1 Pressure and Level measurement

$$\text{Pressure} = \frac{\text{force}}{\text{area}} \tag{1}$$

1.1 Pressure measurement

Pressure is the force exerted by gases and liquids due to their weight. Pressure units are a measure of the force acting over a specified area. It is most commonly expressed in pounds per square inch (psi), pascals (Pa or (N/m^2)) in metric units or bar. Bar is equivalent to100000 N/m^2, which were the *SI* units for measurement [1].

Terms applied to pressure measurements:

Total vacuum which is zero pressure or lack of pressure, as would be experienced in outer space.

Vacuum is a pressure measurement made between total vacuum and normal atmospheric pressure.

Atmospheric pressure is the pressure on the earth's surface due to the weight of the gases in the earth's atmosphere and is normally expressed at sea level as 101.36 kPa. The pressure decreases above sea level and at an elevation drops.

Absolute pressure is the pressure measured with respect to a vacuum.

Gauge pressure is the pressure measured with respect to atmospheric pressure.

Differential pressure is the pressure measured with respect to another pressure and is expressed as the difference between the two values.

Process pressure measuring devices may be divided into three groups [2]:

1. Based on the measurement of the height of a liquid column,
2. Based on the measurement of the distortion of an elastic pressure chamber,
3. Electrical sensing devices.

Manometers

Most forms of liquid-column pressure-measuring devices are commonly called manometers.

$$p = \frac{F}{S} = \frac{mg}{S} = \frac{\rho V g}{S} = \rho g h \tag{2}$$

Liquid-column pressure-measuring devices are those in which the pressure being measured is balanced against the pressure exerted by a column of liquid. If the density of the liquid is known, the height of the liquid column is a measure of the pressure. When the height of the liquid is observed visually, the liquid columns are contained in glass or other transparent tubes. The height

of the liquid column may be measured in length units or calibrated in pressure units. Depending on the pressure range, water and mercury are the liquids most frequently used. Because the density of the liquid used varies with temperature, the temperature must be taken into account for accurate pressure measurements.

Because of their inherent accuracy, manometers are used for the direct measurement of pressure and vacuum. Nowadays manometers largely serve as standards for calibrating other pressure-measuring instruments.

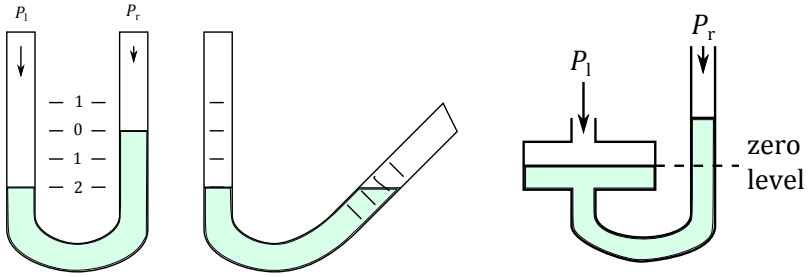

Figure 1: U-tube, inclined-tube and well-type

Advantages
- ✓ Simple operation and construction
- ✓ Inexpensive

Disadvantages
- ✓ Low pressure range (water)
- ✓ Higher pressure range requires mercury
- ✓ Readings are localized
- ✓ Size

Mechanical Pressure

Measured pressure deforms some elastic material (usually metallic) within its elastic limit, the magnitude of the deformation being approximately proportional to the applied pressure.

Many pressure sensors depend on the deflection of a *diaphragm* for measurement.

Advantages
- ✓ Provides isolation from process fluid
- ✓ Good for low pressure
- ✓ Inexpensive
- ✓ Wide range
- ✓ Reliable and proven
- ✓ Used to measure gauge, atmospheric and differential pressure

The diaphragm is a flexible disc, which can be either flat or with concentric corrugations and is made from sheet metal with high tolerance dimensions [3].

The Bourdon tube works on a simple principle that a bent tube will change its shape when exposed to variations of internal and external pressure. As pressure is applied internally, the tube straightens and returns to its original form when the pressure is released.

