Modern pressure sensor technology

Differential pressure sensors – an ambiguous term

In pressure sensor technology several terms have come into use that describe various physical methods of measurement. These include absolute pressure, relative pressure, and differential pressure measurements. Many users are not aware of the fact that several different things are understood by "differential pressure sensing". The following article aims to explain these terms, using piezoresistive sensors as examples. In particular a frequently required setup version which AMSYS [1] refers to as "bidirectional differential pressure sensors" demonstrates the differences between the single versions.

Principle of differential pressure measurement

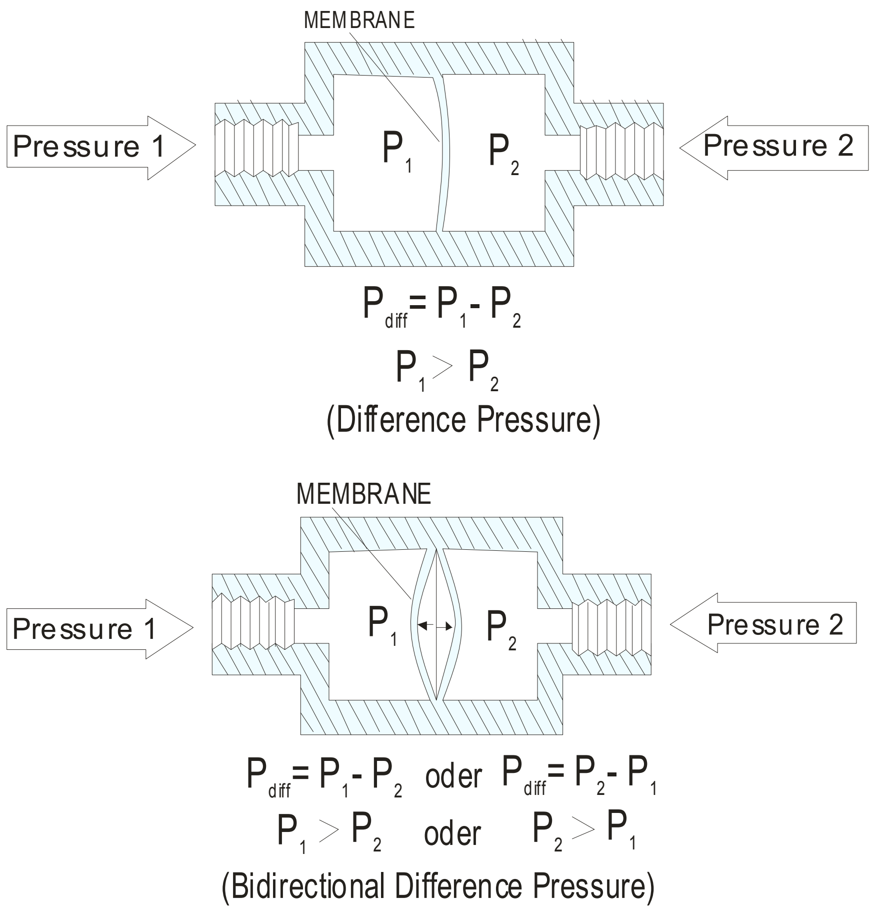

***Figure 1*: The principle of differential pressure measurement, with normal differential pressure sensor at the top and bidirectional differential pressure sensor at the bottom**

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Measuring of differential pressure

