Pressure measuring technology

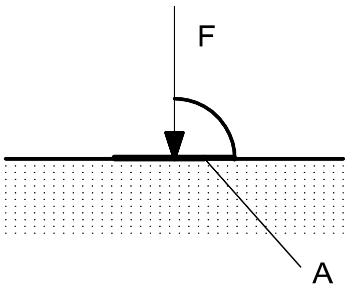
General information

Next to temperature, pressure is the most important physical state variable in process engineering, because it gives information about the pressure situation of liquids and gases in processing lines as well as about the load on the apparatus.

1. Definition pressure

As you will know, the pressure is defined as the force F normal to the surface per area A.

$p = F / A$



The units for the pressure measurement are defined in the international standard ISO 1000 and the German standard DIN 1301:

one pascal corresponds to a pressure of one newton per square metre:

$1 \text{ Pa} = 1 \text{ N/m}^2$

In practice, in Europe engineers usually use the units bar or mbar, which correspond to:

bar ; mbar

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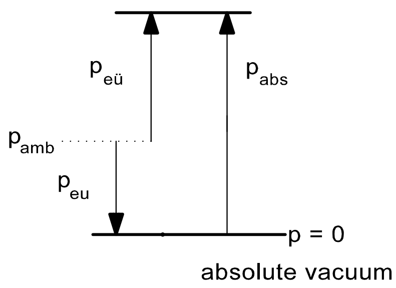
$1 \text{ Pa} = 10^{-5} \text{ bar} = 10^{-2} \text{ mbar} = 0{,}01 \text{mbar}$
$1 \text{ hPa} = 1 \text{ mbar}$ (hectopascal)

2. Types of pressure

A particular role in pressure measurements is played by the earth's atmosphere. The atmospheric pressure is present everywhere and exerts the same pressure on all bodies.
Under normal conditions, at sea level it is 1013.25 mbar = 1013.25 hPa. Technical pressure measurements are most often made against atmospheric pressure. The atmospheric pressure or ambient pressure is p_{amb} (= p ambient).



Depending on the reference pressure, the following pressure types are distinguished:

- absolute pressure
- differential pressure
- positive or negative overpressure with respect to atmosphere
  (also called relative overpressure or underpressure).

If the pressure is quoted with a vacuum as the reference (p = 0), the measurement is of the absolute pressure (p_{abs}).

The difference between two pressures p_1 and p_2 is called the pressure difference $\Delta p = p_1 - p_2$ or differential pressure $p_{1,2}$.

The difference between an absolute pressure p_{abs} and the current (absolute) atmospheric pressure p_{amb} is called the gauge pressure p_e. The gauge pressure pe has a positive value (p_{eo}) if the absolute pressure is greater than the atmospheric pressure pamb. It has a negative value (p_{eu}) if the absolute pressure is smaller than the atmospheric pressure. Negative gauge pressure is also called underpressure.

3. Measuring principles

The pressure is measured by a number of different methods. With regard to the principle of functioning, the following are relevant for measuring and control technology:
- Pressure gauges with sealing liquid (direct pressure gauges)
- Elastic pressure gauges (indirect pressure gauges)
- Electrical pressure transmitters.

3.1 Pressure gauges with sealing liquid have these days lost importance but are still commercially available. Liquid manometers operating with a sealing liquid are mainly used for measuring very small pressures and pressure differences.

