# Baumer Term Definitions of Sensor Properties

## Scope

This document explains properties of sensors, especially the terms used in technical data. It should enable the user to evaluate the information given in data sheets according to their requirements.

The information given must not be understood as a specification and Baumer does not assume any responsibility for the information provided.

**Note: Section 4.2 on page 52 contains an alphabetically sorted subject index.**

## Contents

# 1 Characteristics of sensors

## 1.1 Measurement chain

Figure 1 shows the further used elements of the measuring chain of a sensor.

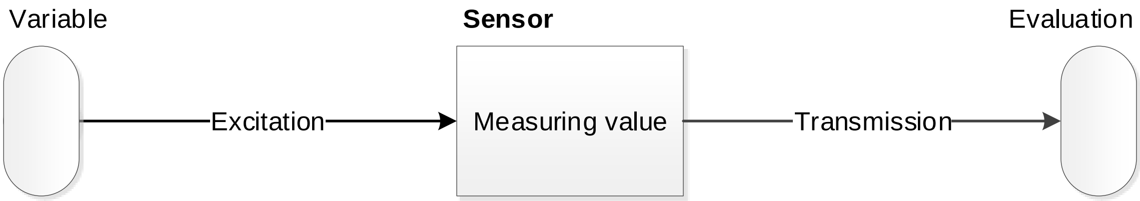



**Figure 1: Principle circuit diagram of the measuring chain of a sensor**

### 1.1.1 Measured variable

The measured variable is the physical value to be measured, e.g. temperature or pressure.

### 1.1.2 Excitation of sensor element

The excitation is obtained by applying a physical value to the sensitive part of the sensor. For a temperature sensor this is the temperature of the medium surrounding the sensor element, for a pressure sensor the pressure acting on the membrane.

### 1.1.3 Measuring value

The value measured and processed by the sensor through the effect of the excitation is the measuring value. A sensor with microprocessor determines this value numerically with a physical unit, a purely analog sensor processes it directly as a current or voltage signal. With switching sensors (e.g. pressure or level switches) the measured value determined at the end is purely binary with the logical states 0 and 1.

### 1.1.4 Transmission of value

The output signal transmits the measured value to the evaluation. Typical signal forms are:

| Signal form | Examples |
|---|---|
| Analog signal | 4 … 20 mA, 0 … 10 V |
| Digital signal | IO-Link, CAN, Modbus, RS485 |
| Mixed analog-/digital signal | HART |
| Wireless standards | Bluetooth, IO-Link Wireless, Wireless HART |

Sensors can transmit their measured value simultaneously with several output signals (e.g. dual-channel with IO-Link and analog output).
Digital signals can be used to output additional information, such as further measured values or diagnostic information.
During parameterization, sensors receive data from a programming tool or a controller; the interface here works bidirectionally.

### 1.1.5 Evaluation of sensor signals

Applications for the evaluation of sensor signals are:

| Application | Examples |
|---|---|
| Automation | PLC (programmable logic controller) |
| Control | Level, saturated steam pressure, ambient temperature |
| Visualization | Lamp, display, screen |
| Alerting | Excessive temperature, pressure too low, dry run pump |

Mixed applications are, for example, control via a PLC (centralized or decentralized) and visualization in the process control system.

## 1.2 Sensor Signal Processing

Examples for used technologies of sensors for signal processing are:

- Analog discrete and integrated circuits
- Digital integrated circuits
- Microcontroller with software
- Analog-to-digital converters (ADC) and digital-to-analog converters (DAC)
- ASICs (application specific ICs) such as signal conditioners and interface components

The sensor element converts the excitation by the measured variable into an electrical signal. In today's digital signal processing, an analog-to-digital converter (ADC) generates a digital value from this. A microcontroller processes this value by linearization, temperature compensation and scaling to produce a digital measuring value. An optional display integrated in the sensor or a digital output uses this value directly. For an analog output signal, a digital-to-analog converter (DAC) generates an analog signal again (see Figure 2).

