All About Measuring Pressure

Preface

Alongside temperature, pressure is one of the most important and most measured variables for applications in research and engineering.

A large number of measuring tasks have become indispensable for a wide range of applications in the foodstuffs industry, in heating, sanitation and air-conditioning, in power generation and technology, in process engineering and in many other areas.

Whatever the application, when it comes to measuring pressure there are some important parameters which have to be observed if reliable results are to be achieved.

In addition to knowledge of the various units, familiarity with the different types of pressure, and their definition, is fundamental to measurement.

The Technical manual deals first and foremost with the context surrounding the electronic pressure measuring process.

The aim of this practical guide is to both enable newcomers to gain an overview of the relevant parameters, and to serve as a reference work for professionals in the industry.

We are grateful for any ideas you may have and will be happy to incorporate these into the next edition.

The Board of Directors

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$$\text{Pressure } p = \frac{\text{Force F}}{\text{Area A}}$$

I. The definition of pressure

Pressure is defined as a force (F) acting on an area (A).

II. Units

SI units are the names given to the basic units of the international system of units. The name comes from the French “Système International d’ Unités.” The SI was established by the General Conference on Weights and Measures (founded by the Metric Agreement of 20 May 1875). The system is now administered and revised by the Bureau International des Poids et Mesures in Sèvres (France). Both the International Standardization Organization (ISO) and the International Union of Pure and Applied Physics (IUPAP) compile international recommendations for the use of the SI which are then laid down as binding at national level. In Germany, the Law on Units in Metrology is the legal foundation for the indication of physical quantities in statutory units. It is mandatory for use in official and commercial transactions. The “guardian” of the units in Germany is the PTB.
The Implementing Order to the Law on Units in Metrology (Units Order) refers to the DIN 1301 standard.
The statutory units are listed in alphabetical order in the annex to the Units Order.

The pascal.

This can be derived from the SI units of the metre and the Newton.
1 Pa = 1 N/m^2. In meteorology pressure is usually indicated in hPa. This unit has replaced the mbar that was previously common. The pascal was named after Blaise Pascal (1623 - 1662), a French mathematician and natural scientist. In industrial applications the unit bar, Kpa or MPa is frequently used.

Since the pascal is a very small unit of pressure, it is primarily used for measuring pressure in clean rooms. But the Pa is also used as a unit of measurement when measuring flows in conjunction with a pitot tube (see also point 14).

$$1\text{ Pa} = \frac{1\text{ N}}{\text{m}^2} \quad \text{where } 1\text{ N} = 1\text{ kg}\frac{\text{m}}{\text{s}^2}$$

The hPa (= mbar) is used primarily in meteorology, but also to some extent in contracting and industry as well.

750 micron = 1 hPa

The units bar, KPa and MPa are the standard units in industrial pressure measuring technology.
The mmH_2O is now almost never used.

The mmHg is used most frequently in medical engineering. Blood pressure, for instance, is measured in mmHg.

The micron is the smallest unit (750 micron = 1 hPa) and is used primarily in vacuuming, e.g. of refrigeration installations.

Imperial units:

- psi (pounds per square inch)
- inH_2O (inches of water)
- in Hg (inches of mercury)

The older units of Torr, atü, ata, atu, atm and kp/cm^2 are no longer common and under the Units Law may no longer be used in official or commercial transactions.

III. Conversion table

	Pa	hPa/mbar	kPa	MPa	bar	psi	mmH_2O	inH_2O	mmHg	inHg
Pa	1	100	1,000	1,000,000	100,000	6,895	9.807	249.1	133.3	3,386
hPa/mbar	0.01	1	10	10.000	1,000	68.948	0.09807	2.491	1.333	33.864
kPa	0.001	0.1	1	1.000	100	6.895	0.009807	0.2491	0.1333	3.386
MPa	0.000001	0.0001	0.001	1	0.1	0.006895	0.000009807	0.0002491	0.0001333	0.003386
bar	0.00001	0.001	0.01	10	1	0.0689	0.00009807	0.002491	0.001333	0.0339
psi	0.0001451	0.0145	0.14505	145.05	14.505	1	0.001422	0.0361	0.0193	0.4912
mmH_2O	0.102	10.2	102	102,000	10,200	704.3	1	25.4	13.62	345.9
inH_2O	0.004016	0.4016	4.016	4,016	401.6	27.73	0.0394	1	0.5362	13.62
mmHg	0.007501	0.7501	7.501	7,501	750.1	51.71	0.0734	1.865	1	25.4
inHg	0.0002953	0.0295	2953	295.3	29.35	2.036	0.002891	0.0734	0.0394	1

The table must be read from top to bottom, e.g. 1 Pa = 0.01 hPa/mbar

IV. Types of pressure

Pressure measurement compares a current pressure with a reference pressure. Pressure measuring technology distinguishes between the following types of pressure, enabling a statement to be made about the relationship between the measuring pressure and the reference pressure.

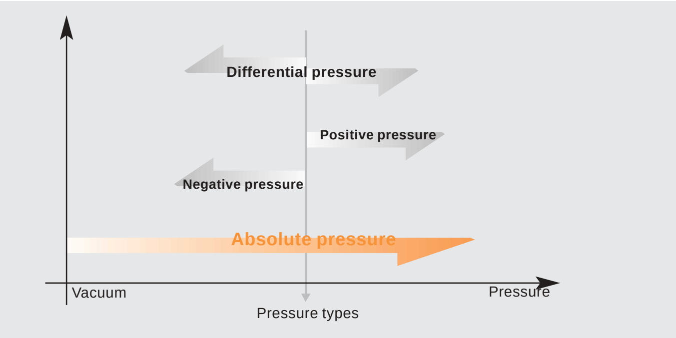
Absolute pressure relates to the vacuous space of the universe (zero pressure).

