

Precision from the deep

Hydrostatic level measurement with submersible pressure sensors

Reliable, precise and uncomplicated: electrical level measurement based on hydrostatic pressure is suitable for a wide range of applications. The measuring instrument for this purpose, a submersible pressure sensor, is easy to install and works at greater depths than other common measurement methods.



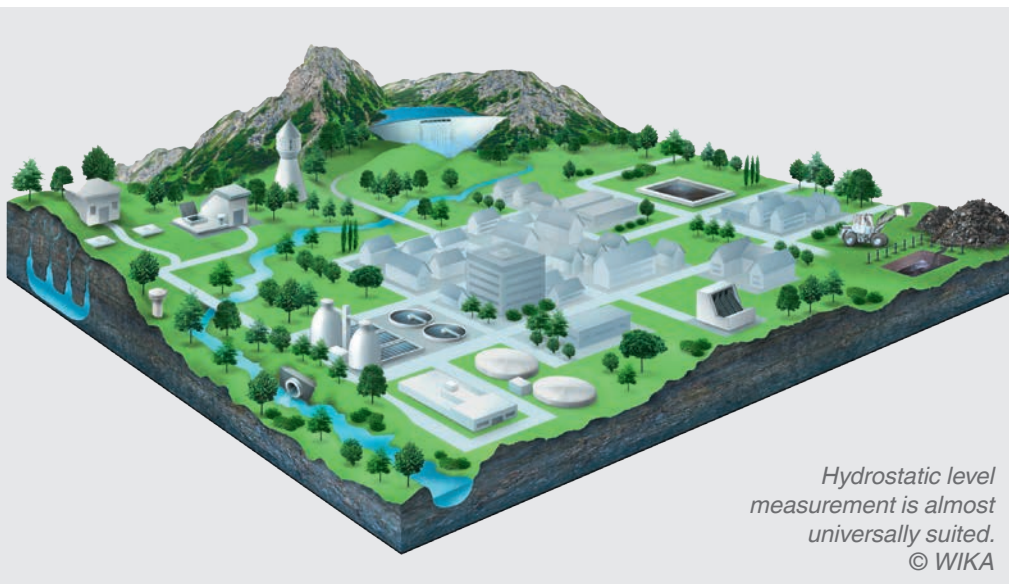
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1. Introduction

Level measurement is a complex undertaking. A glance at VDI / VDE Directive 3519 suffices to confirm this. Thirteen different methods are listed there for limit level detection and / or continuous measurement, from visual (i.e. reading directly) to radar and ultrasonic. The choice depends on a whole range of criteria, for example the type of medium (liquid or solid) and its material properties or the geometry and height of the vessel.

The bottom pressure method, which is among those mentioned in the list, is particularly flexible and can be implemented with comparatively little installation effort. Hydrostatic level measurement, as it is widely known, can be used for all liquid media and is ideal for tanks as well as for basins, shafts and open reservoirs. When it comes to applications at great depths, it is practically without alternative. The hydrostatic method has many advantages and is one of the most common forms of electrical level measurement.



2. The measuring principle – insensitive to physical influences

Hydrostatic level measurement is used to determine the level of a liquid in a vessel. It is based on the following principle:

A liquid produces hydrostatic pressure due to its specific density and gravitational force. This hydrostatic pressure changes analogously to the filling height. The height of the liquid column can thus be calculated from the measured pressure value and the density of the medium (*more on this in chapter 3*).

If pressure is the decisive parameter, the measurement is

- Insensitive to many of the medium's physical properties such as conductivity, the dielectric constant or viscosity
- Unaffected by the vessel geometry and any installed equipment

2.1. The sensor technology – submersible pressure sensors

Submersible pressure sensors were developed specifically for measuring hydrostatic pressure (*for details of their functionality and design, see chapter 4*). They are usually supplied in a gauge pressure version.

Submersible pressure sensors are lowered down to the bottom of the tank, lake or shaft by their connecting cable. Their weight is adequate for this even at great depths. In narrow shafts, an additional weight can be useful to ensure that the cable remains taut.

The sensor element at the lower end of the housing detects the pressure prevailing at the bottom. The measured value is then transmitted to a downstream logic unit, which calculates the filling height (and possibly also the volume).