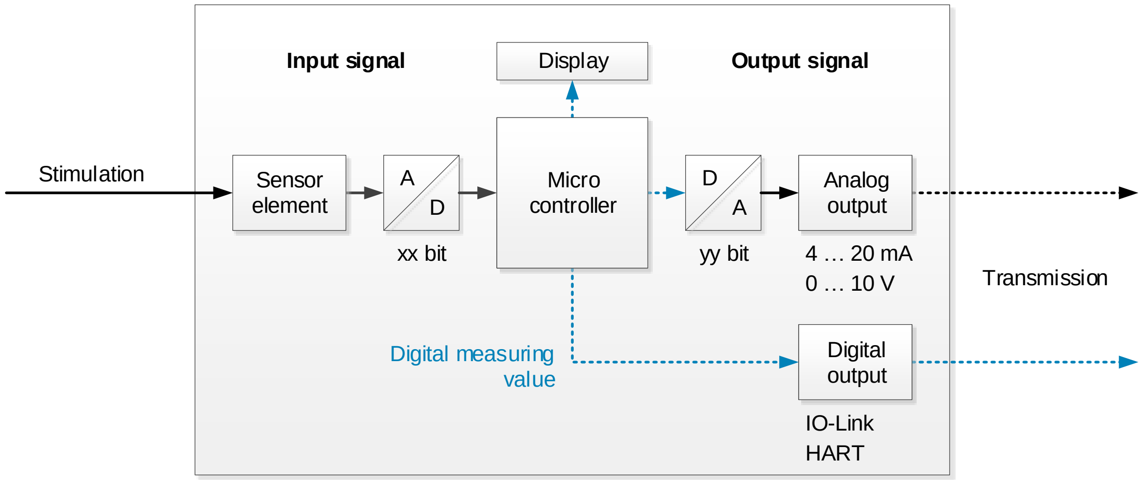



**Figure 2: Diagram of a digital sensor signal processing with analog or digital output**

The specifications for the accuracies of the input and output signals can be given separately. This optionally includes the specification of the bit resolutions of ADC (xx) and DAC (yy). For analog outputs, their deviations such as linearity and temperature dependency must also be taken into account. For digital signal outputs, e.g. via IO-Link, only the accuracy of the input is of interest, since a digital output signal is no longer distorted.

Example for a temperature transmitter with analog output:

| **Input signal** | |
|---|---|
| Sensor element | Pt100 |
| Max. measuring error (-200 … 200 °C) | 0.05 °C |
| Temperature coefficient ( ambient temperature) | ≤ 0.01 °C/K |
| Resolution | 17 bit |

| **Output signal** | |
|---|---|
| Current output | 4 … 20 mA, 2-wire |
| Accuracy | 0.025 % FSR |
| Temperature coefficient ( ambient temperature) | ≤ 0.01 %/K |
| Resolution | 14 bit |

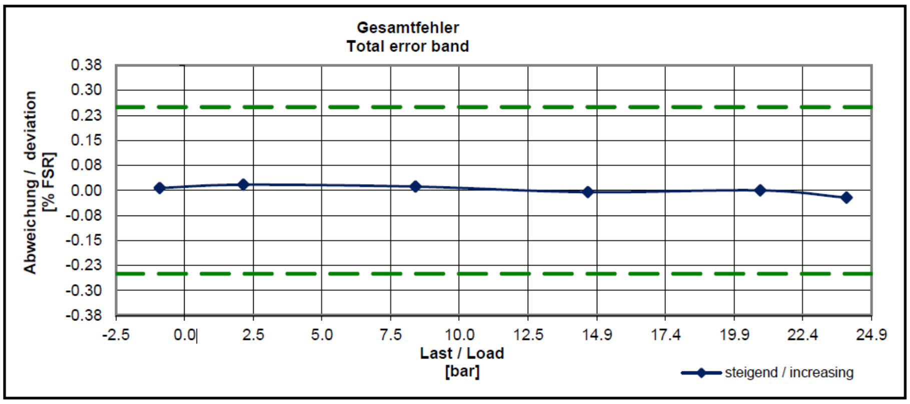
## 1.3 Test and adjustment procedures

### 1.3.1 Calibration

Calibration is the determination of measurement deviations (see 2.1.5) of a test sample (e.g. sensor) to a reference measurement (e.g. accredited laboratory measuring instrument). A calibration protocol displays these data, see example in Figure 3). Calibration does not change the sensor, i.e. it does not interfere with the sensor, neither hardware nor software. The application (e.g. PLC) can use calibration data to correct systematic deviations. This has to be carried out for each sensor unit and also when exchanging it for service.