Absolute pressure:
– measured pressure above absolute zero
– reference, ideal vacuum
– measuring pressure is always greater than reference pressure

Positive pressure:
– measured pressure above the barometric daily air pressure
– reference ambient pressure
– measuring pressure is always greater than reference pressure

Negative pressure:
– measured pressure below the barometric daily air pressure
– reference ambient pressure
– measuring pressure is always less than reference pressure

Differential pressure:
– measured pressure above or below any desired reference pressure
– measuring pressure is always greater than reference pressure



P_{atm}

This is the most important pressure for life on earth. Atmospheric pressure arises through the weight of the atmosphere that surrounds the earth. The atmosphere extends up to an altitude of about 500 km. Air pressure decreases constantly up to this altitude (absolute pressure p abs = zero). Atmospheric air pressure is also affected by weather-related fluctuations. On average, p atm at sea level is 1013.25 hPa. However, it can fluctuate by up to ±5 % according to highs or lows in the weather.

Pressure meters and their areas of application

What are known as differential pressure meters can measure positive pressure and negative pressure as well as differential pressure. The important thing here is to connect the right pressure to the right connection, i.e. a positive pressure to the + and a negative pressure to the – connection. With the right connection, a differential pressure meter can cover the entire measuring range in both the positive and the negative direction.
If a meter has a measuring range of 0...200 hPa, for instance, a positive pressure, a negative pressure and a differential pressure within the 200 hPa range can be measured.

Why always the correct pressure at the right connection?

If a meter is used to measure a negative pressure and this is connected to the + connection, some meters will indicate a part of their measuring range with a – sign, but will stop after a certain value (both to protect the sensor and because all pressure sensors are only calibrated in the positive range). If the user does not take this into account, incorrect measuring results will be obtained. Some other meters indicate “out of range” on the display after a certain measured value.

Barometric pressure can be measured with absolute pressure meters. There are two types of barometric atmospheric pressure. One is the pressure related to the particular altitude, the other the absolute pressure converted to sea level. The converted absolute pressure is primarily used in meteorology in order to ensure comparability. It is known that the average value related to sea level is 1013.25 hPa. All values above that indicate high pressure, all below indicate low pressure. An absolute pressure meter can also be used to measure the vacuum (counterpressure = 0). An absolute pressure meter always has only one hose connection and cannot be zeroed.

V. Pressure measuring processes

Probably the most basic way of measuring pressure is to use liquid pressure meters. The pressure to be measured is compared against the height of a liquid column. A variety of liquids are used according to the pressure to be measured.

At an altitude of 1 m the following measured values are obtained:

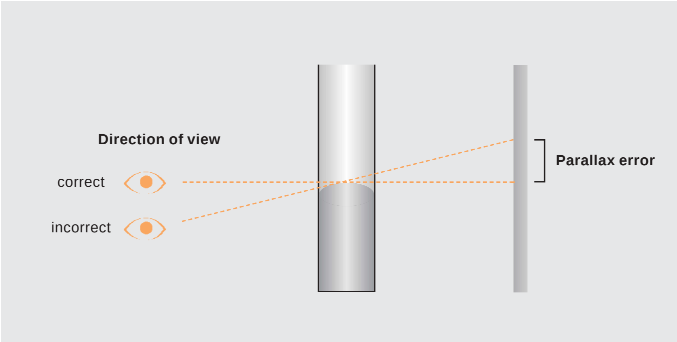
- Alcohol 78.5 hPa
- Water 98.1 hPa
- Mercury 1334.2 hPa

It can be seen, then, that liquid pressure meters are mainly suitable for tiny or small positive pressures/differential pressures.

Although measurements with these pressure meters are relatively reliable, some important parameters must be noted.

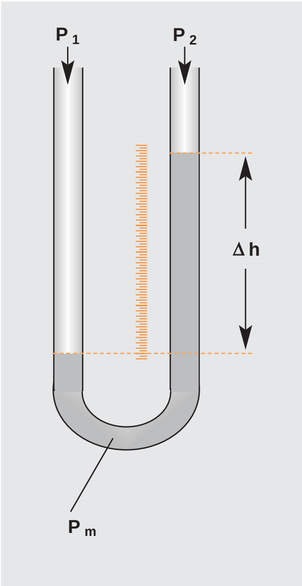
- It is essential that the connection is absolutely horizontal, as even slight deviations will result in misleading figures.
- The handling operations for portable measurements are not optimal. The liquids have to be filled in again at every location and the manometer must be recalibrated. Depending on the liquid, this must be done with extreme care (e.g. mercury is extremely toxic even in low concentrations and for this reason is now little used).
- The differing densities of the liquids mean that they must never be mixed together!!!
- In order to avoid parallax errors, the measured value must be read absolutely horizontally.

Parallax error

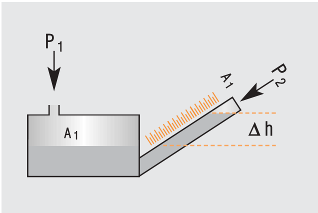


Some examples of liquid pressure meters.

