Precision level sensing with low-pressure module MS5536-60

The task on hand

Level sensing as it is understood in modern process automation is much more than simply "tank half full" or "tank a quarter full". Using suitable sensors, levels, inlets and outlets can be measured to obtain valuable information on process dynamics. These application notes aim to illustrate how such measurements can be carried out using precision pressure sensor MS5536-60 [1].

Contents:

Pressure measurement with silicon sensing elements

When measuring differential pressure, two pressures P_1 and P_2 are compared which are applied externally via a pressure path (package) to the top and bottom of a silicon sensing element with a membrane (*Figure 1*). As a rule, the following condition applies: $P_1 \leq P_2$ or, vice versa, $P_1 \geq P_2$. With most silicon-based sensors the requirement is usually that only one pressure ratio can be recorded and evaluated, either $P_1/P_2 \geq 1$ or $P_1/P_2 \leq 1$. Generally, measuring pressure with this limitation is referred to as differential pressure sensing [2].

Furthermore, pressure sensors whose membrane has been optimized to match the relevant pressure range are also subject to the condition that $P_1 - P_2 \leq P_{max}$ or $P_2 - P_1 \leq P_{max}$, where *Pmax* is stipulated by the technical conditions and specified as positive maximum pressure or burst pressure.

Figure 1 is a schematic diagram of how the deflection of the membrane belonging to a differential pressure sensing element is to be perceived under various applications of pressure. The change in sign in the output signal signifies nothing other than a change in the membrane deflection.

Measuring relative pressure

Should one of the active pressures P_1 or P_2 be equal to the ambient pressure effective outside the system (e.g. such as atmospheric pressure P_{atm}), we then speak of relative pressure sensing, to which the same applies as to differential pressure with the limitation that P_1 or $P_2 = P_{atm}$. In this case, no connecting tube for ambient pressure is required. This can be applied to the sensing element through a simple opening in the sensor package (*Figure 3*).

The sole remaining connecting tube is thus the typical distinguishing feature between relative pressure and differential pressure sensors.

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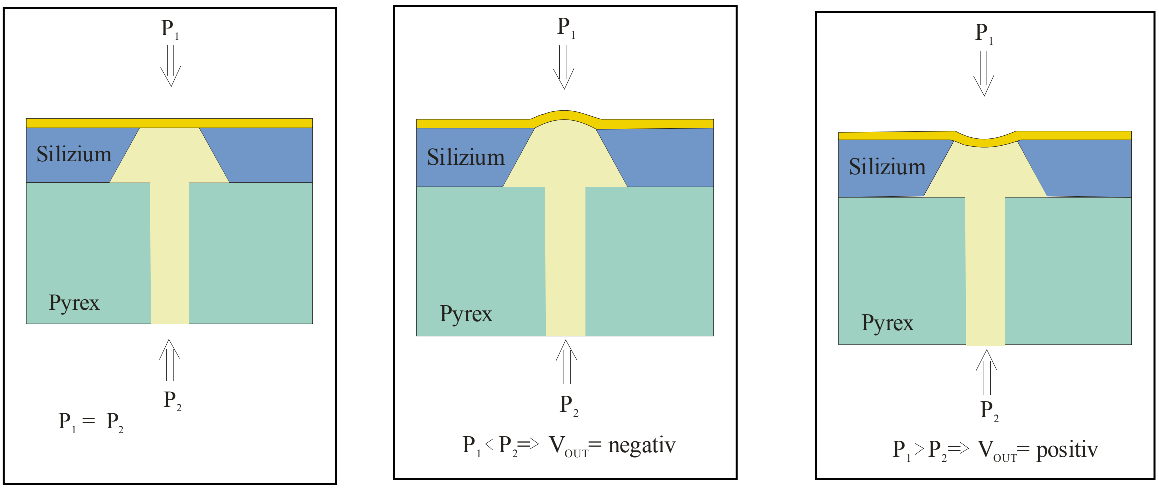


Figure 1: **How a piezoresistive sensing element functions in the measurement of differential pressure (relative pressure)**

Level sensing

In principle, level sensing with pressure sensors is the same as measuring relative pressure where, for example, pressure P_1 is equal to ambient pressure and pressure P_2 to ambient pressure plus the pressure generated by the weight of the liquid column (hydrostatic pressure).

Figure 2 is to be used to explain Pascal's law that forms the physical basis of level sensing with a pressure sensor.

The following applies to the hydrostatic pressure extant in a vessel filled with liquid and open to ambient pressure:

$P(h) = \rho \cdot g \cdot h$ (see *Figure* 2).

This means that at a constant liquid with a density of ρ = f(T) the pressure prevalent at the point of measurement is proportional to height of the liquid *h* (up to the measuring point). To this must be added ambient pressure P_{atm} active on the surface of the liquid. The pressure prevalent in the open vessel thus becomes $P = P_{atm} + P(h)$.

