Course Name:
IoT & Applications (18EI2T09)

Module-3:

Class-3:

Humidity, Pressure, Liquid Level, Vibration; Photo-electric Sensors, Conductive type sensor; Signal conditioning & interfacing

1. Humidity Sensing Devices

Humidity and moisture measurements are necessary in weather monitoring or heating-ventilation-airconditioning (HVAC) and process industries where moisture present in gases or liquids or solids constitutes an important parameter for monitoring. Methods employed in these kinds of measurement vary widely depending upon the requirement of accuracy of measurement. We will consider here only a few of such methods.

Relative humidity. Relative humidity (RH) is defined as:

$$\mathrm{RH} = \left.\frac{\text{Mass of water vapour actually present in } V \text{ volume of air}}{\text{Mass of water vapour necessary to saturate } V \text{ volume of air}}\right|_{T_0\,^\circ\mathrm{C}}$$

$$= \left.\frac{\text{Pressure of water vapour actually present in } V \text{ volume of air}}{\text{Pressure of water vapour necessary to saturate } V \text{ volume of air}}\right|_{T_0\,^\circ\mathrm{C}}$$

$$= \frac{\text{Saturation vapour pressure of air at the dew-point}}{\text{Saturation vapour pressure of air at } T_0\,^\circ\mathrm{C}}$$

Hygrometers, which are used generally to measure humidity, can broadly be divided into two categories:

1. RH hygrometers
2. Dew-point hygrometers

RH is measured as percentage

Types of Hygrometers

1.1 Impedance Hygrometer

1.2 Piezoelectric Hygrometer

1.3 Capacitive Hygrometer

1.4 Nuclear Magnetic Resonance Hygrometer

1.5 Time Domain Reflectometry Hygrometer

1.6 Wet and Dry Bulb Hygrometer

1.7 Hair Hygrometer

1.8 Dunmore Cell

1.9 Pope Cell

1.10 Solution Conductivity Cell

Capacitive Hygrometer

We have seen in Section 6.2 that the capacitance of a parallel plate capacitor changes with the change in the intervening dielectric material. This property is utilised in constructing capacitive hygrometers which can be used to measure RH of air or moisture content in a sample gas.

Two variants are used—one uses alumina (aluminium oxide) desiccant as thick dielectric between electrodes while the other uses a thin layer of the same desiccant.

In the former application [Fig. 13.8(a)], two concentric metal cylinders form capacitor plates and the annulus between the electrodes is filled with alumina. Two spring-loaded metal discs are used to support the alumina and insulated electrode cylinders.

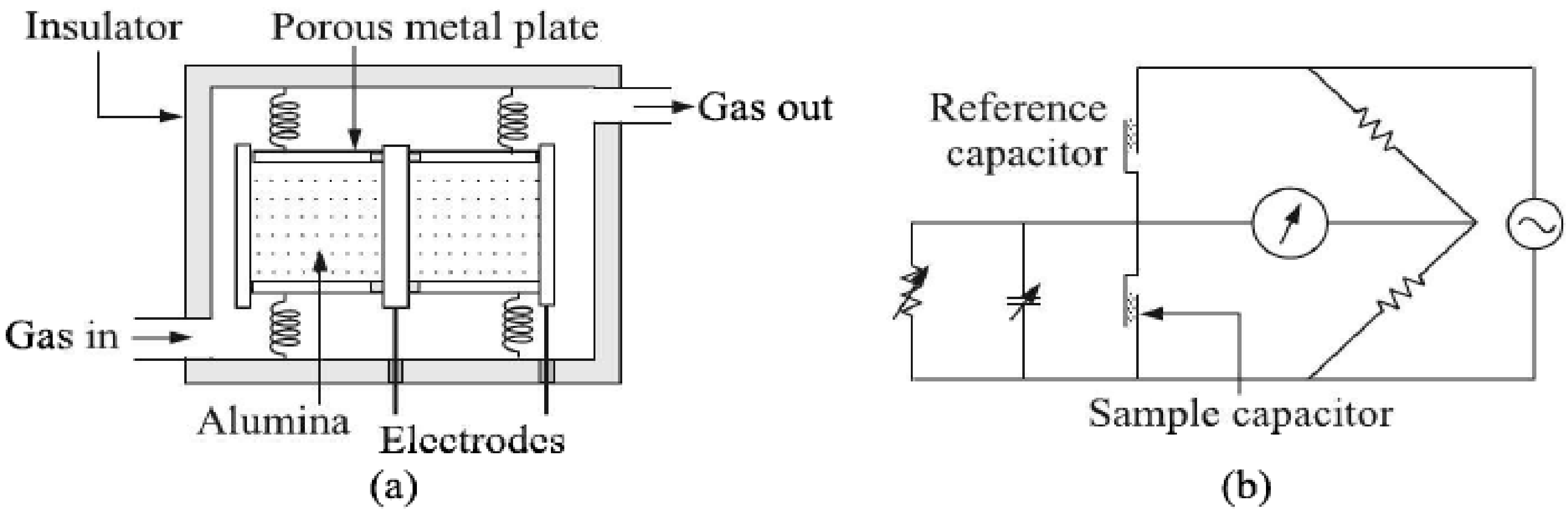


Fig. 13.8 (a) Thick-layer desiccant capacitive transducer (sectional view), and (b) measurement bridge.