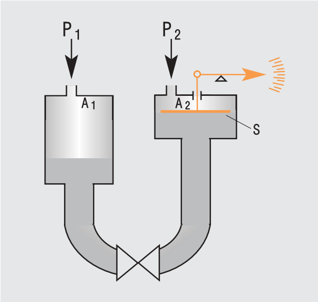
U-tube manometer



Float manometer



Inclined-tube manometer



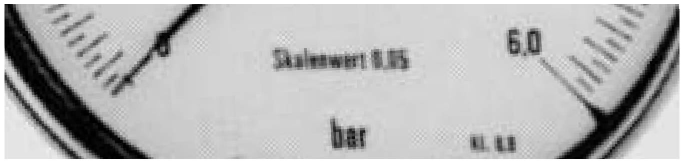
The mechanical manometer

When, following the industrial revolution (at the beginning of the 19th century), it became necessary to measure greater pressure ranges (e.g. due to the introduction of the steam engine) and the liquid pressure meters were no longer sufficient in terms of range and mechanical stresses (vibrations), new types of pressure meters had to be developed. This led to the mechanical manometer. In the manometer, a spring is deformed by a pressure applied to it. This deformation can be used to move a dial train so that the corresponding pressure can be read off on a scale. Various types of spring are used in practice, e.g. tube springs, pressure capsules, membrane springs, etc.). The measuring path of the spring can range from a few tenths of a millimetre to a maximum of 10 mm.

Mechanical manometers are characterised by their robustness and ease of operation. They are also relatively cheap to manufacture. They do, however, have some disadvantages. The mechanical deformation means that there is a risk that material fatigue will cause the spring not to return to its original position. The return function of the spring to its original position is also called hysteresis (see point 9.4).

Mechanical manometers can only be used to measure the relative/positive pressure or the absolute pressure (depending on the version). In addition, their class (accuracy) is only in the region of 1 %fs (see also point 9), i.e. the measurements are not particularly accurate.

Information on the dial face.



Other pressure measuring processes include:
- pressure balances
- piston pressure meters
- piston pressure balances

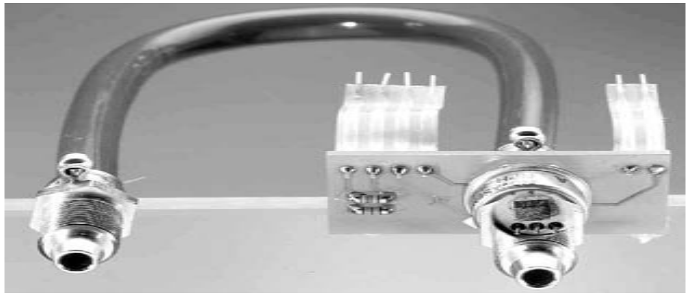
The following principles and processes are predominantly used in electrical pressure measuring:
- piezoresistive
- foil strain gauges
- thick-film strain gauges
- thin-film strain gauges
- capacitive
- inductive
- piezoelectric

VI. Advantages of electric pressure meters
- high accuracy (up to class 0.05)
- excellent hysteresis behaviour (low deformation of the sensor)
- good reproducibility
- many units integrated in the meter (worldwide use)
- data recording => documentation
- damping
- ease of handling

VII. Description of the Testo measuring principle
In practice, and particularly at Testo, the piezoresistive principle and inductive pressure measurement have become the most widely applied.

Piezoresistive pressure measurement.

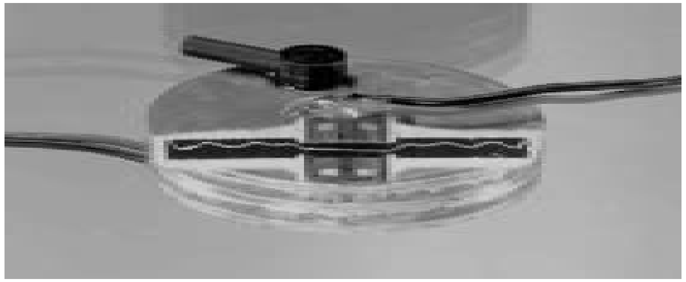
In the piezoresistive principle, the measuring element consists of a silicon chip on which several resistors (usually 4 - 6) are engraved. If the silicon chip is charged with pressure, it deforms (only a few mm = thus excellent hysteresis behaviour). This deformation leads to changes in the resistance values, enabling the pressure applied to be calculated.



The advantages:
– small sensor size
– excellent hysteresis behaviour
– high accuracy

The disadvantages:
– their small size makes them relatively susceptible to temperature fluctuations (the sensor should be temperature compensated)

The inductive displacement sensing process.
In the inductive distance sensing process two pressure measuring cells made from copper beryllium are used. Copper beryllium is characterised by its excellent dynamic behaviour and high elasticity. The two measuring cells are attached to each other (one for positive pressure, the other for negative pressure). As soon as they are charged with a pressure, the measuring cells elongate. This elongation is then measured by means of an inductive displacement gauge, i.e. the elongation of the pressure measuring cell is measured.



The advantages:
– high accuracy
– good elastic behaviour of the pressure measuring cell (good hysteresis)
– temperature fluctuations have relatively little effect on the measurement

The disadvantages:
– relatively large size of the sensor

VIII. Pressure and temperature

The two parameters of pressure and temperature are directly related.

A brief consideration of pressure in gases.
Molecules in gases move around randomly in a closed pressure system. When these molecules collide against the walls of the pressure systems, pressure is created. As long as the temperature remains constant, so does the pressure.
If the gas is heated, though, the speed of the molecules and the pressure in the system rise (the molecules collide against the walls of the system at a greater speed = expansion). If a gas is cooled, the opposite applies and the pressure falls.

Gases can be heavily compressed in contrast to liquids or solids.

In electronic pressure meters, the influence of temperature on the electronics also plays an important role. The signals of electronic components behave differently at varying temperatures. In practice, pressure meters are usually temperature compensated. Temperature compensation is very important if data is recorded (logging function).

An example:
Assumption: In a production factory without a night shift, i.e. where there is no operation at night, a malfunction occurs in an installation to which a pressure measuring system is connected. For reasons of cost, the factory heating is turned down at night. A manometric capsule connected to the system keeps a long-term record. The pressure in the system is kept constant by means of a compressor.