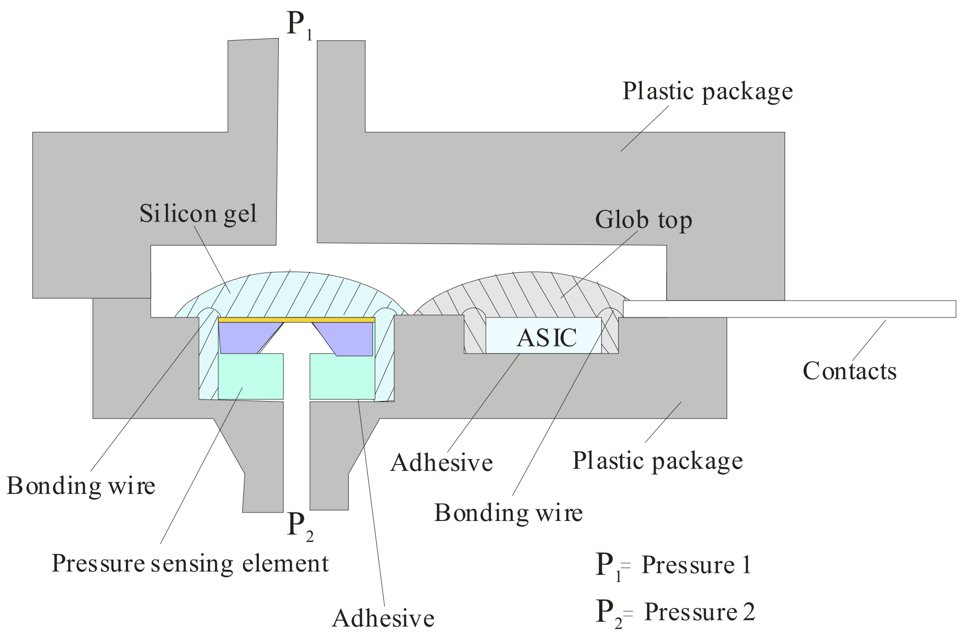

Figure 2: Cross section of a piezoresistive differential pressure sensor

When measuring differential pressure two pressures P_1 and P_2 are compared which are applied externally through the relevant housing (see *Figure 2*) to the upper and lower side of the sensing element (see *Figure 3*). As a general rule is, $P_1 \leq P_2$ or vice versa, $P_1 \geq P_2$.

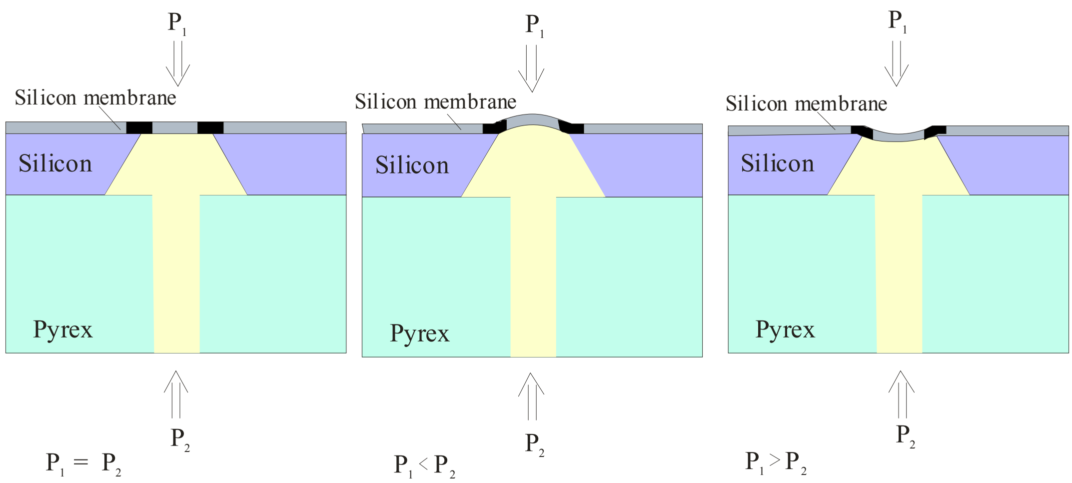

***Figure 3:* Silicon sensing element membrane behavior when measuring differential pressure when $P_1 = P_2$, $P_1 < P_2$, and $P_1 > P_2$**

Figure 3 is a schematic diagram of how the deformation of the membrane belonging to a differential pressure sensing element is to be perceived under various applications of pressure.