Two identical capacitors are used—the sample gas or liquid is passed through one and the other is used as reference. The two capacitors form two arms of a bridge [Fig. 13.8(b)] which is excited by a 15 kHz sinusoidal voltage.

Before the sample gas is passed, the bridge may be balanced with the help of a variable resistor and capacitor. Once the sample gas is passed through the sample capacitor, the bridge is thrown out of balance, the offset voltage being a measure of the moisture content of the sample.

The thin-layer-desiccant-type capacitive hygrometer is constructed by depositing a layer of alumina on ultra-high purity aluminium substrate and vacuum coating the alumina with a thin film of gold (Fig. 13.9).

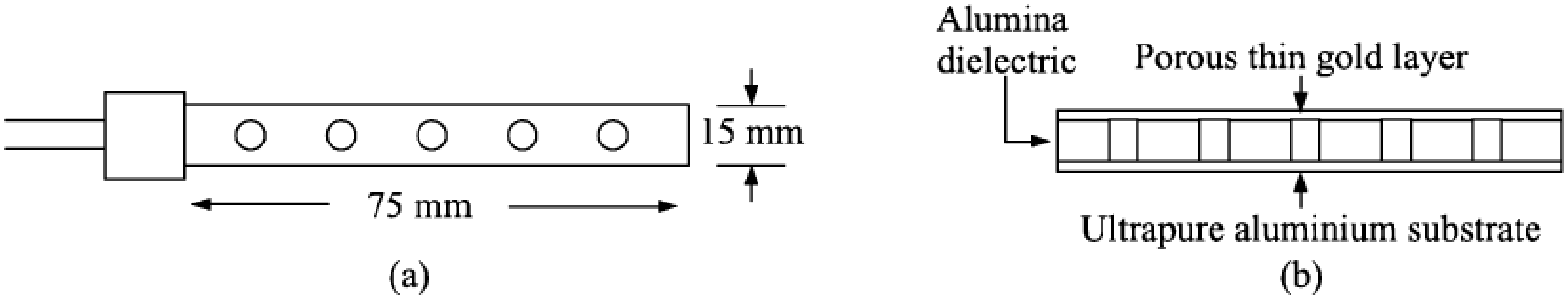


Fig. 13.9 Thin desiccant layer capacitive transducer: (a) probe with holes, and (b) sectional view of the probe.

Table 13.1 Advantages and disadvantages of a capacitive hygrometer

Advantages	*Disadvantages*
1. Small size	1. Calibration curve nonlinear
2. Probe-type packaging	2. Needs periodic re-calibration to compensate for ageing and contamination
3. Wide measurement range	3. Low measurement accuracy
4. Suitable for measuring moisture content in many gases including hydrocarbons	4. Each sensor needs to be calibrated individually
5. Being a capacitor, it can be easily incorporated in microprocessor-based electronic instrumentation	5. Cannot be used to measure moisture content in polar materials such as alcohols, because then it starts conducting at its exciting frequency of 15 kHz

Impedance Hygrometer

The construction of impedance hygrometer is very similar to that of the thin-layer capacitive hygrometer. In this case, ac impedance, rather than capacitance of the cell is measured by a suitable bridge. While the capacitance vs. RH curve is nonlinear, the inductance vs. RH curve is linear over a good range (Fig. 13.10).

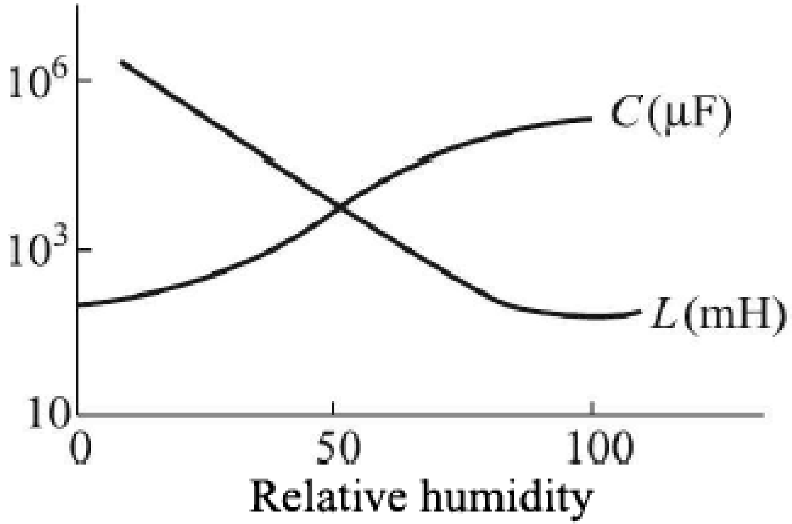


Fig. 13.10 Characteristic curves of capacitive and inductive hygrometers.

As in the case of thin-layer capacitive transducer, the impedance hygrometer can be used to measure moisture content in most of the gases and liquids except polar ones like alcohol.