Theoretically, conventional pressure transmitters could likewise be used for hydrostatic level measurement in a vessel. However, these measuring instruments would need to be screwed in from the outside either directly into the bottom or as near to it as possible. Even with a favourable mounting position, installing them would be less straightforward than is the case with submersible pressure transmitters. Furthermore, there is a potential risk of leakage at the measuring point.



Submersible pressure sensors are easy to install regardless of the design and application. | ©WIKA

3. Pressure and density – the level calculation

Hydrostatic pressure increases with the height of the liquid column due to gravity. The filling height “h” is accordingly calculated using the following formula:

$$h = p / (\rho * g)$$

p = Hydrostatic pressure [Pa]

ρ = Density of the liquid [kg/m³]

g = Gravitational force or gravitational acceleration [m/s²]

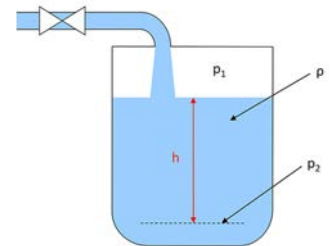
h = Height of the liquid column [m]

For example, the pressure in a water tank increases by approximately 10,000 Pa (= 100 mbar) for every metre below the surface. A rule of thumb can be derived for this application as follows: a pressure of 100 kPa (= 1 bar) corresponds to a water column height of 10 m ($h = 100,000 \text{ Pa} / (\sim 1000 \text{ kg/m}^3 * \sim 10 \text{ m/s}^2) = 10 \text{ m}$). With other media, the specific density is needed to obtain a similar rule of thumb as a starting point for selecting or specifying the most suitable submersible pressure sensor. However, a more precise calculation should always be carried out, to take account of the effect of temperature on density as well as the gravitational force at a particular location (see chapter 3.1).

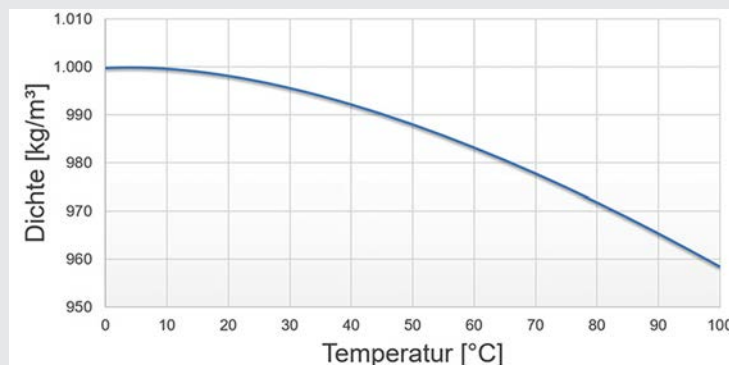
There is continuous venting during hydrostatic level measurement in open basins or vessels, i.e. pressure compensation between the gas above the liquid and the atmosphere. The pressure of the overlying gas can be disregarded when calculating the filling height for this reason. Variations in atmospheric pressure can be fully compensated with the help of submersible pressure sensors in gauge pressure design, in other words the sensor measures the hydrostatic pressure relative to atmospheric pressure.

3.1. Temperature effect and compensation

With hydrostatic level measurement, the accuracy of the results is influenced by temperature variations in the medium. This is because the density of any medium ($\rho = m / V$) is subject to the effect of temperature according to the physical law whereby a volume expands as the temperature increases at constant pressure. The medium’s density consequently shrinks if the temperature rises and vice versa. Since the hydrostatic pressure “p” remains constant in open geometries, this temperature effect has negative impacts for the measurement result. In order to obtain a precise statement on the filling height, the hydrostatic pressure which is measured for a liquid must always be correlated with the medium temperature.



Schematic diagram of a level calculation according to the hydrostatic principle.
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Density of water at 1013 mbar atmospheric pressure.
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Example: The density of water at room temperature (20°C) is 998.20 kg/m³. If the same value is assumed for a calculation with water heated to 80°C, a measurement error of 2.7% will be observed because water at 80°C has a density of only 971.79 kg/m³. The difference is even greater with oils and fuels. For instance, an error of approximately 4.5% is likely for an engine oil in the above calculation.