Advantages
- ✓ Wide operating range
- ✓ Inexpensive
- ✓ Fast response
- ✓ Good sensitivity
- ✓ Direct pressure measurement

Disadvantages
- ✓ Localized measurement only
- ✓ Nonlinear transducer, linearized by gear mechanism
- ✓ Hysteresis on cycling
- ✓ Sensitive to temperature variations
- ✓ Limited life when subject to shock and vibration

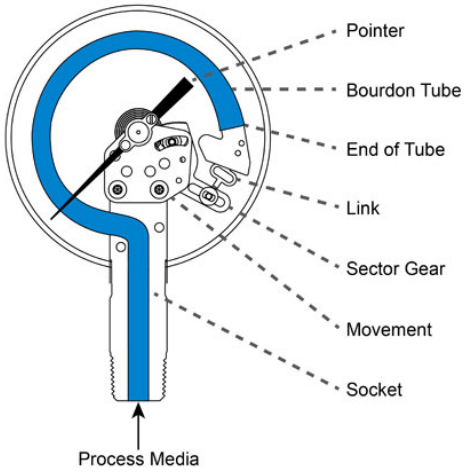

Figure 2: Bourdon tube [4]

Bellow is an expandable element made up of a series of folds or corrugations called convolutions.

The tip of the tube moves with the internal pressure change and is easily converted with a pointer onto a scale. A connector link is used to transfer the tip movement to the geared movement sector. The pointer is rotated through a toothed pinion by the geared sector.

When pressure is applied to the bellows it elongates by stretching the convolutions and not the end diaphragms. Bellows devices can be used for absolute and differential pressure measurements.

Advantages
✓ Simple construction
✓ Easily maintained
✓ Inexpensive

Disadvantages
✓ Hysteresis on cycling
✓ Sensitive to temperature variations
✓ Poor over-range protection

1.2 Electrical Methods

Several different technologies exist for the conversion of fluid pressure into an electrical signal response. These technologies form the basis of electronic pressure transmitters: devices designed to measure fluid pressure and transmit that information via electrical signals such as the $4-20\ mA$ analog standard, or in digital form such as HART or FOUNDATION Fieldbus [5].

Strain Gauge

When a wire or other electrical conductor is stretched elastically, its length is increased and its diameter is decreased. Both of these dimensional changes result in an increase in the electrical resistance of the conductor. Devices utilizing resistance wire grids for measuring small distortions in elastically stressed materials are commonly called strain gauges. Pressure-measuring elements utilizing strain gauges are available in a wide variety of forms. They usually consist of one of the elastic elements described earlier to which one or more strain gauges have been attached to measure the deformation.

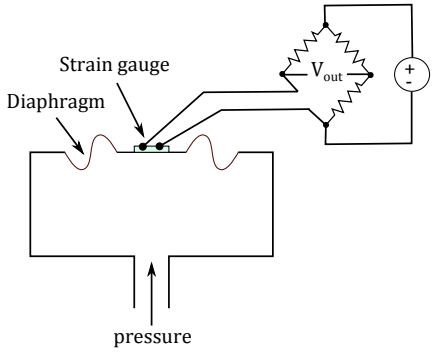

Figure 3: Strain Gauge

There are two basic strain gauge forms: bonded and unbonded. Bonded strain gauges are bonded directly to the surface of the elastic element whose strain is to be measured. The unbonded strain gauge transducer consists of a fixed frame and an armature that moves with respect to the frame in response to the measured pressure. The strain gauge wire filaments are stretched between the armature and frame. As strain gauges are temperature sensitive, temperature compensation is

required. The strain gauges are usually connected electrically in a Wheatstone bridge configuration [2].

Advantages	**Disadvantages**
✓ Wide range (7.5 $kPa - 1400$ Mpa)	✓ Unstable due to bonding material
✓ Accuracy up to 0.1%	✓ Temperature sensitive
✓ Small	✓ Thermoelastic strain causes hysteresis
✓ Stable and fast	✓ Require regulated power supplies

Piezoelectric Transducers

Certain crystals produce a potential difference between their surfaces when stressed in appropriate directions. Piezoelectric pressure transducers generate a potential difference proportional to a pressure-generated stress. Because of the extremely high electrical impedance of piezoelectric crystals at low frequency, these transducers are usually not suitable for measurement of static process pressures [2].

Advantages	**Disadvantages**
✓ Accuracy 0.075%	✓ Dynamic sensing only
✓ Pressure measurement up to 70 MPa	✓ Temperature sensitive
✓ Small size	✓ Require special cabling and signal conditioning
✓ Robust and fast	
✓ Self-generated signal	

2 Level Measurement

The measurement of level can be defined as the determination of the location of the interface between two fluids, separable by gravity, with respect to a fixed reference plane. The most common level measurement is that of the interface between a liquid and a gas. Other level measurements frequently encountered are the interface between two liquids, between a granular or fluidized solid and a gas, and between a liquid and its vapor.