Piezoelectric Hygrometer

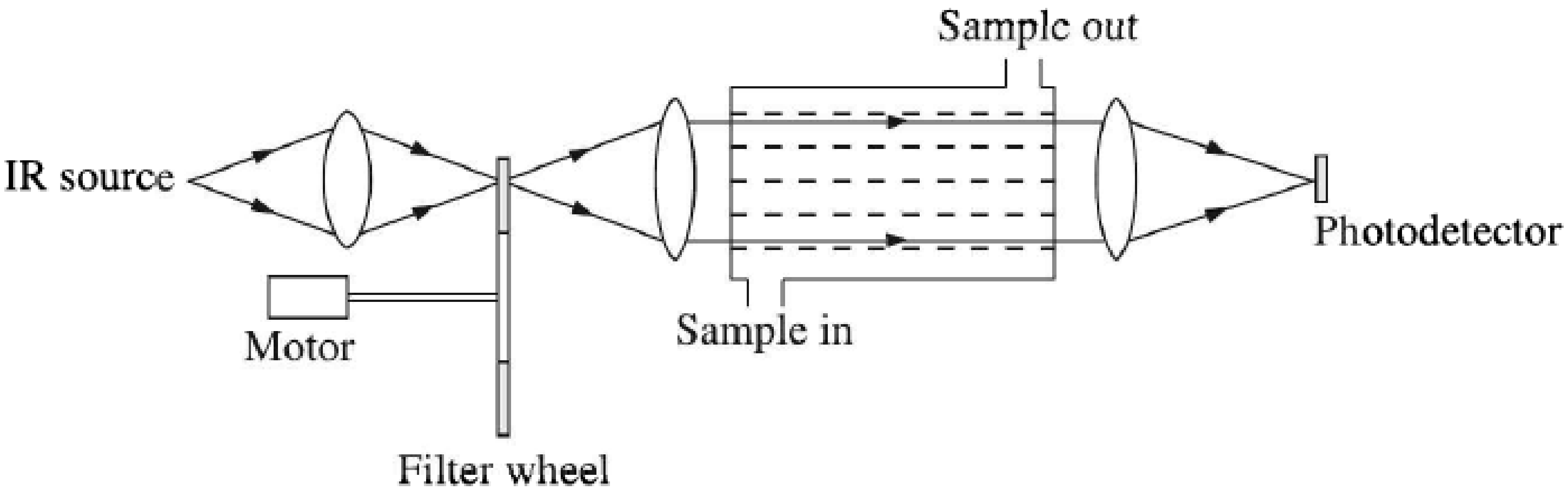
A piezoelectric crystal, when excited by an ac signal, starts vibrating at a frequency which is the natural frequency of vibration of the crystal. This natural frequency of vibration is related to the mass of the crystal. Thus, if a piezoelectric crystal, can be somehow loaded with the moisture or water vapour of the atmosphere, its frequency of vibration will change. This property is utilised in the construction of piezoelectric hygrometer.

A suitable piezoelectric crystal, such as quartz, is coated with a hygroscopic material and exposed to the sample gas. The hygroscopic material absorbs the sample moisture, increases the mass of the vibrating piezoelectric crystal and thereby decreases its frequency of vibration. This decrease in the frequency of vibration is a measure of the moisture content of the sample.

To increase the accuracy of measurement, two identical piezoelectric transducers may be used—one exposed to the moist sample and the other to dry gas—at the same flow rate. A little later, the gas flow between transducers may be interchanged by energising and de-energising the solenoid valves that are suitably placed in the flow path of gases. This ensures a better accuracy and maintenance of transducers.

Infrared Absorption Hygrometer

Near infrared radiations (NIR) of wavelengths 1.45 μm, 1.93 μm and 2.95 μm are strongly absorbed by water. So, an infrared radiation of either of these wavelengths may be sent through the sample gas [Fig. 13.11(a)] or reflected from the solid sample [Fig. 13.11(b)] and the resultant attenuation may be measured to determine the moisture content of the sample.



(a)