For most sensors, for reasons explained below, the requirement is that just one pressure ratio, i.e. $P_1/P_2 \geq 1$ or $P_1/P_2 \leq 1$, is recorded and evaluated. In general, measuring pressure with this restriction is called "differential pressure sensing".

As a general rule, for pressure sensors whose membrane has been optimized to suit the required pressure range the condition also applies that $P_1 - P_2 \leq P_{max}$ or $P_2 - P_1 \leq P_{max}$, with permissible maximum pressure P_{max} dependent on and specified by the given technological conditions of the sensing element.

Besides the aforementioned restriction imposed by maximum pressure P_{max}, there is another condition which must be taken into account depending on the application, namely the resistance of the sensor housing to pressure applied on the both of the pressure ports. This means that neither P_1 nor P_2 may exceed a certain value which is dependant of the packaging of the sensor. AMSYS describes this value as the maximum system or common mode pressure P_{System}; for example,

P_{max} = 20 mbar, P_1 = 10.01 bar, and P_2 = 10 bar;

$P_1 - P_2$ = 10.01 bar -10 bar = 10 mbar < $P_{max.}$

If the housing has been constructed to cope with a P_{System} = 7 bar maximum, in this example both inputs would be 3 bar over the permitted system pressure, which could result in the sensor being destroyed.

This means that another condition especially for differential sensors should be observed, namely $P_1, P_2 \leq P_{SYSTEM}$.

These two boundary conditions must be heeded if the user would like to measure differential pressure in a specific ambient pressure.

The question whether $P_1/P_2 \geq 1$ or $P_1/P_2 \leq 1$ will be recorded is of prime importance to the aspect of media sensitivity when assembling AMSYS pressure sensors.

For the purpose of substrate bonding the upper membrane surface has several small metal surfaces (pads) made of refined aluminum that are not corrosion resistant. These are usually protected by a layer of silicon gel. As these gels are only selectively protective, no universal protection can be guaranteed. It must therefore be ensured that the planned sensors are protected from the contact media, which may be corrosive.
The reverse of the silicon sensing element (in the AMS 4711 example [2], this is made of glass, silicon oxide, and ceramic) is extremely media resistant and has unlike the topside no aluminum pads. It is thus often advisable to apply the critical media or liquids to the underside of the sensing element; this should be taken into consideration in relation to application safety when choosing suitable sensors. In the case of figure 2 the condition for media compatibility is $P_1/P_2 \leq 1$.

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Signal conditioning

As silicon sensing elements in a normal bridge circuit can generate a differential signal of approximately ≤ 150 mV maximum (depending on membrane sensitivity) as a full scale signal, an instrumentation amplifier is first required for signal conditioning. This amplifies the signal with a minimum offset and offset drift so that it can be easily conditioned. In the downstream single-ended conversion stage the differential signal is referenced to a fixed potential. This reference point is normally zero, so that with differential sensing elements (ideally with identical resistors) 0 V is measured as an output signal without applied pressure. In the ensuing signal conditioning process this value is either digitized and calibrated or set to the required offset value in volts or milliamps by a voltage or current output stage. In the AMS 4712 example [3], this value is 4 mA, for instance.

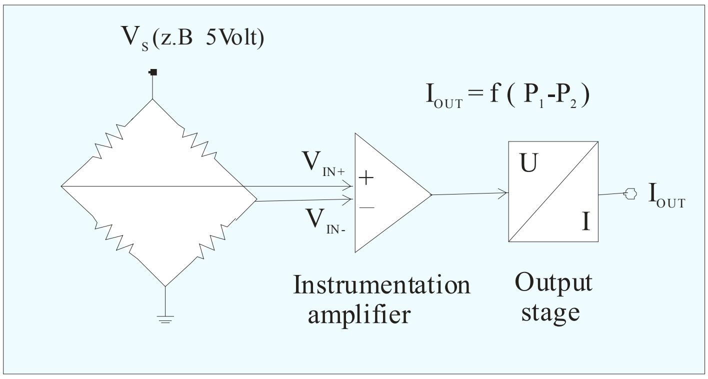

Figure 4: **Signal conditioning electronics with an analog current output stage**

If the instrumentation amplifier is configured in such a way that it can only amplify positive input voltages, and if the higher voltage is present at its positive input, when $P_1 \geq P_2$ the transfer characteristic shown in *Figure 5* is produced.