What does the pressure meter now record and show?

Meter 1 = not temperature compensated
The meter indicates a fall in the values as the room becomes increasingly colder. Once the room is heated up again the next day, the meter shows that the pressure is rising again until a constant room temperature is reached. Yet the pressure in the system has remained constant.

Meter 2 = temperature compensated
The meter shows the actual (permanently the same) value in the system, even though the ambient temperature has changed.

Conclusion: If long-term monitoring is to be carried out, it is essential that the pressure meter is temperature compensated. If only a brief check or short measurement of a pressure system is carried out, there is no need to have offset temperature compensation since the meter is zeroed before the measurement and so temperature influences will not become a factor.

Caution: Extreme temperature differences such as those which can occur in winter (meter was in the car the whole night at e.g. –10 °C and is then used for measurement in a room at 20° C) cannot be offset even by optimal temperature compensation. It is therefore essential that the meter is adjusted to the temperature over a long period (approx. 0.5 h, depending on the temperature difference). The optimum solution is to let the meter adjust unpressurized and switched on.

Temperature compensation is a very awkward and cost-intensive matter, since the meters are adjusted in the climatic cabinet at 2 - 3 temperatures. It takes some time until the temperatures in the climatic cabinet are stable.

IX. Accuracy (influencing factors)

The accuracy of pressure meters is usually indicated in classes. Thus class 1.0 = accurate to within 1 % of the measuring range (fs = full scale, fv = final value).

Example:
Differential pressure meter with measuring range 1000 hPa, class 1 => absolute accuracy ±10 hPa.

It is important to remember the basis on which a manufacturer states his accuracy. There are two variations:
fs / fv = of full scale / final value
mv = of measured value

There is no single meter for all applications in pressure measurement. This is because of the class. Since the error is indicated as a % of fv, the absolute error rises as the measuring range increases. This means that if most applications lie in the low hPa range and higher pressures are measured only sporadically, a meter with a high measuring range would not be appropriate. After all, since the absolute error in the high measuring range is relatively high, the measuring error in the lower pressure ranges is much too large (see chart “The right meter for the application”). One alternative for these cases of a limited range is to use meters with a variable measuring range. The final value is divided into two measuring ranges. However, in these meters one of the two measuring ranges has a higher class and the other a lower class (example: the testo 520 for a small measuring range has class 0.5; for a large measuring range class 0.2). It can therefore occur that two or more meters have to be used to achieve accurate measurements in the small and the large measuring range.

Accuracy is made up of the following parameters:
linearity / temperature coefficient / hysteresis

	*testo 525 (0 … 200 hPa)		*testo 525 (0 … 7 bar)	
Meas. press.	Deviation	Dev. % from mv	Deviation	Dev. % from mv
10 hPa	0.4 hPa	4 %	14 hPa	140 %
20 hPa	0.4 hPa	2 %	14 hPa	70 %
50 hPa	0.4 hPa	0.80 %	14 hPa	28 %
100 hPa	0.4 hPa	0.40 %	14 hPa	14 %
150 hPa	0.4 hPa	0.27 %	14 hPa	9.33 %
200 hPa	0.4 hPa	0.20 %	14 hPa	7.0 %
500 hPa	out of range	0.20 %	14 hPa	2.8 %

The example shows that if the wrong meter is chosen, a possible measuring error of 140 % can occur in the 10 hPa range. At 20 hPa the measuring error is still 70 %.

*Accuracy: 0.2 % of final value

Linearity
Linearity is the value of the maximum deviation of the characteristic curve from the ideal straight through the zero and end point.

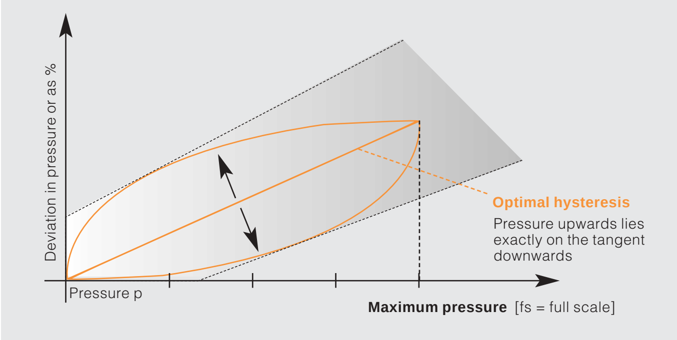
If a pressure meter is not temperature compensated (or only in a limited temperature range), the manufacturer indicates the temperature coefficient. Thus the details for the testo 512 are e.g. ±0.04 % fv / K related to a nominal temperature of 25 °C.

So what does that mean?
The testo 512 has an accuracy of class 0.5 at 25 °C. The measuring range 0...20 hPa is used by way of example. Thus the meter has an absolute error of ±0.1 hPa at 25 °C.
If this temperature now varies by 2 K (from 25 °C to 27 °C), this absolute error is exacerbated by a temperature error of ±0.0016 hPa.
If a sensor is charged with pressure, it will bend. The maximum elongation should be achieved at the final value of the measuring range (leaving the overload aside for a moment). If this pressure is taken away from the sensor, a properly functioning sensor should return to its original form (to the zero point). Put more simply: if a spring is extended to its maximum and this extension then relaxes, the spring should adopt its original status again.

Hysteresis
In technical terms, hysteresis means the difference of the output signal of a pressure on the way to the final measuring range value and back.

In pressure measurement, because of hysteresis, the meter can display a different value at the same measuring point on the way up (towards the measuring range final value) to that on the way down (towards zero point).

If only the accuracy is indicated in the technical specifications of a meter, normally all the parameters described are included.