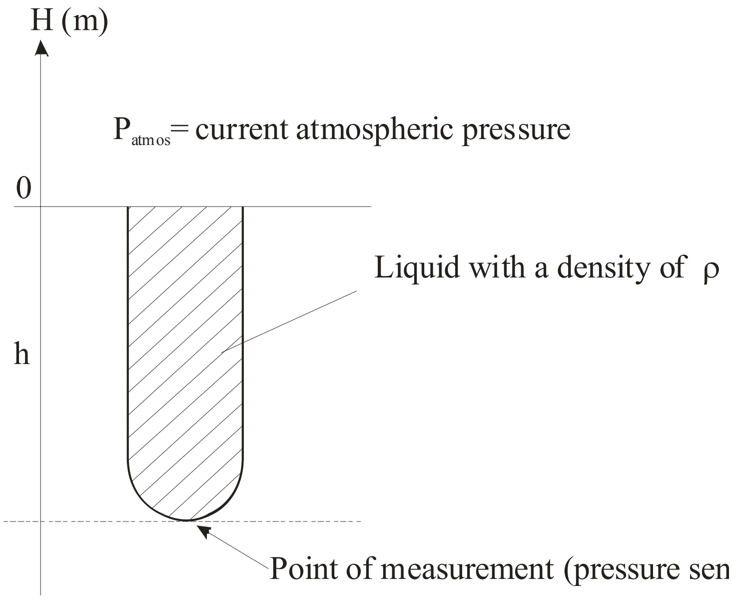
If a relative pressure sensor is affixed at the point of measurement (initially at the lowest point of the vessel), one side of which measures the active total pressure *P* and the other side of which is connected to ambient pressure P_{atm}, the effects of the ambient pressure stand out on the upper or lower side of the membrane. This would show no deflection if P_{atm} were to be applied to both sides. It follows that the membrane and thus also the sensor only react to the difference between pressure P_{atm} and pressure P_{atm} + *P(h)*, i.e. to the hydrostatic pressure *P(h)* in the vessel.

The following equation is used for conversion:

1.000 Pa = 10 mbar or = 10 cm water column at 4°C.

As the differential pressure alone determines the deflection of the membrane, the magnitude of the ambient pressure is not relevant. At an ambient pressure of 1.000 mbar, for example, and a maximum fill level of, say, 50 cm, a low-pressure sensor with a pressure range of 0 to 50 mbar can thus be deployed. At a water column of 10 cm and a room temperature of 4°C the pressure sensor would display an output signal relevant to a pressure of 10 mbar.

It is sensible to adapt the pressure range of the sensor to suit the task to be measured or rather the maximum fill level, as otherwise the output signal would be lowered by the ratio sensor pressure range/maximum hydrostatic pressure.



$$P = P_{atmos} + P_{hydrost.}$$

$$P_{hidrost.} = f(h) = \rho * g * h \quad (Pa)$$

with ρ = density... = f (T) (kg/m^3)

g = gravitational acceleration 9,32 m / s^2

h = liquid height (m)

Figure 2: **Pressure ratios in pressure sensing**

In practice several technical points must be taken into consideration when positioning the sensor for level measurement; these may require a different form of assembly (*Figure 4*).

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MS5536-60 as an example application

The low-pressure module MS5536-60 (*Figure 3*) which allows a precision liquid level measurement consists of a silicon pressure sensing element and integrated signal conditioning circuitry, both mounted on a ceramic substrate with lead-free soldered connections.

The main function of the module is that of a 16-bit A/D converter that converts the analog pressure sensing value of the sensing element into a 16-bit word. In addition to the pressure, the temperature of the sensing element is also digitally converted in the same way. As the output voltage of the pressure sensing element heavily depends on temperature and manufacturing tolerances, these effects must be eliminated by compensation of the modul. To this end, the individual correction data determined during manufacture and stored internally on MS5536-60 is linked to the measurement values ascertained. This is done in an external microprocessor which with the help of a simple algorithm offsets the current measured pressures and temperatures against the correction data, thus individually calibrating the module.

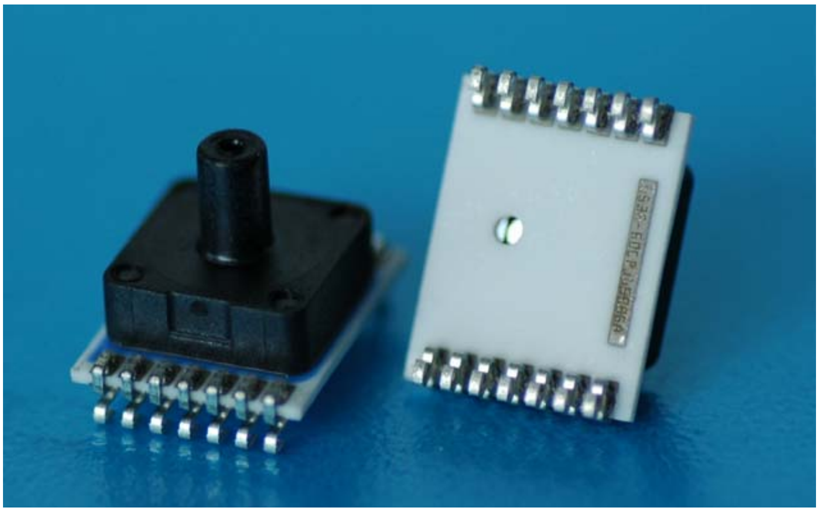

***Figure 3*: MS5536-60 (top: connecting tube; bottom: opening for ambient pressure)**

Module MS5536-60 can be connected up directly to a standard microprocessor – without the need for expensive additional components, such as instrumentation amplifiers or A/D converters.

