Pressure sensors: Design considerations and technology options

Introduction to pressure sensors: Design considerations and technology options

There are many different types of applications for pressure sensors, which create a need for a wide variety in sensor types and characteristics. Variants are available for harsh or corrosive environments and aimed at high-integrity applications such as use in medical equipment. Others are intended to provide low cost for use in consumer mobile devices. Here’s our guide to pressure sensors, how they work and what to look out for.

WHAT IS A PRESSURE SENSOR?

Broadly speaking, pressure sensors convert the pressure of the atmosphere, gas or liquid they are exposed to into an electrical signal.

There are three different types of pressures that can be measured: gauge, absolute and differential.

Gauge pressure (fig 1) is the pressure measured relative to the ambient atmospheric pressure. It can be positive for pressures higher than atmospheric, or negative for lower pressures. Ambient atmospheric pressure is usually sensed via a hole in the packaging. A typical application for a gauge pressure sensor is to measure liquid levels in a vented tank using the difference in hydrostatic pressure and ambient atmospheric pressure.

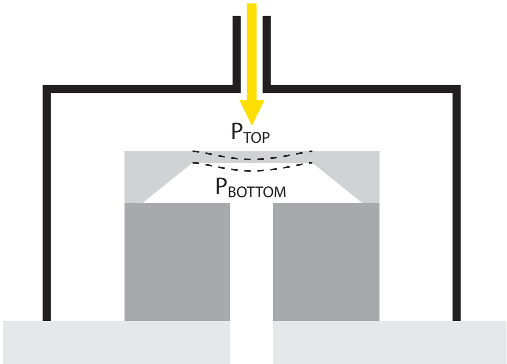

Figure 1: The top side pressure, P_{TOP}, must be higher than the gauge reference, P_{BOTTOM}, and results in positive change of differential output voltage of the pressure sensor. The gauge reference is identical to the local atmospheric pressure level.

Absolute pressure sensors (fig 2) will give the result relative to zero (a perfect vacuum). This is useful in applications that are measuring atmospheric pressure, perhaps to determine altitude. Absolute pressure sensors are also used in pressure measurement applications that will be used at different altitudes; since atmospheric pressure varies with altitude, gauge pressure wouldn't give an accurate reading. This type of sensor is also used in applications such as tyre pressure monitoring systems to optimise tyre performance.

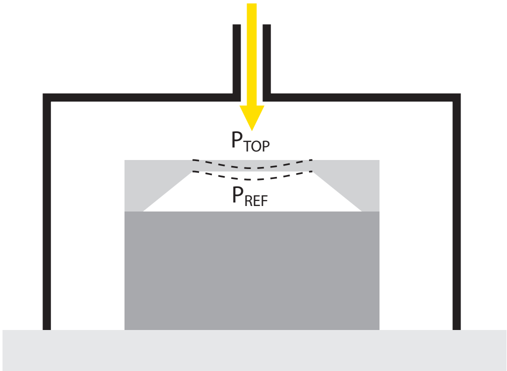

Figure 2: Absolute pressure sensor. Top side pressure, P_{TOP}, results in positive change of differential output voltage of the pressure sensor.

Differential pressure sensors (fig 3) measure the difference in pressure between two samples, similar to how a gauge sensor works, but differential sensors are sometimes used to detect the pressure difference either side of an object, for example. Differential pressure sensors are often used to monitor airflow in HVAC applications.

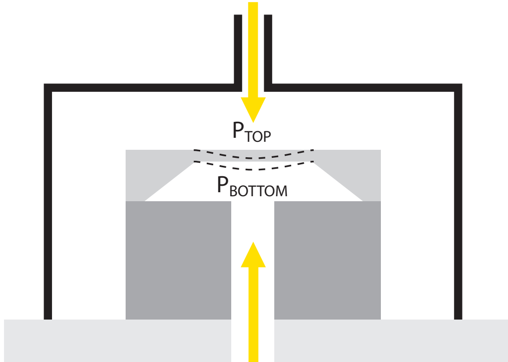

Figure 3: Differential pressure sensor. A top side pressure, P_{TOP}, higher than the bottom side pressure, P_{BOTTOM}, results in positive change of differential output voltage of the pressure sensor. Bottom side pressure being higher than top side pressure results in negative change of differential output voltage of the pressure sensor.

Specifying absolute pressure sensors where they aren't really required is a common mistake; the majority of industrial applications can use gauge pressure. It's important to fully understand the application's requirements before making a selection to ensure an accurate, efficient and economical choice.

Pressure sensors come in several different types. You will see pressure sensors described as sensors, transducers and transmitters, and while these terms are sometimes used interchangeably, the devices they describe aren't technically the same.