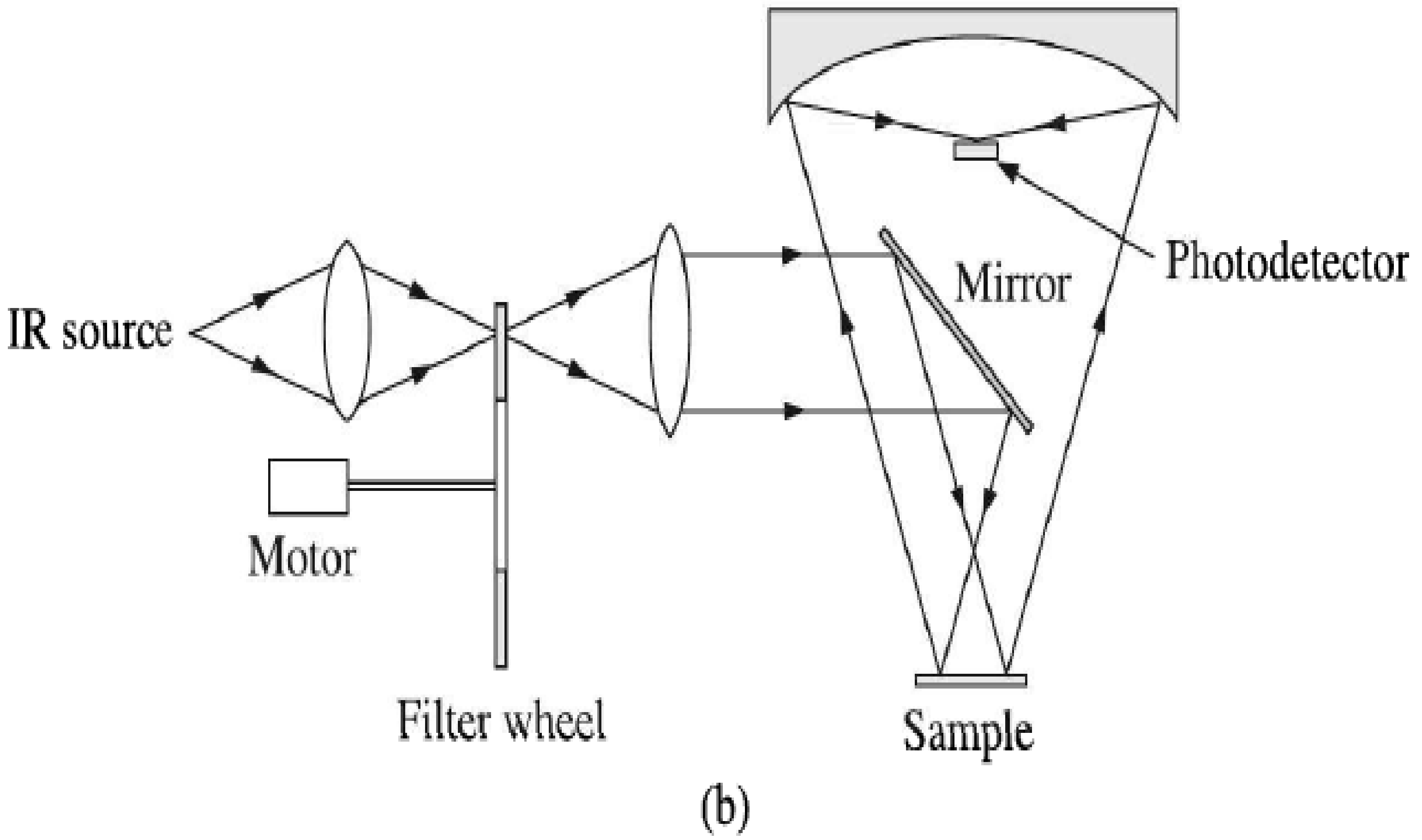


Fig. 13.11 Infrared absorption hygrometer: (a) for gas or liquid sample, and (b) for solid sample.

2. Pressure Sensing Devices

Definitions

While specifying pressures, three terms are used, namely

1. Absolute pressure
2. Gauge pressure
3. Vacuum pressure

Absolute Pressure

Absolute pressure is the pressure that includes the atmospheric pressure which is acting on all substances unless they are placed in evacuated enclosures.

Gauge pressure is the most often used method of measuring pneumatic **pressure**. It is the relative **pressure** of the compressed air within a system. **Gauge pressure** can be either positive or negative, depending upon whether its level is above or below the atmospheric **pressure** reference.

Vacuum pressure is measured relative to ambient atmospheric **pressure**. It is referred to as pounds per square inch (**vacuum**).

Potentiometer type

The potentiometric secondary transducer consists of a precision potentiometer, the wiper arm of which is mechanically linked to a force-summing device like the bellows, Bourdon tube or diaphragm. We have shown such an arrangement in Fig. 8.15 using bellows as the force-summing device. The movement of the bellows causes the wiper arm to move across the potentiometer. The potentiometer, in turn, converts the mechanically detected deflection of the force-summing device into a resistance measurement using a Wheatstone bridge circuit.