A commonly used level devices are: float-actuated, displacer, and head devices, etc.

2.1 Direct level sensing

Level gauges are perhaps the simplest indicating instrument for liquid level in a vessel. Sightglass is to liquid level measurement as manometers are to pressure measurement: a very simple and effective technology for direct visual indication of process level. In its simplest form, a level gauge is nothing more than a clear tube through which process liquid may be seen.

Advantages
✓ Very simple
✓ Inexpensive

Disadvantages
✓ Not suitable for automated control
✓ Maintenance - requires cleaning
✓ Fragile

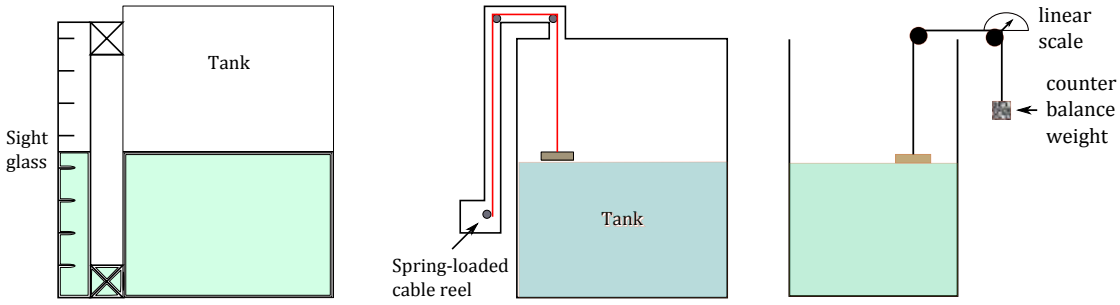

Figure 4: Sight gauge, float with spring-reel, float with linear scale

2.2 Floats

The float material is less dense than the density of the liquid and floats up and down on top of the material being measured. An advantage of the float sensor is that it is almost independent of the density of the liquid or solid being monitored.

The float is at one end of a pivoted rod with the other end connected to the slider of a potentiometer. Changes in level cause the float to move and hence move the slider over the potentiometer resistance track and so give a potential difference output related to the liquid level [1, 6].

Advantages
✓ Large level measurement
✓ Inexpensive

Disadvantages
✓ Maintenance - requires cleaning
✓ Mechanical wear

A variety of float-actuated level devices which transmit the float motion by means of magnetic coupling have been developed. Typical of this class of devices are magnetically operated level switches and magnetic-bond float gauges. A typical magnetic-bond float gauge consists of a hollow magnet-carrying float which rides along a vertical nonmagnetic guide tube. The follower magnet is connected and drives an indicating dial similar to that on a conventional tape float gauge. The float and guide tube are in contact with the measured fluid and come in a variety of materials for resistance to corrosion and to withstand high pressures or vacuum. Weighted floats for liquid-liquid interfaces are available [2].

2.3 Pressure sensors

Hydrostatic Pressure

The most commonly used method of indirectly measuring a liquid level is to measure the hydrostatic pressure at the bottom of the container. The depth can then be extrapolated from the pressure and the specific weight of the liquid can be calculated

$$P = h\rho g, \tag{3}$$

where P - pressure, h - height, ρ - relative density, g - acceleration due to gravity. Hydrostatic pressure transducers always consist of a membrane which is connected either mechanically or hydraulically to a transducer element. The transducer element can be based on such technologies as inductance, capacitance, strain gauge or even semiconductor [5].

It is a requirement of this type of measurement that static pressure is measured. The sensor therefore, should not be mounted directly in the product stream as the pressure measured will be too high and the level reading inaccurate. For similar reasons, a pressure sensor should not be mounted in the discharge outlet of a vessel as the pressure measurement will be incorrectly low during discharge.

Advantages
- ✓ Simple to assemble and install
- ✓ Simple to adjust
- ✓ Reasonably accurate

Disadvantages
- ✓ Dependent on relative density of material
- ✓ More expensive than simpler types
- ✓ Expensive for high accuracy applications

Differential pressure

To minimize potential measurement errors, in certain applications electronic differential pressure measurement may be an alternative. To obtain an electronic differential pressure measurement, two gauge pressure transmitters are used. One transmitter is placed at the bottom of the tank to measure the height of the liquid column plus pressure (A). The second transmitter is located at the top of the tank where it measures the head pressure only (B). The two $4-20\ mA$ signals can then simply be subtracted ($level = A - B$) to obtain the actual level measurement [7].