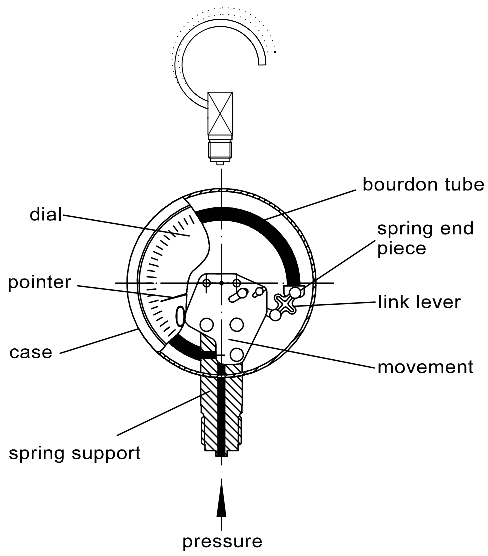
3.2 Elastic pressure gauges

In industrial measuring applications for local measurements and reading off the pressure, elastic pressure gauges are mainly used. They are of a simple, robust and reliable design and do not require any external energy.
They transmit the pressure by the elastic deformation of a baffle wall within a pressure chamber. This deformation is mechanically transferred to the pressure dial.
Because of the simple measuring principle and the robust construction, mechanical pressure gauges are used in the wide pressure range from 2.5 mbar to 1,000 bar.

3.2.1 Bourdon tube pressure gauges

The measuring element of a mechanical pressure gauge with Bourbon tube contains an elastic Bourdon tube which is clamped at one end. This elastic measuring element is deformed in proportion to the applied pressure.

For ranges up to 60 bar, the measuring element consists of a stainless steel tube with an oval cross-section which is bent in the shape of a circle and closed at the end. For ranges above 60 bar, helically wound round tubes with a smaller cross-section and greater wall thickness are used. If the interior of the tube is exposed to the pressure to be measured, the radius of the bend is changed. The movement of the closed end of the spring is a measure of the pressure to be measured and is displayed by means of a pointer element.



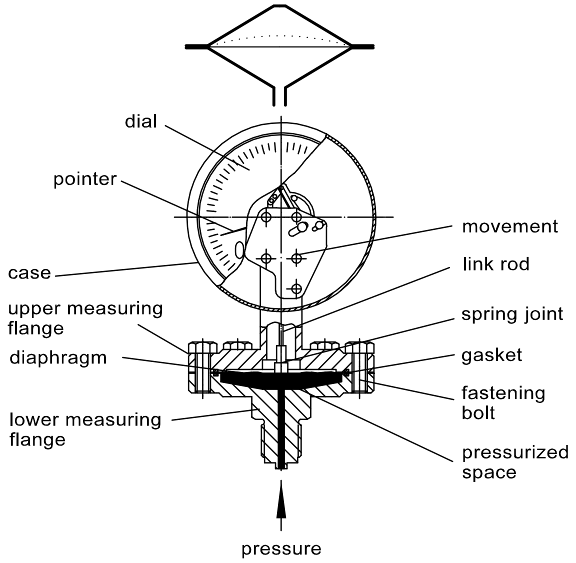
3.2.2 Diaphragm pressure gauges

For measuring gaseous and liquid media in the overpressure and underpressure ranges of 0...25 mbar to 0...25 bar, pressure gauges with diaphragms are used.

The measuring element consists of a circular membrane. This membrane, which is clamped between an upper and a lower flange, is deformed by the pressure applied to the measuring chamber.

The size of the deformation is a measure of the pressure. Diaphragm systems have the following advantages:

- because of the large area of the end stop, high security against overpressure can be realised
- protective foils made from special materials can protect the diaphragm against particularly aggressive media.

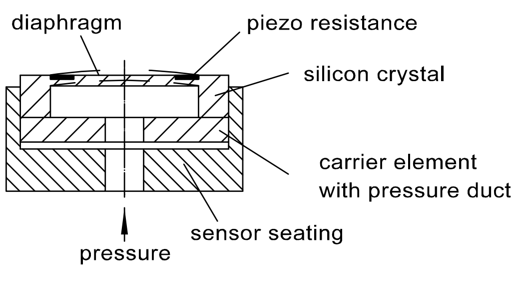


3.3 Electrical pressure transmitters

The measuring principle of electrical pressure transmitters is based on the change in the electrical properties of resistors, capacitors and inductors as a function of pressure. They are suitable for measuring rapidly changing pressures. The measuring signal is processed by means of a suitable measurement amplifier. For the electronic processing of pressure measurements, electrical pressure transmitters are used almost exclusively.