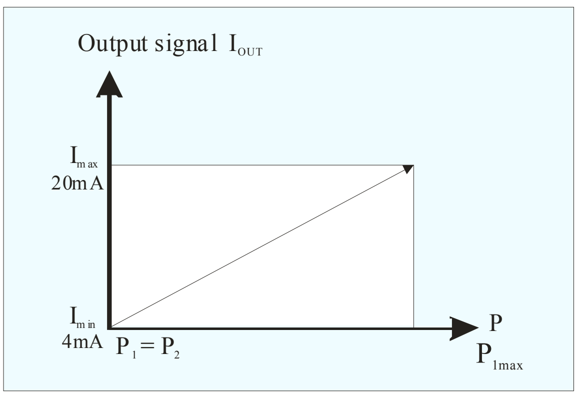

Figure 5: **Transfer characteristic with a positive input signal, e.g. AMS 4712**

Input signal

In the case of electronics designed for $P_1 \geq P_2$, if a negative value is present at the instrumentation amplifier input (e.g. $V(P_1) < V(P_2)$), or if the offset is negative (e.g. an amplifier offset), the sensor output signal will display the zero or the value that corresponds to zero (such as 4 mA) until the input signal meets the condition $V(P_1) \geq V(P_2)$, i.e. the input signal is greater than or the same as the negative bias voltage.

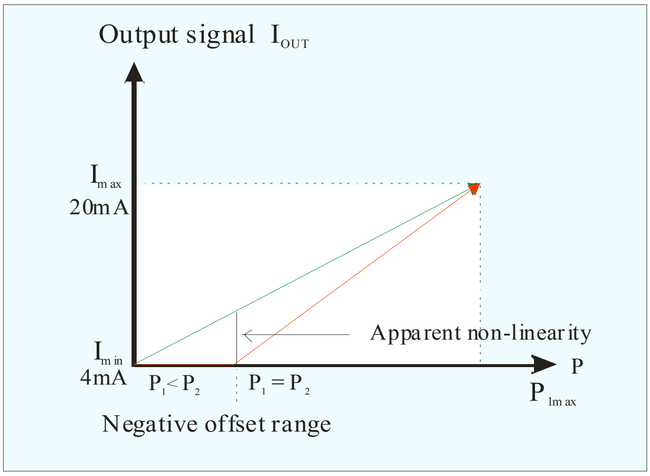

Figure 6: **Transfer characteristic with a negative input offset, or $P_1 < P_2$**

To the user, the existing negative offset at the amplifier input in the *Figure 6* transfer characteristic, for example, then appears as a drift or misalignment, which can be treated as a non-linearity in a two-point measurement (offset and endpoint). This drift (a negative input signal) must be taken into account and compensated in the detection electronics. This means that the quality of the sensor output signal depends on the polarity of the sensing element signal and the characteristics of the amplifier electronics.

Bidirectional differential sensors

Besides the application described above there are other practical applications which require that both conditions $P_1 \leq P_2$ and $P_1 \geq P_2$ are met in one pressure system. These include, for example, ventilation and air exhaust systems, overshooting and/or undershooting a given liquid level, inhalation and exhalation setups, etc. These measurement tasks could not be undertaken using the differential measurement method previously outlined.
As there is no generally established term for this kind of pressure sensing, AMSYS has decided to call sensors that can measure this type of differential pressure "bidirectional differential pressure sensors". These sensors are capable of measuring both positive and negative differential pressure.