A simple, three-wire, synchronous serial interface circuit joins the module electronically to a downstream processor. The protocol does not require a specific driver or interface component and can be implemented in any microprocessor with standard I/Os. The required 32.768 kHz clock signal is generated by an external oscillator, familiar from clock applications and available as an inexpensive standard component.

The silicon pressure sensing element and particularly the aluminum bond pads are protected against moisture by a silicone gel and against mechanical damage by a plastic casing. The package with its plastic connecting tube is hermetically sealed to the ceramic substrate and enables pressure to be applied to the top of the sensing element. Ambient pressure is applied via the back opening in the ceramic substrate on the underside of the membrane.

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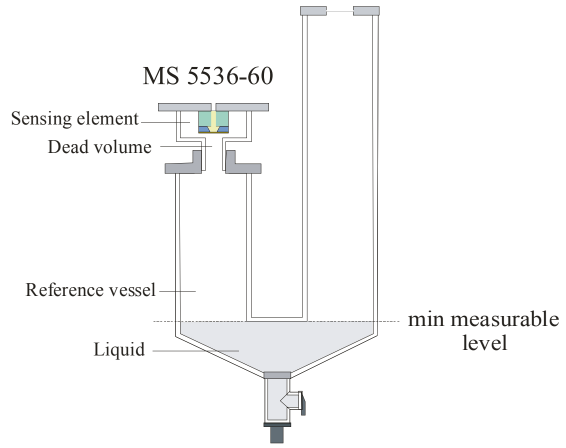

Figure 4: **Example assembly with an almost empty tank**

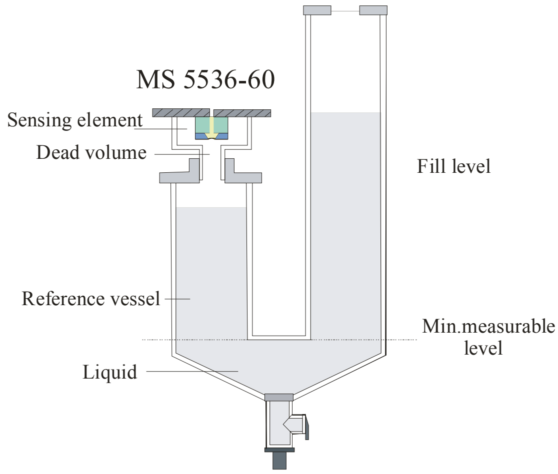

Figure 5: **Example assembly with an almost full tank**

When measuring levels directly with a silicon pressure sensor (i.e. without an oil filled cavity and separation membrane, for example), it must be taken into account that the sensor should be mounted above the liquid level of a reference vessel (see *Figures 4* and *5*). This is to ensure that the liquid does not come into direct contact with the sensing element and this become damaged by corrosion, for example, despite the silicone gel. On no account should aggressive liquids be used.

So that level measurements are precise, it should also be ensured that the dead volume between the surface of the liquid and the membrane is filled with air which both acts as a buffer between the sensor and the liquid and whose compressibility is dependent on temperature. This means that with deviations in liquid temperature the temperature-dependent dead volume influences the fill level to be measured and that this should be accounted for in the software correction with minor deviations in level.

In a precision measurement not only the temperature-dependent dead volume must be taken into consideration; the temperature-dependent density is also an important factor. In principle, the temperature sensor on MS5536-60 can be used for this purpose. In conjunction with the required degree of accuracy, however, the condition applies that the sensor module must have the same temperature as the liquid. This can be achieved with a sufficiently good thermal coupling.

MS5536-60 has been optimized for use at pressures of about 60 mbar (corresponding to a 60 cm water column at 4°C) and has a resolution of 0.05 mbar (equal to a 0.5 mm water column) at an average of 2–8 pressure cycles. In order to achieve a greater accuracy, it is recommended that the offset be recalibrated at regular intervals using the application software. To this end, the calibrated value of a defined pressure state should be determined at, for example, $\Delta P = 0$. The difference between the displayed value and the current value can be stored and used for correction purposes in future measurements.

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Conclusion

MS5536-60 is a calibrated and compensated low-pressure module with a high resolution which had been designed for level sensing. Exploiting the available possibilities, changes in level of 0.5 mm can be measured; with knowledge of the geometric dimensions, the amount of inflow or outflow liquid is thus able to be determined with a very high degree of accuracy.

Further information: www.amsys.de

[1] Datasheet MS5561: www.amsys.info/products/ms5536-60.htm

[2] Application notes aan505: www.amsys.info/special/notes.htm