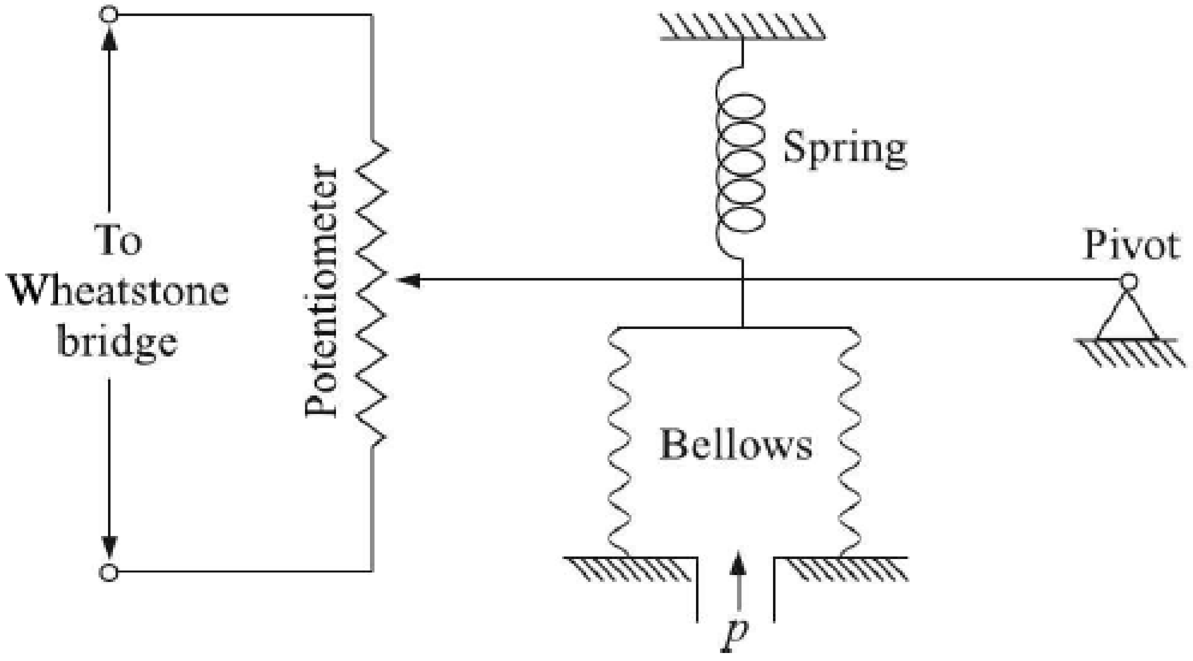


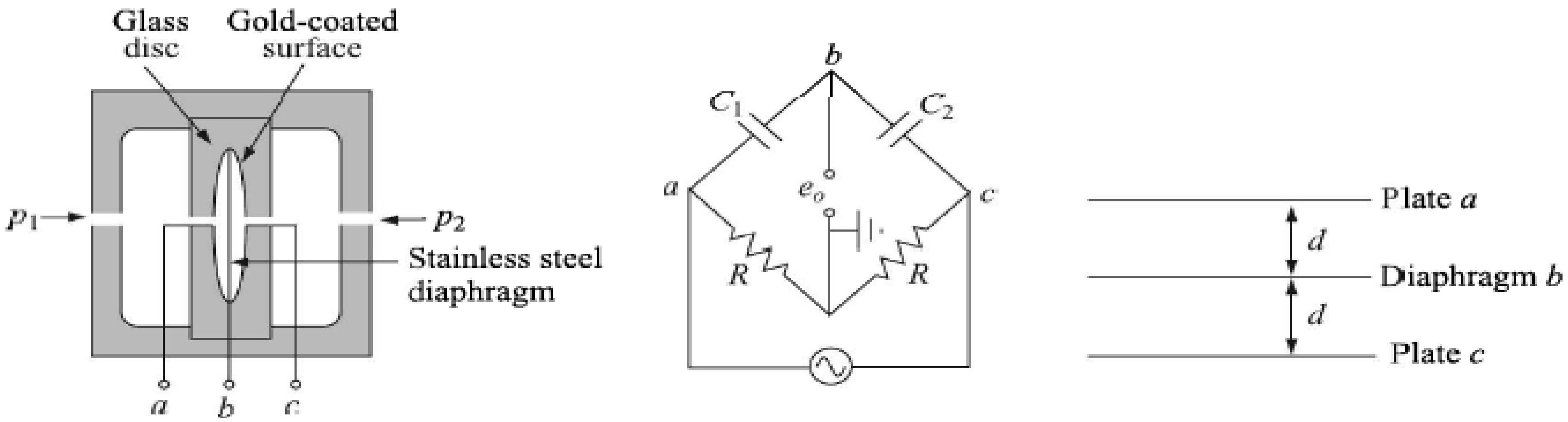
Fig. 8.15 Potentiometer type secondary transducer using a bellows force-summing device.

Apart from the threshold problem of the mechanical nature of the linkage between the wiper arm and the force-summing device, temperature effects introduce errors into this type of measurement. However, potentiometric transducers can be made extremely small and installed in a small space like that offered by the housing of a 10 cm dial pressure gauge. They provide a strong output signal that can be read without further amplification. Above all, they are inexpensive.

Pressure gauges having potentiometric secondary transducers can measure pressures between 5 and 10,000 psig (35 kPa and 70 MPa) with an accuracy lying between 0.5% and 1% of the FSD.

Capacitive Transducers

A special construction [Fig. 8.18(a)] is used for capacitive pressure transducers. Spheroidal depressions of a depth of about 0.025 mm are ground into two glass discs which are held face to face with a taut thin stainless steel diaphragm in between. The depressions are coated with gold to form two fixed plates of the differential capacitor and the diaphragm forms the movable plate. So, this is essentially a differential arrangement of capacitors as shown in Fig. 8.18(c). We have already seen in Section 6.2 at page 189 that such an arrangement produces an output voltage that is proportional to the displacement of the movable plate. Though the plates are not strictly parallel here, it can be shown that the linear relationship remains valid for small displacements of the diaphragm.



(a) (b) (c)

Fig. 8.18 Capacitive pressure transducer: (a) construction, (b) bridge arrangement, and (c) capacitor configuration.

Photoelectric Transducers

The arrangement is shown in Fig. 8.19(a). With the application of pressure, the diaphragm is depressed with a consequent reduction in the width of the aperture and, therefore, a reduction in the intensity of light falling on the photon detector. This causes a variation in the output voltage owing to the variation of current in the circuit.