If accuracy plays a subordinate role in level monitoring, it is not necessary to compensate the temperature by correcting the density. This also applies when no, or only minor, temperature variations occur in the process. However, if the application requires precise hydrostatic level measurement regardless of any variations in the temperature of the medium, density change compensation is a must. If the medium's current temperature is known, the actual density can be used to calculate the filling height and rule out measurement errors. In this case, submersible pressure sensors integrating a temperature probe are recommended.

3.2 Measurements in a closed system

Submersible pressure sensors can also be integrated into closed systems. However, this is rather more complicated because in this kind of system, the pressure in the gas phase above the medium is not the same as atmospheric pressure. This pressure additionally affects the liquid column. The submersible pressure sensor therefore measures a total pressure made up of the hydrostatic pressure of the liquid and the gas pressure on that liquid. The level, on the other hand, remains unchanged, meaning that the result will be distorted.

An additional pressure measuring point is required in this case for the gas zone in order to calculate the level correctly. It is equipped with a conventional pressure sensor that is installed either on the side of the vessel or on top.

The liquid level in a closed vessel is calculated according to the following formula:

$$h = (p_2 - p_1) / (\rho * g)$$

p_2 = Total pressure (hydrostatic pressure + pressure of the gas contained in the vessel) [Pa]

p_1 = Pressure of the gas contained in the vessel [Pa]

ρ = Density of the liquid [kg/m³]

g = Gravitational force or gravitational acceleration [m/s²]

h = Height of the liquid column [m]

The consequences of dispensing with a second pressure measurement can be illustrated using the example of a closed tank containing a volatile medium such as petrol. The following basic parameters are assumed:

p_2	(Measured total pressure):	200,000 Pa (= 2 bar)	$\rho = 750 \text{ kg/m}^3$
p_1	(Measured gas pressure):	120,000 Pa (= 1.2 bar)	$g = 9.81 \text{ m/s}^2$
$p_{1\text{-typ}}$	(Typical gas pressure):	130,000 Pa (= 1.3 bar)	

The filling height can be determined extremely precisely by means of the hydrostatic pressure using two measuring points and by compensating the influence of the gas pressure on the measured value:

$$h = (200,000 \text{ Pa} - 120,000 \text{ Pa}) / (750 \text{ kg/m}^3 * 9.81 \text{ m/s}^2) = 10.9 \text{ m}$$

If only an estimate is available for working with, for example based on the typically prevailing gas pressure, even relatively minor pressure variations in the process could result in significant errors in the level calculation.

$$h = (200,000 \text{ Pa} - 130,000 \text{ Pa}) / (750 \text{ kg/m}^3 * 9.81 \text{ m/s}^2) = 9.5 \text{ m}$$



Level measurement with a submersible pressure sensor in a closed system requires an additional measuring point for the pressure in the gas zone above the medium.

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In other words, even small variations of 10,000 Pa (= 100 mbar), as in this realistic example, will give rise to massive errors equivalent to approximately 13% of the filling height. In particular, under-measurement could lead to process-critical errors such as unwanted spillover of the medium into a second tank.

4. The main considerations for submersible pressure sensors

As mentioned earlier, submersible pressure sensors are quite simply the best option available for hydrostatic level measurement. The most important quality features here are the resistance and watertight sealing of the sensor and connecting cable to the medium as well as to the prevailing pressure, and secondly the mechanical stress on the housing and cable. Submersible pressure sensors are used for a wide variety of liquids. They must therefore have unrestricted IP68 ingress protection with unlimited immersion time at the relevant measuring depth.

Purpose-designed and built submersible pressure sensors can determine filling heights of up to several hundred metres reliably – a feat unmatched by other level measuring instruments in the market today.

4.1 The measuring cell

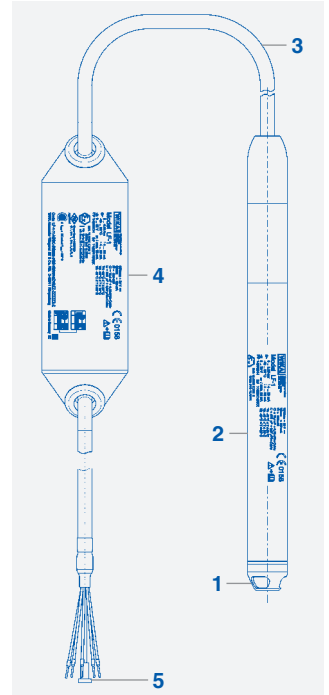
The measuring cell of a submersible pressure sensor serves to record the hydrostatic pressure at the measuring point. It must ensure accurate and reliable results even in the most adverse conditions – in dirty media containing particles or fibres, in contact with abrasive substances or when sludge forms.