Advantages
- ✓ Reasonably accurate
- ✓ Simple to adjust
- ✓ Level measurement in pressurized or evacuated tank

Disadvantages
- ✓ Dependent on relative density of material
- ✓ Maintenance intensive
- ✓ Quite expensive for differential pressure measurement

One of the practical advantages of pressure sensors is undoubtedly the fact that they are so easy to calibrate.

See also Bubble-Tube method [7].

2.4 Ultrasonic Measurement

Ultrasonic level sensors work by sending sound waves in the direction of the level and measuring the time taken for the sound wave to be returned. As the speed of sound is known, the transit time is measured and the distance can be calculated.

This non-contact form of measurement is ideal for many industrial applications for which corrosive conditions, changing product characteristics, and other factors make contacting level measurement devices less suitable. The measurement system consists of a transducer or sensor, mounted on the tank or silo, and either a remote measurement transmitter or transmitter electronics built into the sensor.

Ultrasonic measurement generally measures the distance between the contents and the top of the vessel. The height from the bottom is deduced as the difference between this reading and the total height of the vessel. Ultrasonic measurement systems are available that can measure from the bottom of the vessel when using liquid.

Advantages	**Disadvantages**
✓ Non contact with product	✓ The temperature is limited to 170 $^{\circ}C$
✓ No moving parts	✓ Not suitable for higher pressures or in a vacuum
✓ Reliable performance in difficult service	✓ Product must give a good reflection and not absorb sound
✓ Suitable for wide range of liquids and bulk products	✓ Product must have a good distinct layer of measurement and not be obscured by foam or bubbling
✓ Unaffected by density, moisture content or conductivity	
✓ Accuracy of 0.25% with temperature compensation and self-calibration	

2.5 Conductive Level Detection

This form of level measurement is primarily used for high and low level detection. The electrode or conductivity probe uses the conductivity of a fluid to detect the presence of the fluid at the sensing location. The signal provided is either on or off (see Fig. 5).

When the fluid is not in contact with the probe, the electrical resistance between the probe and the vessel will be very high or even infinite. When the level of the fluid rises to cover the probe and complete the circuit between the probe and the vessel, the resistance in the circuit will be reduced [7].

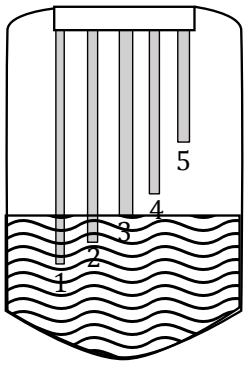

Figure 5: Conductive Level Detection

Advantages

✓ Very simple and inexpensive

✓ Good for dual point control (level switching control) in one instrument

✓ Good for high pressure applications

✓ Very simple and inexpensive

Disadvantages

✓ Possible electrolytic corrosion

✓ Restricted to conductive and non coating processes

✓ Limited application for products of varying conductivity

2.6 Capacitive Level Measurement

Capacitance-type level measurements are based on the fact that the electrical capacitance between two electrodes varies with the dielectric constant of the material between them. A typical continuous level measurement system consists of a rod electrode positioned vertically in a vessel, the other electrode usually being the metallic vessel wall (see Fig. 6).

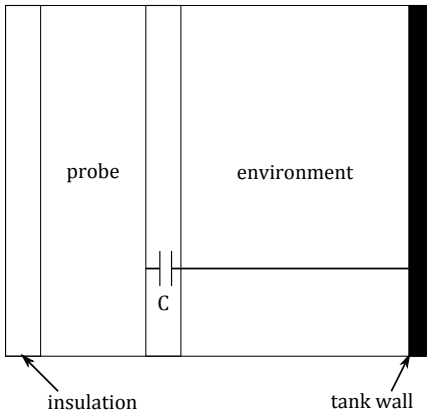

Figure 6: Capacitive Level Measurement

The electrical capacitance between the electrodes is a measure of the height of the interface along the rod electrode. The rod is usually conductively insulated from process fluids by a coating of plastic.

Advantages

✓ Very simple and inexpensive

✓ Wide application range
✓ Good accuracy
✓ Suitable for highly corrosive media
✓ Well-known and proven technology

Disadvantages

✓ Sensitivity to changes in the material properties
✓ Buildup

The dielectric constants of most liquids and solids are markedly higher than those of gases and vapors (by a factor of 2 to 5). The dielectric constant of water and other polar liquids is 10 to 20 times that of hydrocarbons and other non-polar liquids [2].

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