Note:
Accuracies indicated in data sheets are always only “worst-case” scenarios. This means that the meter may have this error, but need not necessarily have it. If extremely accurate measurements are required, it is recommended that the meter is calibrated (see also point 17) so that the real absolute deviation of the meter used can be ascertained. With some meters a calibration report is supplied on delivery (e.g. testo 520/525).

X. The measuring process

– temperature adjustment (preferably while the meter is in operation)
– zero meter unpressurized
– connect the meter to the pressure system (right pressure at the right connection => large pressure (or positive pressure) to + / smaller pressure (negative pressure) to –
– carry out measurement

XI. Overload versus static pressure

Every pressure meter accepts an overload. The overload is expressed either as an absolute value (e.g. 1000 hPa) or as a multiple of the measuring range (e.g. twofold = measuring range 1000 hPa = overload = 2000 hPa). Overload is understood to mean the maximum pressure (positive pressure) which can be exerted at a connection without the sensor being damaged. If the overload is exceeded, the sensor is “overpressurized” and irreparably faulty.

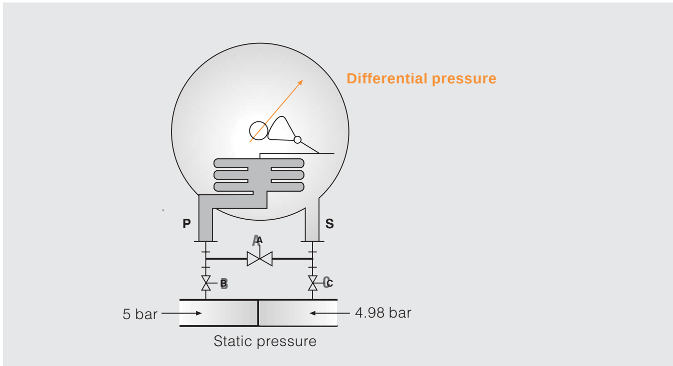
The static pressure of a meter can be significantly higher than the overload. The static pressure must be led to both connections of the pressure meter at the same time.

Where do high static pressures occur?
A good example of them are pressure systems in which the flow rate is to be measured. To be able to measure a low flow rate (m/s), a pressure meter with a relatively small measuring range (error) is required. But what about if a pressure system has a static pressure of e.g. 7 bar? If one were to use a meter with a range of 0...7 bar and a class of 0.1 here, a flow rate of 10 m/s would result in a maximum error of ±54.11 m/s. This figure is absolutely out of the question!

It can be seen, then, that the measuring range of 7 bar is much too great. So what next? A meter with a small range but which can withstand a high static pressure must be used instead. If we make the same calculation as before, but use a testo 525 with a measuring range of 0...25 hPa and a class of 0.1 (this meter accepts a static pressure of maximum 7 bar even in the smallest measuring range of 25 hPa), the maximum error at a flow rate of 10 m/s is then only ±0.1933 m/s.

How can the static pressure be exerted at both connections at the same time?
1. Depressurize the system first, then connect the meter (or introduce the pitot tube into the system) and bring the pressure evenly up to operating pressure.
2. Should it not be easy to depressurize the system, there is the possibility of installing a bypass:

Bypass:



Regulator A is opened. Regulators B and C are closed. Then regulator B is opened. The entire static pressure is now applied at the sensor. Then regulator C is opened and A is closed. Thus the reduced pressure is now applied on the side after the constriction. The differential pressure can then be measured.

Important: At the end of the measurement you must proceed in the reverse order, otherwise the sensor would be destroyed.

XII. Measuring in liquids

When measuring pressure in liquids, you must ensure that the meter is at the same height as the measuring point. If the meter is placed lower than the measuring point, it will indicate a higher value; if it is placed higher, it will indicate a lower value. This is because the force due to the weight of the water will be added to the actual system pressure.

Should a height difference be unavoidable, the following formula can be used to calculate the pressure difference:

$\Delta p = (\_F - pL) \times g \times \Delta h \times 10$ (bar)

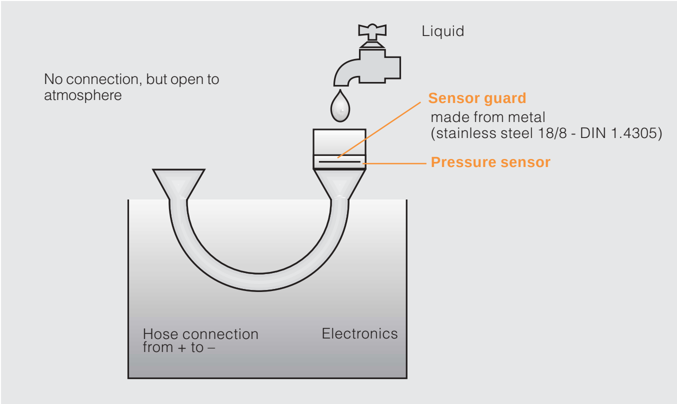
$\Delta p = (\_F - pL) \times g \times \Delta h \times 10$ (bar)
Δp = difference of the measuring range (bar)
$\_F$ = density of the liquid (kg/m3)
pL = density of air (1.205 kg/m3)
g = gravitational acceleration (9.81 m/s2)
Δh = height difference (m)

In principle, piezoresistive sensors should not be charged directly with liquids. Since the sensor is open (not encapsulated), there would be a short-circuit which might destroy the sensor. If measurements are to be carried out in liquids, though, there are two ways of doing so:

Option 1: brief measurements at relatively low pressures.

A relatively long hose must be used for this purpose. This long hose should be arranged in a U-shape.

Why?
When a long connecting hose is used, air is trapped in the hose before the liquid. This presses against the sensor and does not damage it. After a certain length of time, however, the liquid diffuses through the trapped air and penetrates through to the sensor. If the hose is arranged in a U-shape, the liquid remains in the lower part of the U because it is heavier than air.