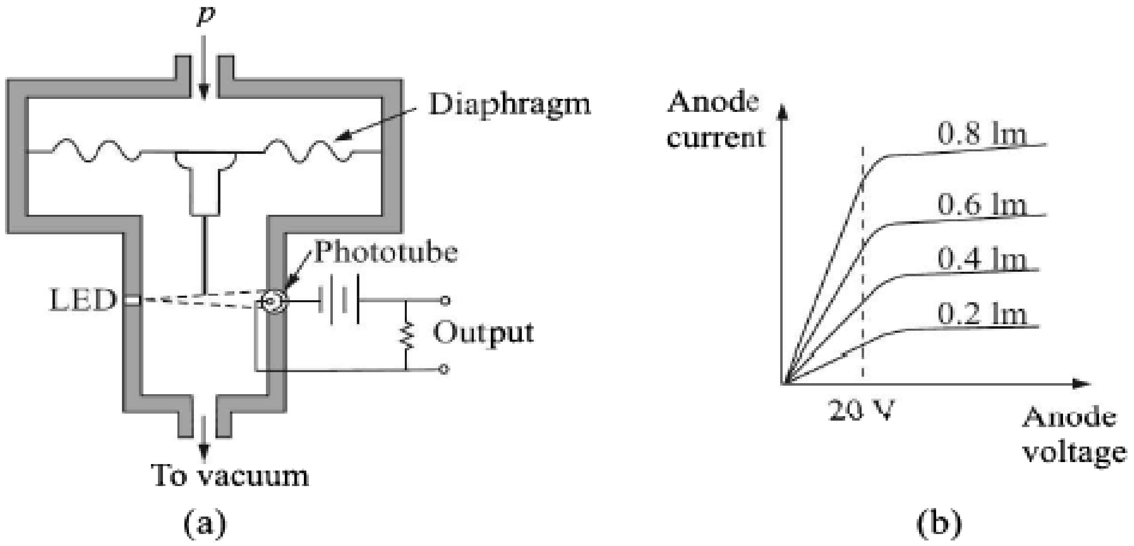


Fig. 8.19 (a) Photoelectric secondary transducer, and (b) phototube characteristics.

A typical phototube[9] characteristics plot is shown in Fig. 8.19(b) which indicates that if the anode voltage is higher than 20 V, the anode current is linearly proportional to the intensity of illumination.

Obviously, such arrangements need a highly stabilised power supply to the lamp and since the photocurrent is of the order of μA, a stable amplifier is necessary for the signal. The other disadvantage is that a rather appreciable displacement of the diaphragm is necessary to produce a detectable current.

Hall Effect Transducer

The Hall effect can be used as a secondary transducer to measure pressure by coupling it with a force-summing device like bellows.

A magnetic assembly is attached to a bellows assembly (Fig. 8.21). As the bellows expands and contracts with the application of pressure, the magnetic assembly is moved. If the sensor is placed in close proximity to the assembly, an output voltage proportional to pressure input can be achieved.

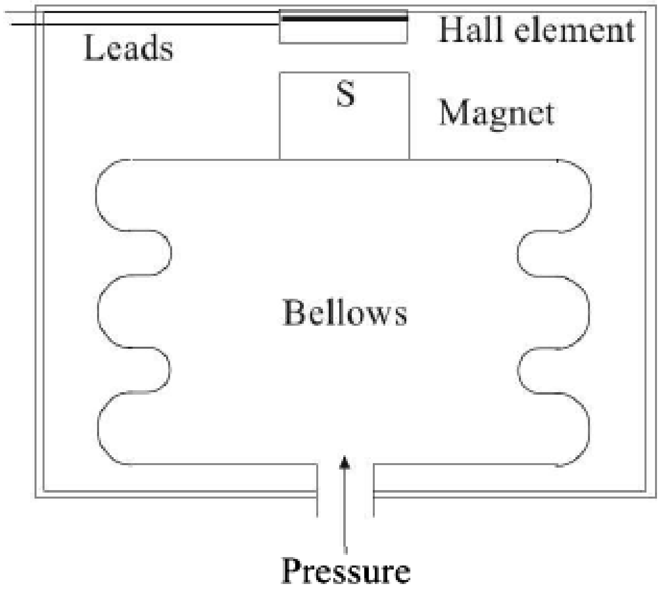
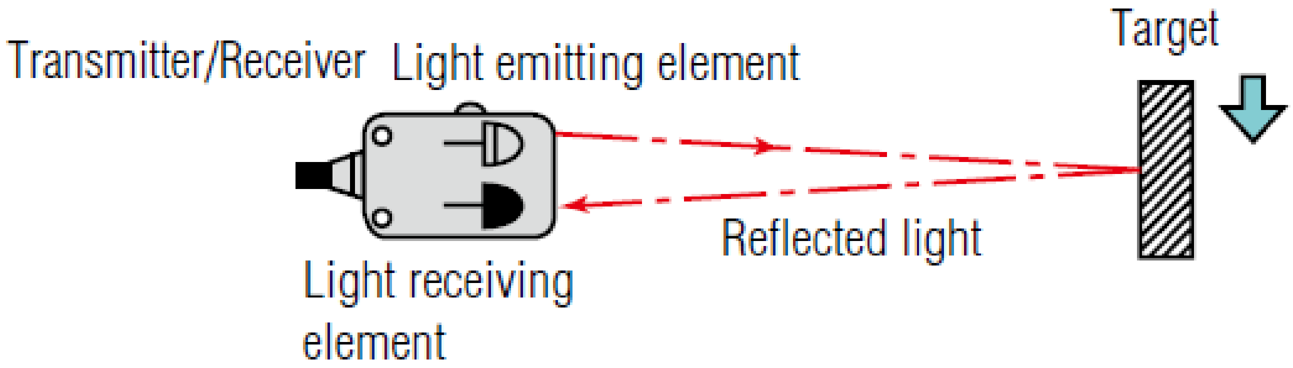


Fig. 8.21 Use of Hall effect transducer in pressure sensing.