Pressure sensors produce an output voltage that varies with the pressure they experience, usually referring to the sensor element that is physically detecting the pressure. Packaged board-mount pressure sensors are available that will require the designer to consider calibration, temperature compensation and amplification separately. Confusingly, the phrase 'pressure sensor' is also sometimes used to describe transducers and transmitters in general.

Pressure transducers, like pressure sensors, produce an output voltage that varies with pressure. A transducer in this context is a sensing element combined with signal conditioning circuitry, perhaps to compensate for temperature fluctuations, and most likely an amplifier to allow transmission of signals further from the source. Note that for most applications there is an advantage to specifying pressure transducers that are temperature compensated rather than trying to implement custom temperature compensation on a pressure sensing element, as the testing required can be complicated.

Pressure transmitters are similar to transducers, but their output current varies with pressure, rather than the voltage. Be aware that in portable applications, transmitters can wear the batteries down if they are consistently used at the top end of their pressure range.

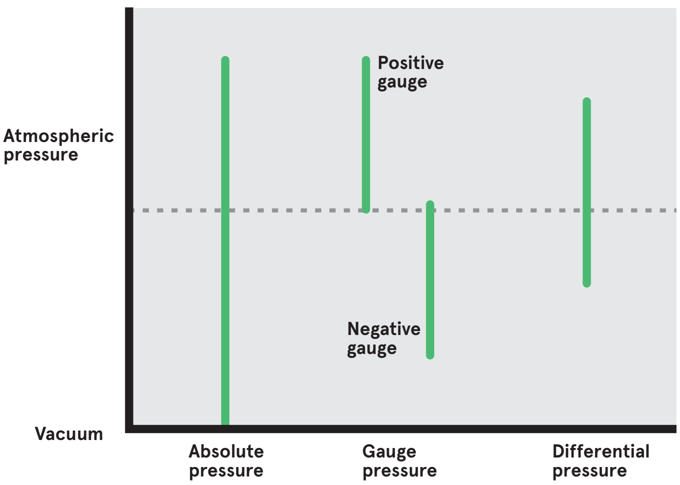

Figure 4: Differences in types of pressure measurement

TYPES OF PRESSURE SENSING ELEMENT

The most common types of pressure sensing technology around today are strain gauges. These sensors use some kind of diaphragm, which deflects due to the pressure it experiences. A strain gauge is attached to the diaphragm, which changes its resistance as the diaphragm deflects, that is as the pressure changes. This change in resistance is usually measured by a Wheatstone-bridge circuit.

Strain gauge technologies include bonded foil, in which a metal foil gauge is glued or bonded to the metal diaphragm, and then two or four diaphragms are arranged into a Wheatstone bridge. These sensors can resist high pressures over a wide temperature range and they respond quickly to changes in pressure.

Also available are sputtered glass strain gauges, in which a layer of glass is sputtered onto the diaphragm, then a foil strain gauge is sputtered onto the glass – that is, there is a molecular bond between the strain gauge, the insulating layer and the diaphragm, rather than it being simply glued on. These sensors are very robust, suitable for long-term use and harsh environments.

Silicon MEMS strain gauges are very common today. They are based on a micromachined silicon diaphragm with a strain gauge or piezoresistive device and temperature sensor grown onto it. These devices can be integrated at chip level with signal conditioning electronics to make pressure transducers or transmitters. The piezoresistive versions (fig 5) use the change in resistance of a material based on strain to record the change in pressure. They employ the same Wheatstone-bridge circuit for measurement as with a conventional strain gauge.

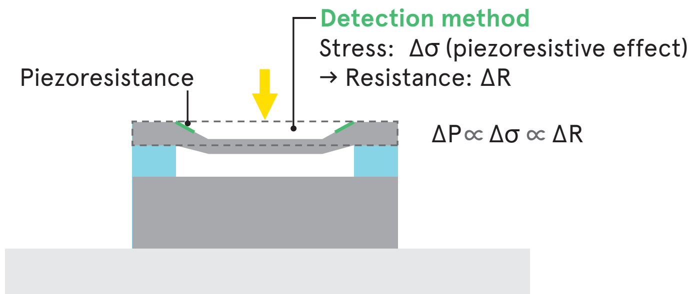

Figure 5: Schematic illustration of a piezoresistive element cross section

Aside from traditional strain gauges, there are also capacitive, piezoelectric and optical pressure sensors. Capacitive pressure sensors (fig 6) use a MEMS diaphragm over a metal surface, which deflects as the pressure changes, changing the system's capacitance.

