



Fundamentals of Pressure Measurement

An Online Continuing Education Course for Engineers

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Credit: 2 Hours / 2 PDH / 2 CPD

Fundamentals of Pressure Measurement

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Introduction

This course is intended to provide an overview of pressure measurement applications for various industries and methods of using and applying the proper pressure measurement instrument for those applications. Covered topics will include measurement applications ranging from vacuum to high pressure as well as differential pressure measurement. Also discussed will be inference measurement of flow rate, density, and volume using pressure measurement devices, as well as various examples of misapplications of pressure measurement devices that can result in the inaccurate or unreliable measurement of pressure. Consideration will be given to factors involved in the proper selection and application of pressure measurement instruments.

Upon completion of this course, you should have a basic understanding of:

- The evolution of pressure measurement technology
- Various types of pressure measurement applications
- Various types of pressure measurement instruments
- Pressure measurement standards
- Proper selection and application of pressure measurement instruments
- Examples of improper application of pressure measurement devices and their results

Pressure and Pressure Measurement Defined

When we refer to pressure in this course, it is as it pertains to fluid pressure. Fluid pressure is generally defined as the measure of force per unit area imposed by a fluid, acting perpendicularly to the surface it contacts. A fluid can be a gas or liquid.

The international standard (SI unit) for pressure measurement is the Pascal (Pa). A Pascal is equivalent to one Newton per square meter (N/m²). In the English system, pressure is typically expressed in pounds per square inch (psi).

There are three basic categories of measured pressure:

- **Absolute pressure** is measured in relation to a perfect vacuum (absolute zero). The absolute pressure imposed by the atmosphere at sea level is 760mmHg (millimeters of mercury).
- **Differential pressure** is the pressure difference measured between two points. When any point other than vacuum or atmosphere is used as a reference, it is considered to be a measurement of differential pressure.
- **Gauge pressure** is pressure measured in relation to ambient air pressure or atmosphere. It is considered to be a relative measurement.

Applications and Industries Utilizing Pressure Measurement

The range of industries and applications utilizing pressure measurement is quite extensive. We need to look no further than our own residential appliances, such as a washing machine or furnace, to find examples of pressure measurement devices. Pressure sensors are used to detect water supply pressure and indirectly measure the level of water in the tub of a washing machine. They are used to detect and confirm the flow of air across a heating/cooling coil or filter in an HVAC (heating, ventilating, and air conditioning) system.

To follow is a random sampling of industries and related applications illustrating how broadly pressure measurement instruments are used:

- *Automotive Industry* – intake air pressure, exhaust pressure, oil pressure, tire pressure, pedal pressure, and powered door obstruction detection
- *Aviation/Aerospace Industry* – inference measurement of air velocity, cabin pressure, brake pedals, hydraulics, and autopilot
- *Petrochemical Industry* – pipeline pressure, inference measurement of tank level, and vapor pressure, hydraulics, pneumatics
- *Commercial and Residential* – building static pressure, indirect washing machine water level, water pressure, indirect measurement of airflow, barometric pressure
- *Chemical and Biotech Industries* – static pressure, pipe and vessel pressure, vacuum, indirect flow rate measurement
- *Medical/Life Science Field* – invasive and non-invasive blood pressure, anesthesia equipment, breathalyzers, CPAP equipment, drug dosing equipment, hospital beds, hospital gas supply, hospital room air pressure, massage machines, medical instrumentation, nebulizers, patient monitoring equipment, respiratory equipment, sleep apnea equipment, spirometers, and ventilators
- *Weather/Environmental Field* – barometric pressure, inference airflow measurement

Early Types of Pressure Measurement Instruments and Devices

The earliest known scaled pressure measurement instrument, according to published data, was a mercury manometer invented in 1643, approximately 378 years ago. Since that time, pressure measurement technology has evolved. Some of the major developmental milestones in that evolution are discussed below:

Barometer and Mercury Manometer

Italian physicist Evangelista Torricelli invented the barometer in 1643, which allowed him to evaluate atmospheric pressure (the force of the air imposed on the Earth's surface).

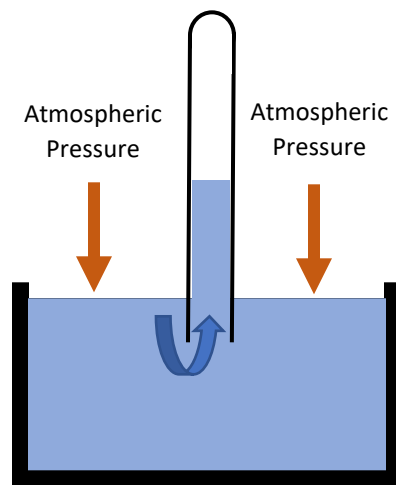


Diagram 1 - Torricelli Barometer

Torricelli is also credited around the same time with the development of a mercury manometer.

A mercury manometer consists of a vertical glass or plastic tube filled with a liquid such as mercury to measure the pressure of gases. There are basically two types: closed and open versions. A closed-tube manometer has a vacuum above the fluid in the closed end, while the open-tube version, as its name suggests, is open to the atmosphere.

A manometer is used to measure the pressure difference between two gases: typically the atmosphere and the gas under test. The three standard types of manometer are the barometer, U-shaped, and an inclined tube filled with either mercury or some other liquid. Alongside the tube is a measuring scale marked off in millimeters or inches of the water column. A manometer is one of the most accurate devices available for the measurement of pressure in the lower ranges (below 10 psi).