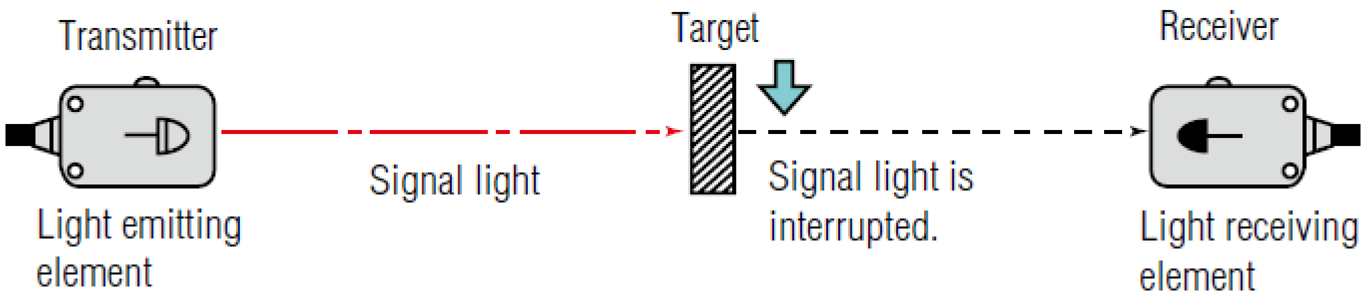
3. Photo-electric Sensors

A photoelectric sensor emits a light beam (visible or infrared) from its light-emitting element. A reflective-type photoelectric sensor is used to detect the light beam reflected from the target. A thrubeam type sensor is used to measure the change in light quantity caused by the target crossing the optical axis.

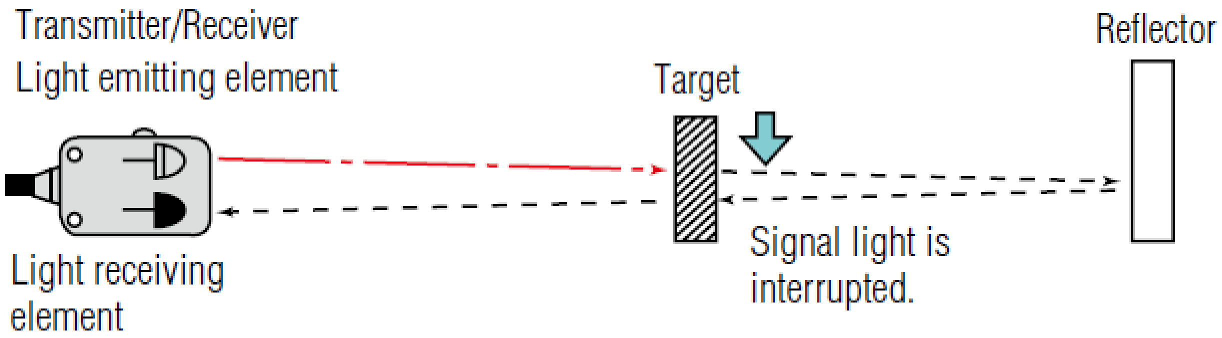
Reflective model



Thrubeam model



Retroreflective model



4. Vibration Sensing Devices

The working principle of vibration sensor is a sensor which operates based on different optical otherwise mechanical principles for detecting observed system vibrations. The sensitivity of these sensors normally ranges from 10 mV/g to 100 mV/g, and there are lower and higher sensitivities are also accessible. The sensitivity of the sensor can be selected based on the application. So it is essential to know the levels of vibration amplitude range to which the sensor will be exposed throughout measurements.

Vibration Sensor Types: The types of vibration sensors include the following.