| **Referenzgeräte** | | **Reference Equipment** |
|---|---|---|
| Bezeichnung | **Kal.-Anlage PPC3 /Budenberg** | Designation |
| Referenznummer | **70006381** | Reference number |

| **Kennlinienabweichung** | **Characteristic curve deviation** |
|---|---|




| Referenzgrösse steigend *Referenz value incresing* [bar] | Ausgangssignal steigend *output signal increasing* [mA] | Abweichung steigend *deviation increasing* [% FSR] | Referenzgrösse sinkend *Referenz value decreasing* [bar] | Ausgangssignal sinkend *output signal decreasing* [mA] | Abweichung sinkend *deviation decreasing* [% FSR] | Hysterese *Hysteresis* [% FSR] |
|---|---|---|---|---|---|---|
| -0.9000 | 4.065 | 0.007 | | | | |
| 2.1255 | 6.003 | 0.017 | | | | |
| 8.3745 | 10.001 | 0.011 | | | | |
| 14.6250 | 13.999 | -0.005 | | | | |
| 20.8748 | 18.000 | 0.000 | | | | |
| 24.0000 | 19.997 | -0.022 | | | | |

**Figure 3: Example for a calibration protocol for a pressure sensor**

### 1.3.2 Adjustment

Adjustment corrects the detected measurement deviations in the sensor. An intervention is made, usually by software, by storing a correction table or a calculation rule (e.g. polynomial function). A calibration table, which is determined at different temperatures and available to the system as a correction table, can compensate temperature dependencies, see 2.1.6.12.1.6 and 2.1.6.2.

## 1.4 User interfaces

### 1.4.1 Indication display

One or more LEDs indicate different states, e.g. "Operating voltage ok" or "Level switch has detected medium”. Multi-colored LEDs can dynamically adapt their luminous color. Thus, several states can be recognized comfortably even from a greater distance. The common selection of colors for signal states is described in the guidelines NE 107 and EN 60073:

| Color | Signal state |
|---|---|
| Green | Voltage supply ok, normal operating condition |
| Green blinking | Maintenance required |
| Blue | Maintenance required, proprietary indication |
| Yellow | Switching state or warning |
| Red | Out of specification, error, danger |
| Red blinking | Function check (measured value invalid/frozen) |

### 1.4.2 Display

Basic technologies of displays for sensors are:

- LED segments (mostly seven-segment)
- LCDs with segments, pictograms, dot matrix or mixed, optionally with backlight

Both technologies can display diagnostic information in different colors, with segment colors for LEDs and backlighting for LCDs.

**Figure 4: Example for a seven-segment LED display with a pressure sensor**

LCDs with dot matrix allow the flexible design of display contents, e.g. the simulation of a pointer instrument or a tank visualization. The dynamic color selection of the backlight clearly displays diagnostic information, e.g. red for measured values outside the permissible range.


**Figure 5: Examples of flexible display contents of an LCD with dot matrix and backlight**

### 1.4.3 Operating elements

Operating elements of sensors with display offer the selection of display contents or programming of parameters. Robust operating elements without housing openings for best possible tightness are:

- Foil switch (with push-point)
- Touch sensitive buttons
- Touch screen


**Figure 6: Examples of robust control elements without housing openings**

The user works very comfortable with the touch screen. The display positions the buttons flexibly and labels them in the selected language depending on the menu selection.

# 2 Technical data of sensors

## 2.1 Performance characteristics

The standard EN 61298-2 is considered the essential basis for the definition of the performance characteristics of sensors. This section describes them with a practical focus supported by examples.

### 2.1.1 Measuring range

The specification of the measuring range basically contains two values, a lower and an upper limit value, together with a physical unit. Between these limit values, the sensor can record and output measured values with a specified measuring deviation.

Example for a pressure sensor:

| | |
|---|---|
| Measuring range | –1 … 24 bar |

### 2.1.2 Measuring span

The measuring span results from the difference between the upper and lower limit value of the measuring range.

Example for a pressure sensor:

| | |
|---|---|
| Measuring span | 24 bar – (–1 bar) = 25 bar |

The specifications of min. and max. measuring span can be found in sensor families to show the limits of the selection possibilities of measuring ranges.

Example for a pressure sensor:

| | |
|---|---|
| Min. measuring span | 0.1 bar |
| Max. measuring span | 40 bar |

### 2.1.3 Full-Scale (FS)

Full-scale means the maximum level as reference value for accuracy specifications. The value is identical with the measuring span from above.

### 2.1.4 Output Range

The output range corresponds to the measuring range by default. The output range can be adjusted by parameterization (turndown) or by specification as an ordering option.
For example, for a pressure sensor with 4 ... 20 mA current output, the lower and upper output range limits for 4 mA and 20 mA must be assigned to the desired pressure range values.