Mercury is the fluid of choice for manometers because of its high density, allowing atmospheric pressure to be balanced by a relatively short column of mercury (760 millimeters or approx. 30 inches) versus the much taller column required for water (10.3 meters or approx. 32 feet). The shorter the column, the more compact and readily transportable the manometer. Unfortunately, there are environmental concerns related to the use of mercury as it is classified as a neurotoxin. While confined within the instrument, it is relatively harmless. If the device is damaged or improperly disposed of at the end of its useful life, there is a risk of exposure to humans and wildlife. Therefore, most inclined gauge or U-tube manometers are used with a dye-colored fluid consisting of approximately 50 % water and 50% ethylene glycol.

The upper range of manometer measurement is limited by atmospheric (or barometric) pressure, which serves as the pressure reference. Maximum measurable pressure utilizing a manometer is limited to approximately 10 psi (pounds per square inch). This pressure measurement limitation later leads to the development of the Bourdon Gauge.



Images 1a and 1b – Examples of General Purpose Inclined Gauge and Digital Manometers

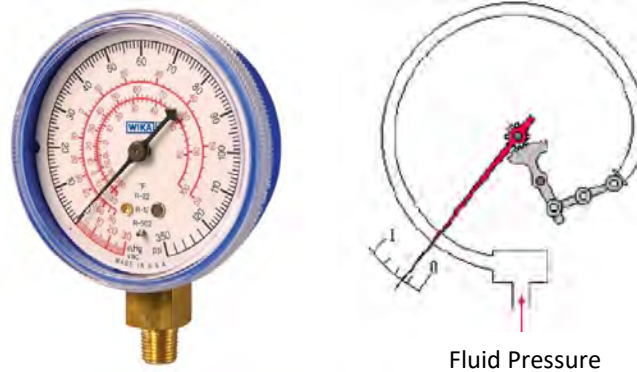
When using a liquid manometer, the user must be cognoscente of “meniscus error.” Meniscus (curvature of the liquid surface) occurs when molecules of the liquid adhere to the sides of the glass or transparent plastic tube. Depending on the direction of pressure applied, the meniscus will be either concave or convex. Either condition can result in a measurement reading error.

Bourdon Gauge

In 1849, Eugene Bourdon, a French watchmaker and engineer, invented the Bourdon gauge. His pressure measurement device allowed accurate measurement of much higher pressures than could be achieved at the time using traditional manometers. Bourdon

initially designed the device for use on steam locomotive engines. It allowed the train engineer to measure pressures over 100,000 psi.

The Bourdon gauge uses a Bourdon tube that mechanically flexes proportionally as pressure in the tube varies. The tube is attached to a dial that indicates the corresponding pressure on a scaled dial face (refer to Images 2a and 2b). These devices are commonly used even today as they are relatively accurate, reliable, and inexpensive standalone gauges. They are found in applications ranging from residential to nuclear.



Images 2a and 2b - Bourdon Gauge (on the left) and Internal Bourdon Tube (diagram) on the right

Differential Pressure Measurement

Differential pressure is defined as the difference in measured pressure between two given points. The open-type liquid manometers previously discussed are a classic example of differential pressure measurement.

A simple example of differential pressure measurement application would be the measurement of differential pressure between the interior of a building and the outside condition (atmospheric or barometric pressure). This is considered to be a measurement of “building pressurization,” with atmospheric or barometric pressure outside the building serving as a point of reference. It is generally desirable for buildings to be slightly pressurized in order to create any flow of air outward through any building leakage points in the building envelope. In doing so, there is less likelihood of undesirable particulate or relatively high humidity air infiltrating the building. Depending on how critical building pressurization, the fan systems within the building may be controlled or influenced by measurement of the static building pressure relative to the atmosphere.

Similarly, differential pressure is measured between the ambient air pressure in a room of a building and the interior of an environmental chamber, oven, or cleanroom. Differential pressure measurement is critical in the case of cleanroom environments where pressure within the cleanroom must be maintained at a higher level than that of the surrounding, less clean areas to prevent the infiltration of airborne particulate.

The third application of differential pressure measurement is a measurement of the pressure differential (pressure drop) across a filter or flow measurement device. Pressure drop across filters can be used to determine when there is sufficient pressure drop (obstruction of flow) to replace the filter.

In the case of a flow measurement device, the measured pressure drop corresponds to a change in flow through the flow measurement device. Examples of flow elements that, when equipped with a differential pressure transmitter or indicator, accurately indicate the rate of flow include rotameters, orifice plates, venturis, Coriolis meters, and nozzles. These devices are referred to as differential flow meters. The greater the pressure differential, the higher the rate of flow.

A very popular, relatively low-cost differential pressure gauge that has been used for many years (invented in 1953 by J. Dwyer) as an alternative to a liquid manometer is the Magnehelic® Differential Pressure Gauge (see Image 3). PVC or rubber tubing is connected to the two barbed pressure fittings on the instrument, and the tubing is routed to the two sensing locations. Differential pressure is applied to either side of a silicone diaphragm. Displacement of the diaphragm moves a magnet, which in turn moves a helix. The helix moves an indicating pointer along a scale on the face of the instrument, which indicates the measured pressure differential between the two sensed locations. These devices are typically scaled in inches of the water column.

Advantages of a Magnehelic gauge over that of a liquid manometer include no liquid added to the instrument, they are generally more rugged, and they are more sensitive.

Pressure Source

Pressure Source

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Limitations of such devices include 1) they are not suitable for certain gases (the diaphragm can be attacked by natural gas and propane); and 2) the device must be checked using a MIST trace gas standard to verify the accuracy of calibration.