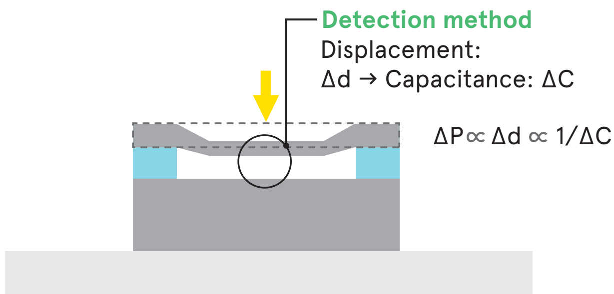

Figure 6: Schematic illustration of a capacitive element cross section

Piezoelectric sensors use an element made of a material that generates electrical energy when they are under strain, such as quartz or tourmaline. Crucially, they only produce energy when the pressure changes, and are therefore suitable only for dynamic pressure measurements (not static pressure). They are also susceptible to shock and vibration. As with strain gauge and capacitive types, piezoelectric sensors can be made using MEMS techniques.

The optical pressure sensor uses fibre Bragg gratings to measure the deflection in a glass fibre caused by changes in pressure on it. It is a technique that is highly suited to conditions where temperature and electromagnetic compatibility may be a problem.

CHOOSING A PRESSURE SENSOR

RANGE AND ACCURACY

When comparing pressure sensors, there are a number of physical and performance attributes to be considered.

Firstly, you'll want to consider the pressure range each sensor is capable of measuring and how that compares to the pressures you want to measure. You may also wish to consider proof pressure - the maximum pressure the device can withstand and then retain functionality when the pressure returns to the operating range, and burst pressure - the pressure that breaks the component such that fluids can leak (which may be dangerous in some applications).

Pressure sensor accuracy is an important performance attribute, which is typically given as a percentage of full-scale pressure over a certain temperature range. Some sensors also exhibit hysteresis, non-repeatability and non-linearity, which should be described on the data sheet, if they apply. Linearity is generally expressed as a percentage of full scale pressure, but there are two methods of measurement (best fit straight line and terminal point) which are not equivalent, so be sure to compare like with like. Long-term stability of devices is also desirable – look for low drift over time as well as good stability over a wide temperature and humidity range – while short-term stability after soldering can also be an issue if the device needs to be used straight away (some sensor types can take hours, or even weeks to stabilise).

ENVIRONMENT AND INTEGRATION

Next, consider the environment the sensor will be operating in. Mechanical robustness may be an issue – the sensor's specification may give an idea of its expected cycle life. The ability to withstand liquids or contaminants may be attained by selecting a stainless steel part (note that most gauge pressure sensors have a hole or vent in the packaging for reading atmospheric pressure, which can get clogged with dirt). Sensitivity to shock and vibration is also particularly important to automotive, transportation and industrial applications.

You should consider how long you have to spend on integrating the sensor into your system. If time is short, a transducer with integrated signal conditioning electronics, temperature compensation, self-calibration, internal diagnostic functions and a digital output may be the best choice. However, if your system has specialist needs and you are working with appropriate design resources, your own custom implementation of the electronics could be the right choice, especially if you are prepared to calibrate the sensor after assembly.

Some other vital parameters are the sensor's response time (vital if real time feedback is required), energy efficiency (check the current consumption figures, especially for transmitters), and physical size. For hard to reach areas or portable equipment, you'll be looking for a compact solution. Modern sensors come in a variety of package sizes and options that also need to be investigated. For example, does the sensor need to be surface mounted onto a PCB or does it need to be mounted in a specific orientation? Both obviously have implications for packaging choice.

TECHNOLOGY SELECTION

The different sensing technologies tend to offer performance in different pressure ranges and suit certain environmental conditions.

PIEZORESISTIVE AND STRAIN GAUGE

The piezoresistive sensor has become a commonly used pressure sensor thanks to the widespread use of MEMS manufacturing technologies. These make the sensors relatively inexpensive to produce, assuming they do not need specialised packaging to handle dirty or hostile environments. However, the sensing elements are sensitive to ambient temperature and their response to changes in temperature is not linear. As a result, the sensors need to be calibrated and their inputs interpreted in the context of temperature. The use of resistance for measurement also presents the issue of demanding a constant current flow while the sensor is active, which increases system energy requirements that may be troublesome in a mobile or IoT context.