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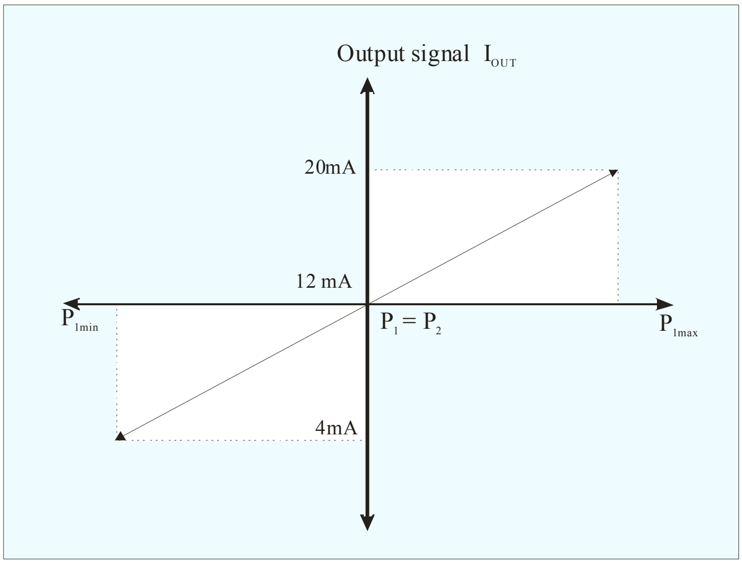

Figure 7: **Transfer characteristic for bidirectional differential pressure sensors**

With these sensors, the differential pressure to be measured can have both a positive and negative polarity. This means that pressure P_1 at port 1 on the topside of the sensing element, for example, can be either greater or smaller than pressure P_2 at port 2 on the underside of the sensing element. The polarity can thus vary during measurement. For pressures P_1 and P_2 at the different ports, the following condition applies:

$P_{min} \leq |P_1 - P_2| \leq P_{max}$ with the boundary condition $P_1, P_2 \leq P_{System}$.

In the above formula P_{max} is the positive and P_{min} the negative ultimate pressure of the relevant pressure range for which the sensors have been designed. P_{System} is the maximum permissible system pressure in relation to the both ports.

Bidirectional differential measurements are only possible when the following two requirements of the sensor system are fulfilled:

a) The membrane structure must behave symmetrically in that it deflects on both sides, and
b) The transfer behavior of the detection electronics must suit the range of the sensing element signal with regard to the offset.

Regarding a): the membrane is a few micrometers thick micro mechanic structure comprising several semiconductor layer. As a rule these are a film of silicon, an oxide coating, and a passivation layer. For this reason the membrane behavior can be direction dependent. In the worst case, it could be subject to the 'click' effect. Manufacturers of silicon sensing elements must therefore ensure that for bidirectional sensors the membrane demonstrates a symmetrical behavior with both positive and negative deflection.

Regarding b): the transfer of the characteristic illustrated in *Figure 7* requires amplifier circuitry in which the instrumentation amplifier is not referenced to zero potential but instead set to half of the full-scale value. For example, for a sensor which should have an output signal of 4…20 mA, in bidirectional differential pressure sensors the offset is set to 12 mA so that signal $P_1 \leq P_2$ ranges from 4 to 12 mA and signal $P_1 \geq P_2$ from 12 to 20 mA.

Conclusion

Differential pressure sensors measure the difference between two pressures. We differentiate this type of measurement from differential pressure sensing where the pressure conditions remain the same. The condition applies that the pressure at one of the ports is always greater/the same as the pressure at the other port. Differential pressure sensing which permits both positive and negative differential pressure is referred to as "bidirectional differential pressure sensing" and is described in the above article.
The above also explains that depending on the application on hand, certain boundary conditions must also be taken into account when selecting differential pressure sensors.

Further information

[1] Website: http://www.amsys.info
[2] AMS 4711 datasheet: http://www.amsys.info/sheets/amsys.en.ams4711_e.pdf
[3] AMS 4712 datasheet: http://www.amsys.info/sheets/amsys.en.ams4712_e.pdf