3.3.1 Piezo-resistive pressure sensors

The applied pressure deforms a membrane embedded into a silicon crystal, which changes its specific resistance if extended or compressed (piezo-resistive effect).



3.3.2 Thin film technology (strain gauges)

For this technology, the sensors used are carrier elements with strain gauges. The electrical resistance of a strain gauge is reversibly changed if it is extended.
For the pressure measurement, the pressure to be measured is transformed by means of a carrier element into a sufficiently large force able to extend or compress a strain gauge. The change in resistance of the strain gauge is proportional to the pressure to be measured.

3.3.3 Ceramic sensor

The capacitive pressure sensor module generally consists of two ceramic components:

- ceramic base
- ceramic membrane

These two basic elements form an electronic capacitor whose capacitance is changed if the membrane is loaded with a pressure.
This capacitance change is used to change the tuning of an electrical oscillator circuit. The output signal is a frequency-dependant signal which, depending on the qualitative requirements, can be further processed analogue or digitally.

4. Definitions

Measuring range, nominal range
According to the standard, the measuring range is defined as the value range for a measured variable (e.g. pressure), for which the measuring deviations or agreed or guaranteed error limits of a measuring device are to be within given error limits.
The limits of the measuring range are the measuring starting value and the measuring end value. The output range for mechanical pressure gauges is called the nominal range. This is the range of all values which can be read from a measuring device.

Measuring span
The difference between measuring start and measuring end value is called the measuring span.

Characteristic curve
The function between the measured variable (pressure) and the output value (displayed or measured value) is described by the characteristic curve. Ideally it is a straight line.

Limit point setting
By setting the limit points of a pressure gauge the start value and the end value are set to the corresponding points on the ideal characteristic curve. Although this definition will result in the largest deviation from the characteristic curve compared to the start setting or to the BFSL (best fit straight line), it is the method most easily understood by the user. With information given in datasheets it is therefore important that it is stated how the error is defined. A deviation of 0.5% from the end value of the characteristic curve during the setting of the limit values corresponds approximately to a deviation of 0.25% from the BFSL.

Deviation from the characteristic curve
The deviation from the characteristic curve is defined as the maximum total error according to IEC 770, consisting of the deviation from the linearity, hysteresis and reproducibility corresponding to the set limit value. This is the deviation of the end value of the measuring range from the ideal characteristic curve in percent. In the case of pressure gauges, in this context the word "accuracy" is also used. The linear deviation is the largest deviation of the characteristic curve from the straight reference line. The hysteresis (hysteresis error) is the difference of the output value for the same measuring point when the pressure is rising or falling. The reproducibility (repeatability) defines the largest deviation in the output value when the measuring point is measured repeatedly.

Temperature error
The temperature error is the maximum deviation of the characteristic curve from the ideal function for measurements at different temperatures. The temperature error is usually quoted with respect to the end value of the measuring range and in percent per 10 K.

Drift
If the reference level of a measurement (e.g. the zero value of a measuring device) changes over a prolonged period without any external influence this is described as drift.

Calibration / adjustment / standardisation (official calibration)
Calibration is the determination of the systematic measuring error. Here the relationship between the input value and the output value of a measuring device is determined and assigned. As part of the calibration, the error in the measuring device is identified.
Adjustment: Bringing a measuring instrument into a state of performance suitable for its use. In metrology, during adjustment a measuring device is adjusted or trimmed in such a way that the output value deviates as little as possible from the ideal characteristic curve.
Official calibration is carried out by the responsible authorities in accordance with the regulations to test whether the measuring device conforms to the statutory requirements, and, in particular, if the statutory error limits are being adhered to.

Overload limit

Overload range: The agreed error limits are being exceeded. Within the overload range, no permanent changes are caused to the measurement-related properties.

Destruction range: The pressure leads to permanent changes to the measurement-related properties. No leaking of the medium being measured.

Burst pressure: Pressure bearing parts burst. Medium being measured may leak..