Option 2: Measuring (long-term) at high pressures.

Either a media-compatible meter can be used to this end, or an adapter (pressure transducer) can be placed on the meter.

Media-compatible meters:
These meters allow all liquids which are compatible with stainless steel 18/8 (DIN 1.4305) to be led directly to the sensor. The sensor is encapsulated, and is protected by the steel. However, media-compatible meters can only be used to measure positive pressure (there is only one pressure connection; the other one is inside the meter and open to ambient pressure).

The structure of piezoresistive sensors does not allow both connections to be encapsulated at the same time, since the electronics are located immediately behind the sensor.

Measuring with one or two adapters.
An adapter can be plugged into many pressure meters. This adapter contains a separating membrane which keeps the liquid away from the sensor. It should be noted that such adapters are not suitable for every meter.

Why is that so?
If the adapter is plugged into a pressure meter, an exactly defined dead volume of air is trapped. If the separating membrane is then charged with liquid pressure, the membrane deforms, compresses the dead volume of air and presses on the sensor. Should this dead volume not coincide exactly with the meter, not only will incorrect measuring values be displayed, but the final measuring range value of the meter will not be reached or could be exceeded.
It is very important that the adapter is always plugged into the meter when unpressurized and only then charged with pressure.

Adapter
The use of adapters offers the advantage that the meter can be employed to measure in both gases and liquids.

If only positive pressure is to be measured, one adapter is used; if differential pressure is to be measured, two adapters are used.

XIII. Which gases can be measured?

You must take particular note of the moisture content of gaseous mixtures, as this can lead to condensed water being produced depending on the dew point temperature. Condensate and particles of dirt can damage the sensor or lead to incorrect readings!

The following are allowed:
Gases (e.g. argon, xenon etc.)
Instrument air (dry, clean air)

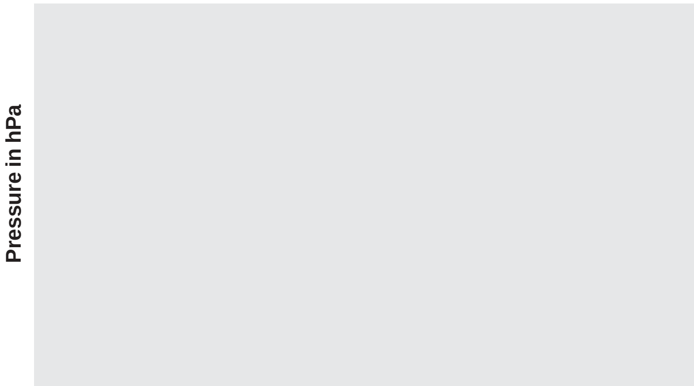
O2	Oxygen
H2	Hydrogen
N2	Nitrogen
O2/N2	Oxygen/nitrogen mixture
CO2/N2	Carbon dioxide/nitrogen
CO/N2	Carbon monoxide/nitrogen
C3/H8	Propane
He	Helium
H2/He	Hydrogen/helium
NO/N2	Nitrogen monoxide/nitrogen
SF6	Sulphur hexafluoride

Natural gas (not too moist)

XIV. Pressure shocks

Now and then what are known as pressure shocks have to be measured. The problem with such pressure shocks is that they occur within fractions of a second. Thus a meter which offers very rapid measuring intervals is needed. There is no point, for instance, in using a meter with a smallest memory interval of 1 second, since the pressure shock occurs within fractions of a second. The meter must perform several measurements every second and it must be possible to record these.

Pressure shock



Pressure shocks can occur in:

- industrial extraction facilities (where the filters are cleaned by means of a pressure shock)
- pressure surges in domestic services pipe systems
- pressure shocks in metal casting
- pressure surges in liquid-carrying pipes (often arising when pumps are switched off or started up)
- pressure surges in systems as a result of quick-acting valves and fittings
- pressure shocks in compressors of refrigeration systems

To measure and evaluate pressure shocks, we are using the testo 525 as an example. The meter performs 10 / 20 measurements per second. The software developed for this meter enables these 10 / 20 measurements per second to be transferred to a laptop, where they can be stored and processed.

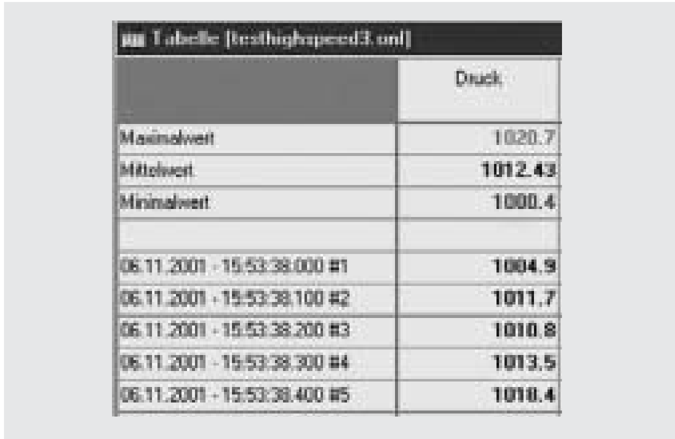


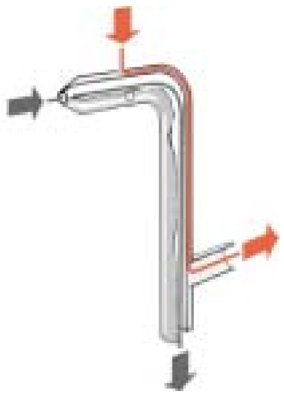
Tabelle [testhighspeed3.onl]

	Druck
Maximalwert	1020.7
Mittelwert	1012.43
Minimalwert	1000.4
06.11.2001 - 15:53:38.000 #1	1004.9
06.11.2001 - 15:53:38.100 #2	1011.7
06.11.2001 - 15:53:38.200 #3	1010.8
06.11.2001 - 15:53:38.300 #4	1013.5
06.11.2001 - 15:53:38.400 #5	1010.4

XV. Measuring flows with a pitot tube

The air-flow speed can be measured using a differential pressure meter and a pitot tube.