Example for a pressure sensor:

| | |
|---|---|
| Output range | 4 mA = –1 bar<br>20 mA = 24 bar |

### 2.1.5 Measuring error

The measuring error describes the difference between a value measured by the sensor and a reference value considered accurate. A certain measuring procedure provides a statement about the accuracy of the sensor. The obtained results refer to the measuring span with a percentage value.

#### 2.1.5.1 Measurement procedure

- Specify measuring points with a certain span modulation. Include the limit values 0 % and 100 % of the measuring range.
- Move from the lower limit value of the measuring range to the first measuring point in the direction of increasing modulation. For the lower limit value of 0 %, do not include a measuring point in the first measurement run because no direction has been defined yet. Move to measuring points slowly to avoid overshooting (see Figure 7).
- Determine the further measuring points in the direction of increasing modulation until full modulation (100% of the measuring span) is reached. Result: measurement curve "Up".
- Continue with decreasing modulation until the measurement starts at 0 % (first measuring value for 0 %). Result: measurement curve "Down".
- Depending on the definition, record further measurement runs of this type in real time. Arithmetically average the measurement curves for each "Up" and "Down" direction separately.
- Depending on the measuring technology, a deviating course of the two measurement curves "Up" and "Down" results due to the hysteresis behavior. This is due to the dependence on the direction of the measuring points. The two curves are additionally arithmetically averaged to the mean value curve "Up, Down", because for some definitions of the measurement deviation the hysteresis is not of interest.
- The measurement procedure consisting of one or more measurement runs is finished.