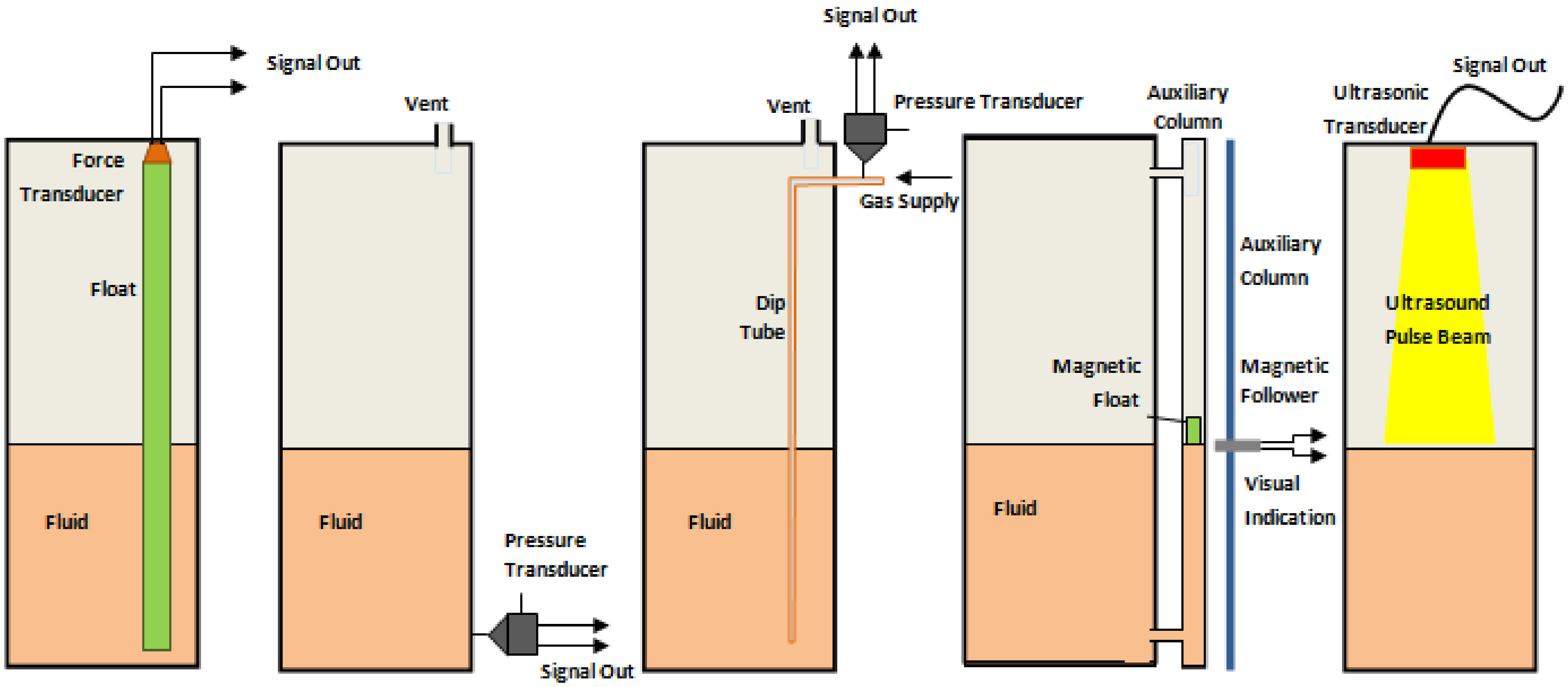
- **Accelerometer Sensor: This sensor is used for general purposes like vibration and shock**
- **Strain Gauge Sensor: These sensors are used for curved surfaces. When mass and size are significant, then strain data is required.**
- **Velocity Sensor: These sensors are used for high-temperature applications like above 700 °F.**
- **Gyroscope Sensor: These sensors are used where orientation information is necessary.**
- **Pressure or Microphone Sensor: These sensors are used for health monitoring, as well as to determine vibration frequency.**
- **Laser Displacement Sensor: This sensor is used to calculate the displacement straight without changing the product or structure.**
- **Capacitive Displacement or Eddy Current: This sensor is used to calculate the displacement straight without changing the product or structure.**
- **Vibration Meter: This type of sensor is used in the diagnosis of equipment.**
- **Vibration Data Logger: Save time & cost, testing in the field (portability important)**

Applications

- The applications of vibration sensors include different industries for measuring the vibration. The exclusive industrial characteristics will decide sensor characteristics.
- For instance, this sensor is used in industries like wind power and mining for slow rotation of turbines with 1 Hz or less frequency response.
- In disparity, the industries like gas and oil need high frequency ranges from 10 Hz to 10 kHz uses these sensors to handle with the speed rotation of gears and turbines.
- The industries which use the vibration sensor mainly include food & beverage, mining, metalworking, gas & oil, paper, wind power, power generation, etc.

5. Liquid Level Sensors

- The different kinds of liquid level sensors include
  - Optical
  - Capacitive
  - Conductive
  - Diaphragm
  - Float



6. Conductivity Sensors

- Conductivity is the measure of a solution's ability to pass or carry an electric current. The term Conductivity is derived from Ohm's Law, E=I•R; where Voltage (E) is the product of Current (I) and Resistance (R); Resistance is determined by Voltage/Current. When a voltage is connected across a conductor, a current will flow, which is dependent on the resistance of the conductor. Conductivity is simply defined as the **reciprocal of the Resistance** of a solution between two electrodes.

Signal Conditioning

- Most analog signals require some form of preparation before they can be digitized. Signal conditioning is the manipulation of a signal in a way that prepares it for the next stage of processing. Many applications involve environmental or structural measurement, such as temperature and vibration, from sensors. These sensors, in turn, require signal conditioning before a data acquisition device can effectively and accurately measure the signal.
- For example, thermocouple signals have very small voltage levels that must be amplified before they can be digitized. Other sensors, such as resistance temperature detectors (RTDs), thermistors, strain gages, and accelerometers, require excitation to operate. All of these preparation technologies are forms of signal conditioning.

- Most signals require some form of manipulation that prepares them for the next stage of processing. This is a crucial process for making analogue signals like temperature and vibration intelligible to data acquisition systems or control equipment. If an incoming signal is not optimised for the in-line digitizer via signal conditioning, it can result in measurement inaccuracies and suboptimal levels of performance.
- Signal conditioning needs vary in capabilities depending on your sensor. Different measurement types and sensor architectures have different signal conditioning requirements. For example, low-voltage analogue signals will typically need to be *amplified* and subsequently *filtered* to reduce background noise before digitization. Other sensors may need to be *excited* by an external voltage to measure mechanical changes as a function of varying electrical resistivity.