The measuring principle.



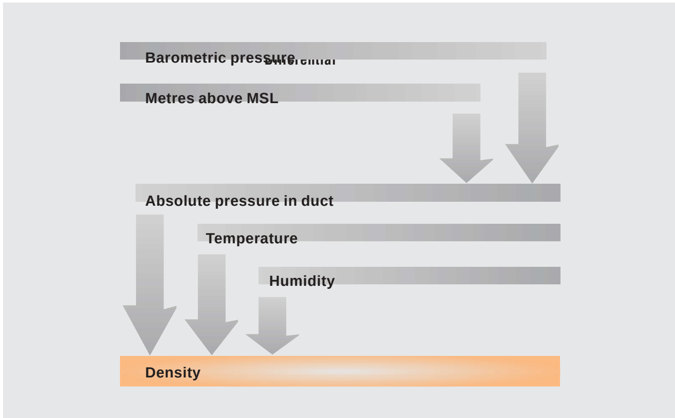
The back pressure arises at the tip of the tube when this is held against the direction of flow. Two hoses connect the pitot tube to the actual measuring sensor; the pressure sensor (make connection “a” at the + connection and connection “b” at the – connection). Both the sum of dynamic pressure + static pressure and the pure static pressure are transferred to the pressure sensor.
This sensor determines the difference between the two pressures. The result is the dynamic flow pressure. This is directly related to the prevailing flow velocity. If the gas density is known, converting the pressure to the flow velocity is simply a matter of working out a root function of what is known as Bernoulli’s equation
(after Daniel Bernoulli, Swiss mathematician, 1700-1782).

$$v\ (m/s) = \sqrt{\frac{2 \bullet p\ diff}{rho}}$$

v (m/s) = flow velocity in m/s
p diff = dynamic differential pressure in Pa
rho = air density in (kg/m3)

The air density plays an important role in pitot tube measurement.

Factors in air density.



Thus air density is heavily influenced by:
– the absolute air pressure
– the temperature of the gas
– the content of the water vapour (humidity)

It is very awkward to measure the density. The user has to measure the parameters that determine density and then calculate the density, or work it out from tables.

It must first be ensured that the measuring medium is air. Air is a gaseous mixture with a constant composition. The usual fluctuations in the composition have no significant effect on the measuring result.

In general, if the air density is not calculated, the normal air density of 1293 g/m3 is assumed (absolute pressure = 1013.25 hPa/mbar; temperature = 0 °C; air humidity = 0 %RH).

Errors in pitot tube measurement
For information: the value at 1013 hPa/mbar, temperature = 20 °C, air humidity = 50 % is 1199 g/m3.

Incorrect air density value
The influence of the individual parameters on the density appears plausible. Cold air is heavier, while warm air is lighter. If the air is warmer than assumed, therefore, its density will be lower and the calculated flow velocity will be too fast. The same will happen if the air is more humid than assumed.
If you forget to adjust the air pressure when travelling into the mountains, the pressure and hence the density fall. The values calculated for the flow velocity will then be too low.

Pitot tube clogged
The pitot tube is relatively easy to service and maintain. In contrast to the vane probe, there is no bearing which can become dirty and no vane to be bent. Nevertheless, before every measurement a visual inspection must be carried out (is the tube kinked? is there visible damage?) as well as what is referred to as a blow-through test (blowing into the connections a and b and feeling whether air escapes from the upper end of the pitot tube).

Incorrect arrangement in the duct
A further important factor is the position of the pitot tube in the duct. If the opening is not exactly in the direction of flow, the measuring results will be misleading. Since the tip cannot be seen in the duct, connection “b” can be used as the reference. It runs exactly parallel to the measuring tip. In order to ensure the correct flow stream, turn the pitot tube slowly backwards and forwards and compare the measuring results. The pitot tube is in its optimal location at the place where the highest value is read.

Hoses kinked
It is important to ensure that the hoses are not kinked between the pitot tube and the pressure sensor (take care with very flexible hoses!!!), because this could produce misleading results.
Hoses not properly connected
Connect the hose of the “a” connection with the + connection and the hose of the “b” connection with the – connection of the pressure sensor.
Inaccurate pressure sensor
Not every pressure sensor is suitable for measuring air flow, particularly in the lower range. What is important is the accuracy of the sensor, as absolute accuracy is used to calculate errors.

An example:

Testo pressure probes for the multi-function meters

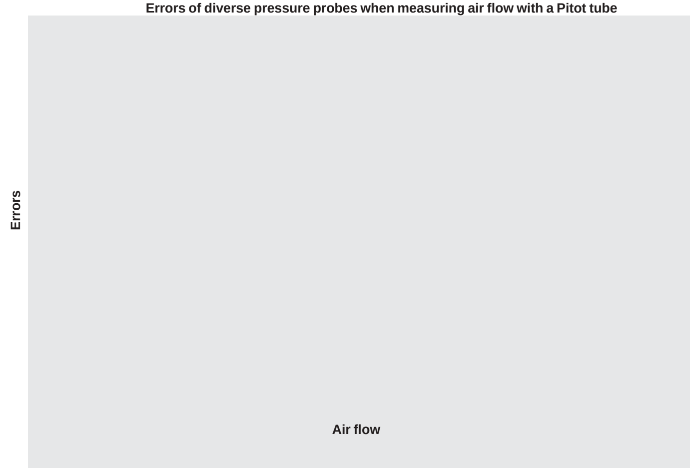
0638.1345; measuring range 0...100 Pa; accuracy ±(0.3 Pa + 0.5 % mv)