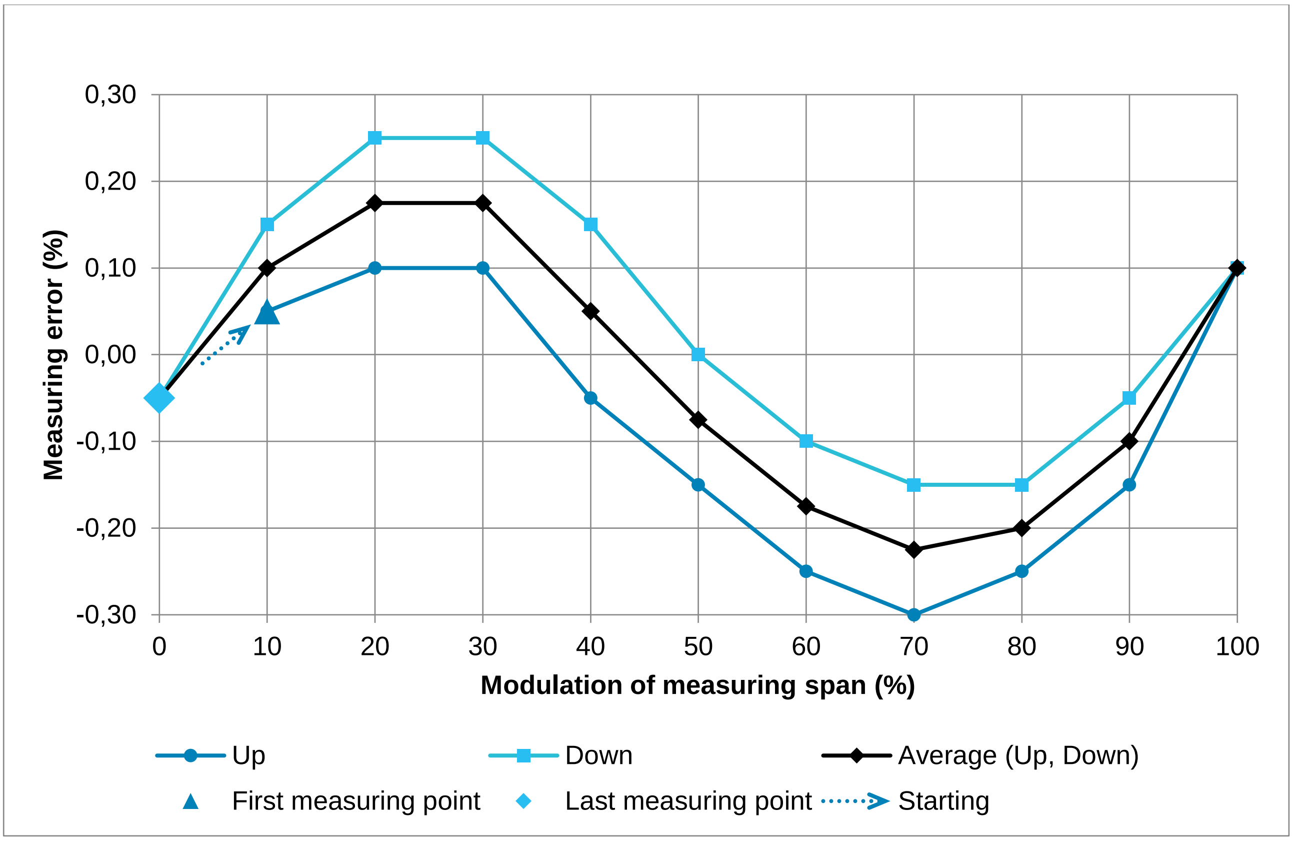



**Figure 7: Result of a measurement run to determine the measurement deviation**

#### 2.1.5.2 Zero point error

The zero point error (alternatively zero offset) results from the lower limit value of the measuring range, the lower range value (see Figure 8).

#### 2.1.5.3 End point error

The end point error is derived from the upper limit value of the measuring range (see Figure 8).

#### 2.1.5.4 Span error

The span error is calculated from the difference between the end point error and the zero point error. It indicates the deviation from the measuring span (see Figure 8).

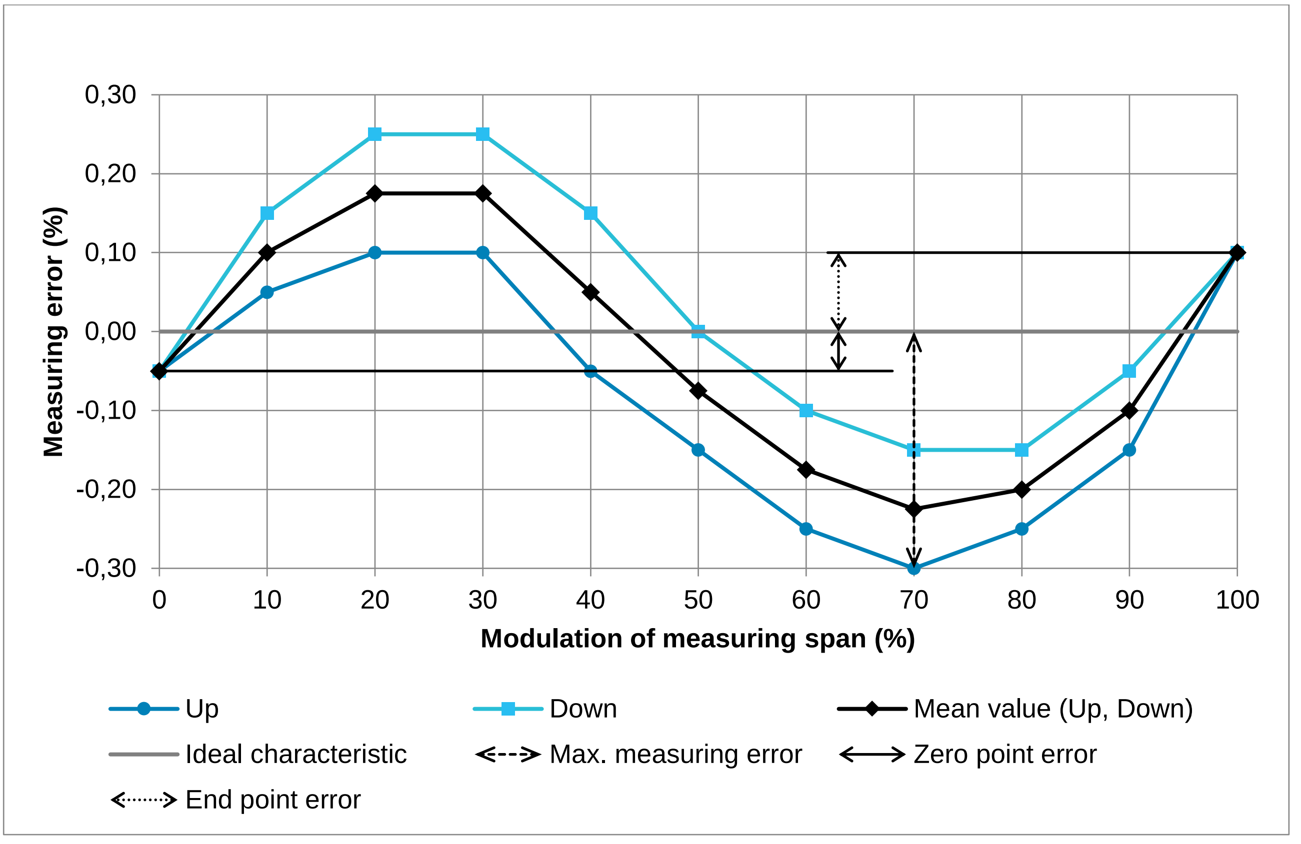



**Figure 8: Definition of zero point error, end point error and span error**

#### 2.1.5.5 Non-linearity

The non-linearity indicates the maximum difference from the mean value curve "Up, Down" to an ideal straight line. There are three different methods defined around the line:

- Limit point setting: Straight runs through the two values for the lower and upper limit value of the measuring range (terminal base line) (see Figure 9).
- Minimum value setting: Position the straight line so that the maximum deviation from the measured curve is the smallest (BFSL = best fit straight line) (see Figure 10).
- Starting point setting: Straight runs through the lower limit value; gradient so that max. deviation from the measured curve is smallest (not shown).

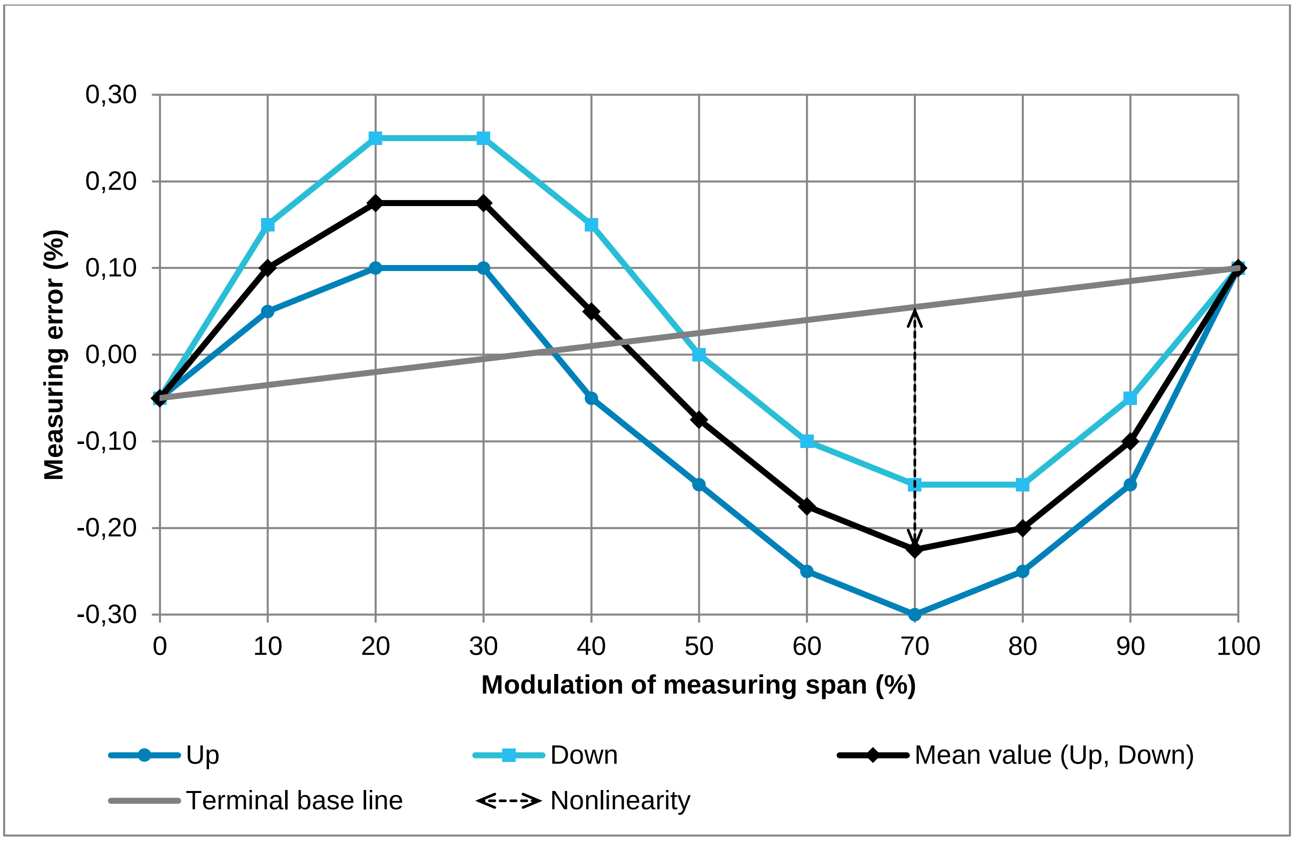



**Figure 9: Determination of non-linearity after limit point setting**

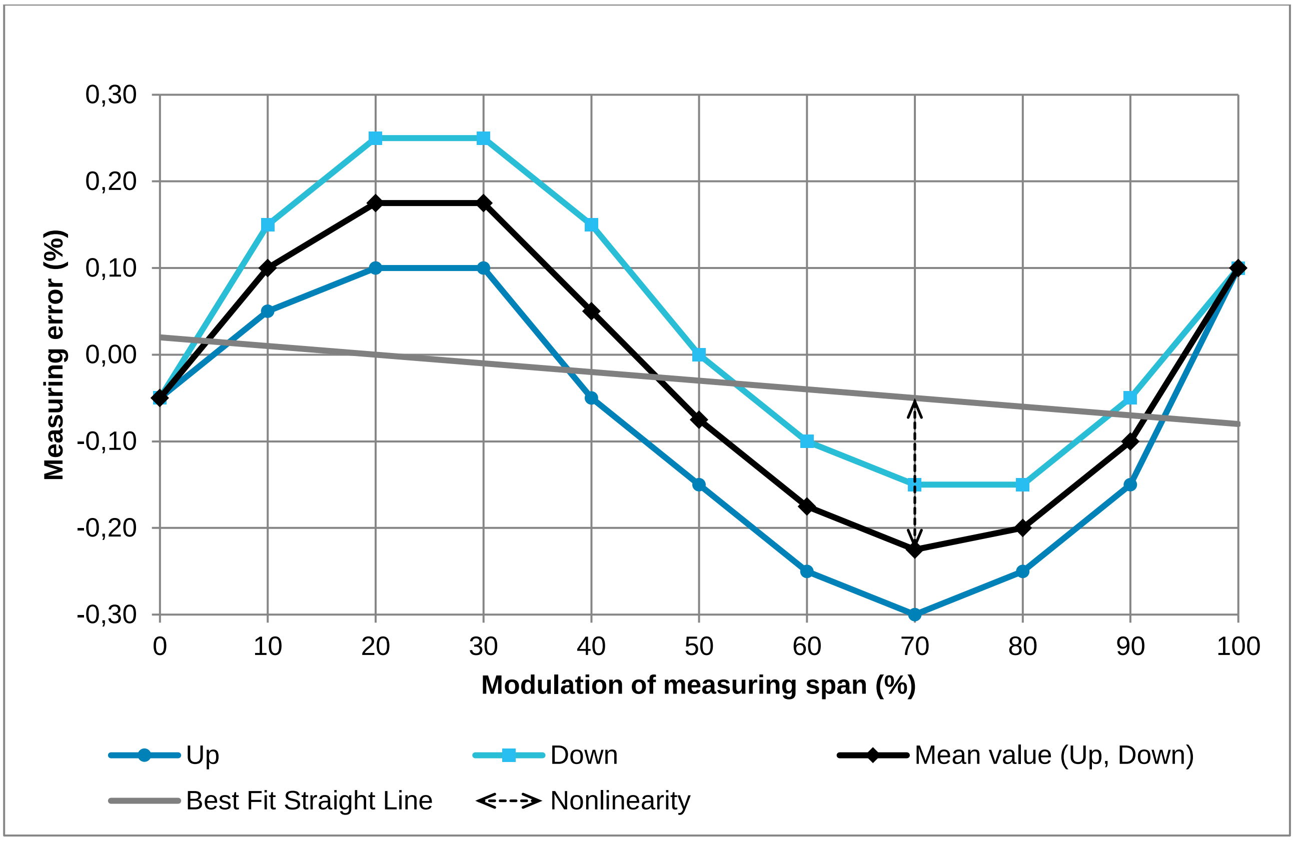



**Figure 10: Determination of non-linearity after minimum value adjustment (BFSL)**

The minimum value setting and starting point setting provide smaller (better) values for the deviations. The straight line cannot be determined analytically but only iteratively.
The mainly used limit point setting normally provides the larger values for the deviations and offers more reserve in the design of the maximum measurement deviation.

#### 2.1.5.6 Hysteresis

Depending on the direction of an approached measuring point, many technologies show different measuring results. This deviation is called hysteresis. At the upper and lower reversal point the curves of both directions meet, because these points are only approached from one direction. To specify the hysteresis, use the value of the maximum distance between the "Up" and "Down" curves (see Figure 11). If there are several measurement runs, select the pair of curves with the largest distance (not the averaged measurement curves).