The main requirements for a measuring cell are consequently maximum resistance to contamination from the medium as well as maximum durability. Specialised manufacturers hence offer submersible pressure sensors with an optimised design and carefully selected materials, from stainless steel to special ceramics. The latter are non-corrosive and any deposits can be easily removed with a soft brush.

4.2 The electronics

The electronics of a submersible pressure sensor are similar to those of conventional pressure sensors. They convert the measured value into a standardised industrial signal with high accuracy, small temperature errors and optimised EMC protection.

The most significant difference as regards the electronics results from the application-specific use of submersible pressure sensors in outdoor environments and the associated risk of lightning strikes. Sophisticated submersible pressure sensors offer built-in overvoltage protection to minimise the effects on the measuring cell in the event of lightning striking nearby and producing voltage surges. Of course, even with the best overvoltage protection, no instrument will survive a direct lightning strike undamaged.



The main components of a submersible pressure sensor:
 1. Protection cap
 2. Product label
 3. Connecting cable
 4. Measuring point tag with product label
 5. Vent capillary with filter element | © WIKA



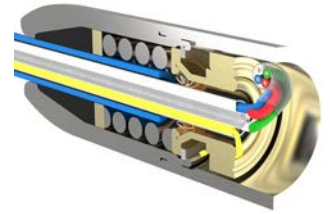
The protection cap protects the diaphragm of the measuring cell from damage. | © WIKA

4.3 The housing

Submersible pressure sensors have a cylindrical housing. The material should be selected specifically for the application, to prevent possible chemical decomposition processes such as corrosion. 316L grade stainless steel is recommended for use in non-critical media. In applications with aggressive liquids, however, a much higher-resistance material such as Hastelloy or titanium should be preferred.

4.4. The cable entry

One weak point of many submersible pressure sensors is the cable connection to the housing. This interface demands a hermetically sealed design that guarantees high resistance to moisture ingress, even at the pressure loads associated with great immersion depths or in the presence of aggressive media. Products where the design of the submersible pressure sensor is based on a standard industrial pressure sensor customised with an optional cable outlet should be strictly avoided for this reason.



Design of the cable entry for a submersible pressure sensor to meet high requirements. | © WIKA

4.5 The cable

The cable of a submersible pressure sensor transmits both the signal and – via a vent capillary – the atmospheric pressure. Like the housing, it is permanently exposed to the direct effects of the medium as well as to the surrounding pressure at the respective immersion depth. If the material is selected incorrectly, there is a risk of fluid ingress into the cable, causing the sensor to fail.

Specialised manufacturers therefore offer user an comprehensive choice of cable materials, to enable the highest possible resistance to the fluid being measured in the target application. Cables made from PUR or PVC, for example, are recommended for standard, non-critical applications, whereas FEP cables are advised for aggressive liquids.

The mechanical durability of the cables must also be taken into account when developing or selecting a submersible pressure sensor. The material must provide maximum pressure resistance, even at great immersion depths, such as in deep wells or for groundwater monitoring. The specific strength of the cable with respect to the weight-related stretching load and direct mechanical effects must likewise be taken into account.



Many applications have a large distance between the measuring point and the read-out unit. A cable box outside the measuring point is an affordable way to bridge this distance. The box takes the high-quality connecting cable of the submersible pressure sensor and connects it to an inexpensive standard cable for onward signal transmission. | © WIKA



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5. Summary

Hydrostatic level measurement offers many significant advantages and is therefore widely used. It is suitable for all liquids and insensitive to most physical influences on the medium. For measuring tasks at great depths, it is often the only alternative.

The method is very effective in vessels, basins and shafts as well as in open reservoirs such as lakes or rivers. The level calculation is based on the value of the hydrostatic pressure and the density of the medium. Submersible pressure sensors, whose design is adapted to the specific requirements of each application, are utilised to measure this pressure. The sensors are lowered by a cable and are easy to install. Hydrostatic level measurement thus also represents a comparatively cost-effective solution.

6. Literature and sources

Picture sources: See individual pictures

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