0638.1445; measuring range 0...10 hPa; accuracy ±0.03 hPa (= 3 Pa)

0638.1545; measuring range 0...100 hPa; accuracy (0...20 hPa) ±0.1 hPa (= 10 Pa)

It can be seen from the graph that the probe with the measuring range 0...100 hPa has a deviation of ±1.55 m/s (= 31 % measuring error) in the lower range of e.g. 5 m/s. The significantly more accurate 100 Pa probe has an error of only ±0.12 m/s (= ±2.4 %).

Errors of diverse pressure probes when measuring air flow with a Pitot tube



The higher the flow velocity, the less the accuracy of the pressure probes in the calculation of the error.

Pitot tube factor

Testo's bent pitot tubes always have a pitot tube factor of 1. If other makes are adapted to Testo pressure meters, it is essential that the correct pitot tube factor is used in the calculations.
A much greater back pressure can be achieved with straight pitot tubes (order nos. 0635.2045 / 2145 / 2245 / 2345) than with the normal ones. The accuracy is almost twice as good. The pitot tube factor for straight pitot tubes is 0.67. Another considerable advantage of the straight pitot tube is its design. It requires much fewer holes for the pitot tube to be introduced into ducts, particularly if these are insulated tubes.
Caution: Note the minimum immersion depth of 150 mm.

Measuring flows above 100 m/s

The normal Bernoulli's equation no longer applies from about 100 m/s. At these high gas speeds, the compressibility of the fluid must be taken into consideration through the following adjustment factor if accurate measurements are to be obtained.

$$K = \left[1 - \frac{1}{2 * \kappa} * \frac{\Delta p}{p_{st}} + \frac{\kappa - 1}{6 * (\kappa)^2} * \left(\frac{\Delta p}{p_{st}}\right)^2\right]^{1/2} \quad \text{where} \quad \kappa = 1.4 \quad \text{(for air)}$$

or

$$K = \left(1 + 0.25 * (Ma)^2\right)^{-1/2}$$

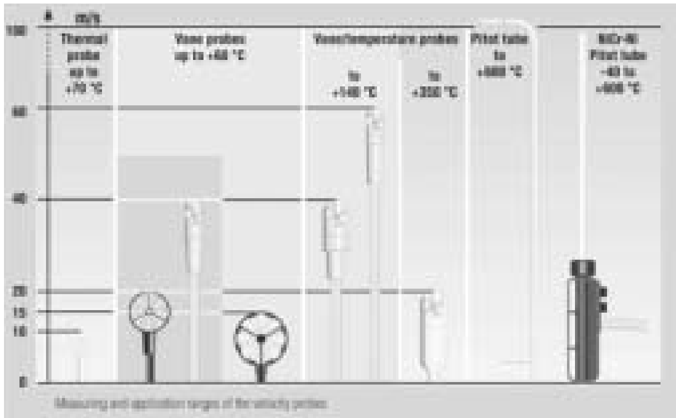
Using this adjustment factor, the air velocity can be calculated as follows:

$$\boxed{v = \alpha * K * \sqrt{\frac{2 * \Delta p}{\rho}}}$$

Symbol	Variable represented	SI unit *)
v	Velocity of the fluid	m/s
pst	Static pressure of the fluid	Pa
ΔP	Differential pressure, back pressure	Pa
ρ	Density of the fluid	kg/m^3
κ	Isentropic exponent	1
K	Adjustment factor	1
α	Pitot tube factor	1
Ma	Mach =	1
	Relationship between the velocity of	
	the fluid and the sound velocity of the fluid	

Advantages of measuring flows by means of differential pressure and a pitot tube

The pitot tube comes to the fore in contaminated and high-temperature environments, as well as for high flow velocities.



Calibration

XVI. Calibration

In the calibration of pressure meters, it is normal to proceed in 5 steps to the final measuring value and in 3 steps back to 0.
You must make particularly sure that the measuring points are not exceeded, as otherwise the hysteresis (see point 9.3.3) will become a factor.

An example:
Suppose you want to calibrate the measuring point 100 hPa. Pressure is built up to nearly 100 hPa by means of a pressure generator. You then approach the measuring point very carefully until it is reached. If you go past the measuring point (e.g. 105 hPa) for whatever reason, you cannot simply release pressure again until you get back to 100 hPa, because you may then achieve different measuring values from above to below than from below to above. In this case you have to start at pressure 0 again. It is also important to observe a pause when generating pressure. If air is compressed by means of a pressure generator, it warms up and expands = the pressure rises. You must then wait until the air has adapted to the ambient temperature. This is the case when the measuring value remains stable.

XVII. Some applications

- Positive pressure / negative pressure in clean rooms
- Measurements in pressure systems (compressor performance)
- On burners (draft measurement Pa + gas flow pressure hPa + combustion chamber pressure hPa + pneumatic bond + supply air velocity m/s + air load m/s)
- Leakage test according to DVGW / TRGI (preliminary/main inspection)
- Filter check
- Pressure shocks (extraction systems)
- Meteorological measurements (absolute pressure)
- Measurements in laboratories (changes in ambient pressure during experiments/tests)
- Leakage searches/consumption rates on compressed air systems by means of leakage function (pressure loss / dimensioning of the system)
- Pressure measurement on refrigeration systems
- Calibration
- Service and maintenance of pumps
- Consumption measurement of gases by measuring pressure loss