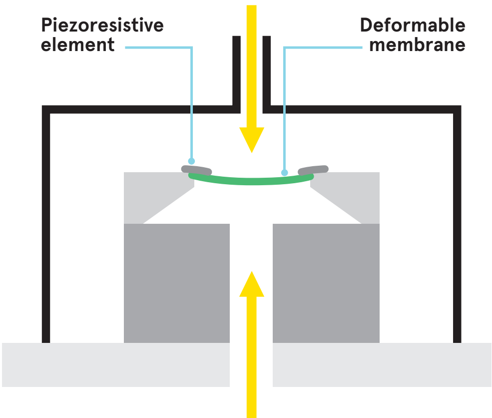

Figure 7: Piezoresistive sensor

Sensors based on strain-gauge principles can be made with lower temperature sensitivity through the use of isoelastic alloys. Another approach is to employ a design that includes a dummy gauge. Specialised designs and materials are often used at higher temperatures because the performance of the alloy changes as the ambient heat levels are pushed far above room temperature.

CAPACITIVE

The capacitive sensor employs two types of membranes: one flexible, the other stiff. The relative movement of the conductive membranes leads to changes in capacitance in those cells. The cells that have stiff membranes act as reference devices. The advantage of this structure is that both sensing and reference cells are exposed to the same thermal conditions and so are relatively immune to changes in ambient temperature. The design is highly suited to battery-powered applications because it does not rely on the presence of a constant current. Capacitive sensors tend to be useful for detecting small changes in pressure, such as those due to altitude. Consumer-class products are able to sense changes of ±0.005hPa, which equates to an altitude change of approximately ±5cm near sea level.

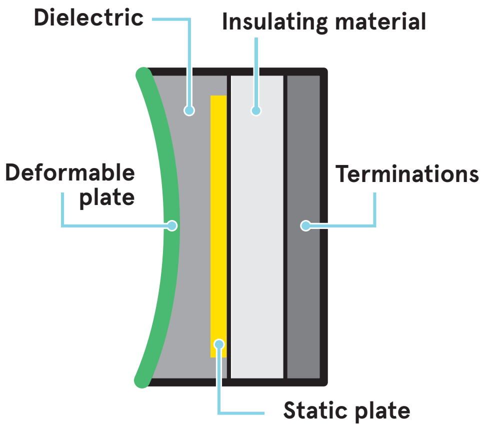

Figure 8: Capacitive sensor

PIEZOELECTRIC

The piezoelectric pressure responds to instantaneous changes in pressure rather than changes compared to a reference such as vacuum or ambient air pressure. They use the production of charge in response to a deflection to operate and so require a dynamic input to operate, unlike the broadly similar piezoresistive technology. A typical application for a piezoelectric sensor is to detect changes in liquid or gas pressure, often within an engine or reactor to measure the efficiency of combustion.

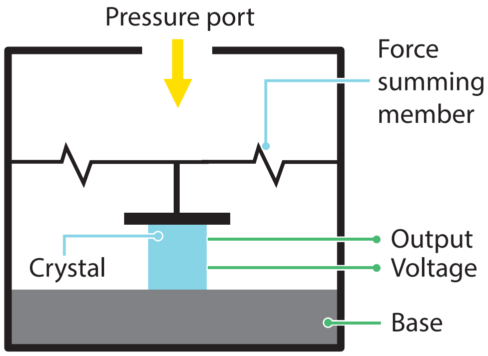

Figure 9: Piezoelectric sensor

OPTICAL

Optical fibre technology is generally employed in challenging applications where the measurement may be highly remote, under high temperature, or may benefit from technologies inherently immune to electromagnetic interference. The technique works by sending pulses of light through an optical fibre and using interference measurements to analyse the change in time of flight for the return pulses after they have reflected off a deformable mirror at the measurement point. A common use for optical sensors is to measure the pressure inside oil wells or for highly sensitive measurements in medicine.

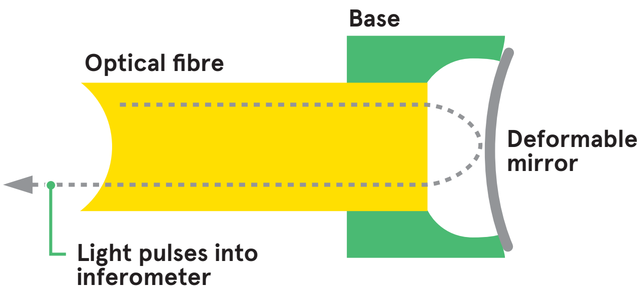

Figure 10: Optical sensor

SUMMARY

Choosing the right pressure sensor can be a complex process regardless of the application, and understanding how pressure sensors are designed and constructed is a key first step to making the best decision. Other technical aspects for consideration include long term stability, energy efficiency, ability to withstand harsh assembly and mounting conditions, form factor, interface and output type. Additionally, commercial considerations include the availability of samples, evaluation boards and technical expertise.

Avnet Abacus stocks pressure sensors from a range of leading manufacturers, and our pan-European team of technical specialists can help you find your optimal solution. Visit **avnet-abacus.eu/ask-an-expert** to get in touch and discuss your design.

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