
8. A potentiometer produces large variation in resistance by
   (a) moving a conductor through a magnetic field
   (b) moving a slider across a resistor
   (c) stretching a metal wire
   (d) thermally expanding a conductor
9. A piezo-electric transducer has all the following advantages except
   (a) small size and high output
   (b) negligible phase shift
   (c) good frequency response
   (d) capability to measure both static and dynamic quantities.
10. All of the following statements with reference to LVDT, are correct except one. Identify that statement. LVDT
    (a) works on the principle of mutual induction
    (b) is a self-generating type of transducer
    (c) cannot be used for the measurement of static variables
    (d) stands for linear variable differential transformer
11. The abbreviation LVDT stands for
    (a) least varying differential transducer
    (b) low varying digital transformer
    (c) linear variable differential transformer
    (d) linear voltage differential transformer

Answers:

1. (a) and (d)	2. (c)	3. (d)	4. (b)	5. (d)	6. (c)	7. (c)
8. (b)	9. (d)	10. (b)	11. (c)			

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