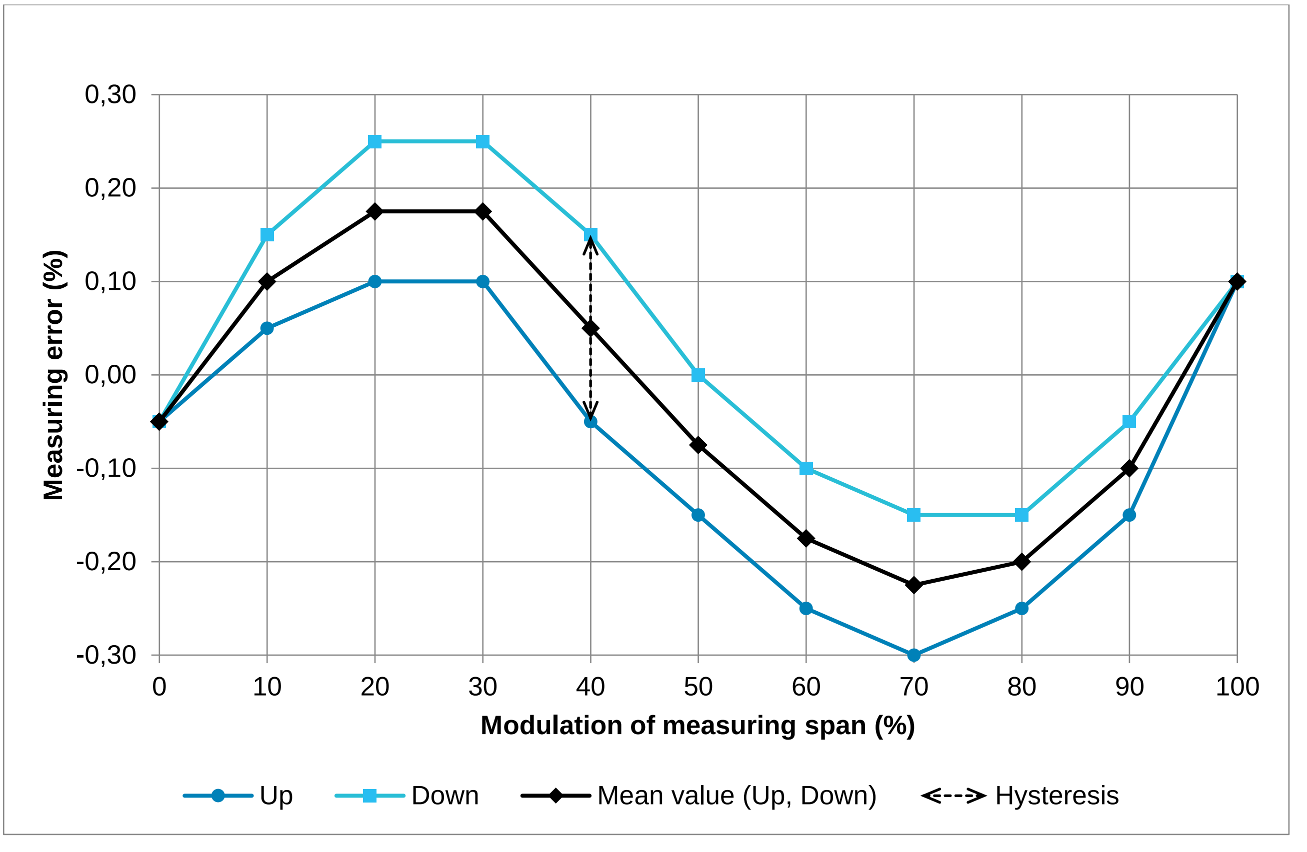



**Figure 11: Definition of hysteresis**

#### 2.1.5.7 Non-repeatability

The largest deviation between two measurement results at the same measuring point observed during multiple runs of a measurement sequence in a short period of time under unchanged ambient conditions is called non-repeatability. The effects of hysteresis are not to be included. Only compare the curves with the same direction, i.e. "Up 1" with "Up 2" ... and "Down 1" with "Down 2" ...

#### 2.1.5.8 Max. measuring error

The specification for the max. measuring deviation considers the maximum difference from the curves of the measuring deviation "Up" or "Down" to the ideal characteristic curve. In case of several recorded measuring runs, use the averaged curves of the same direction.

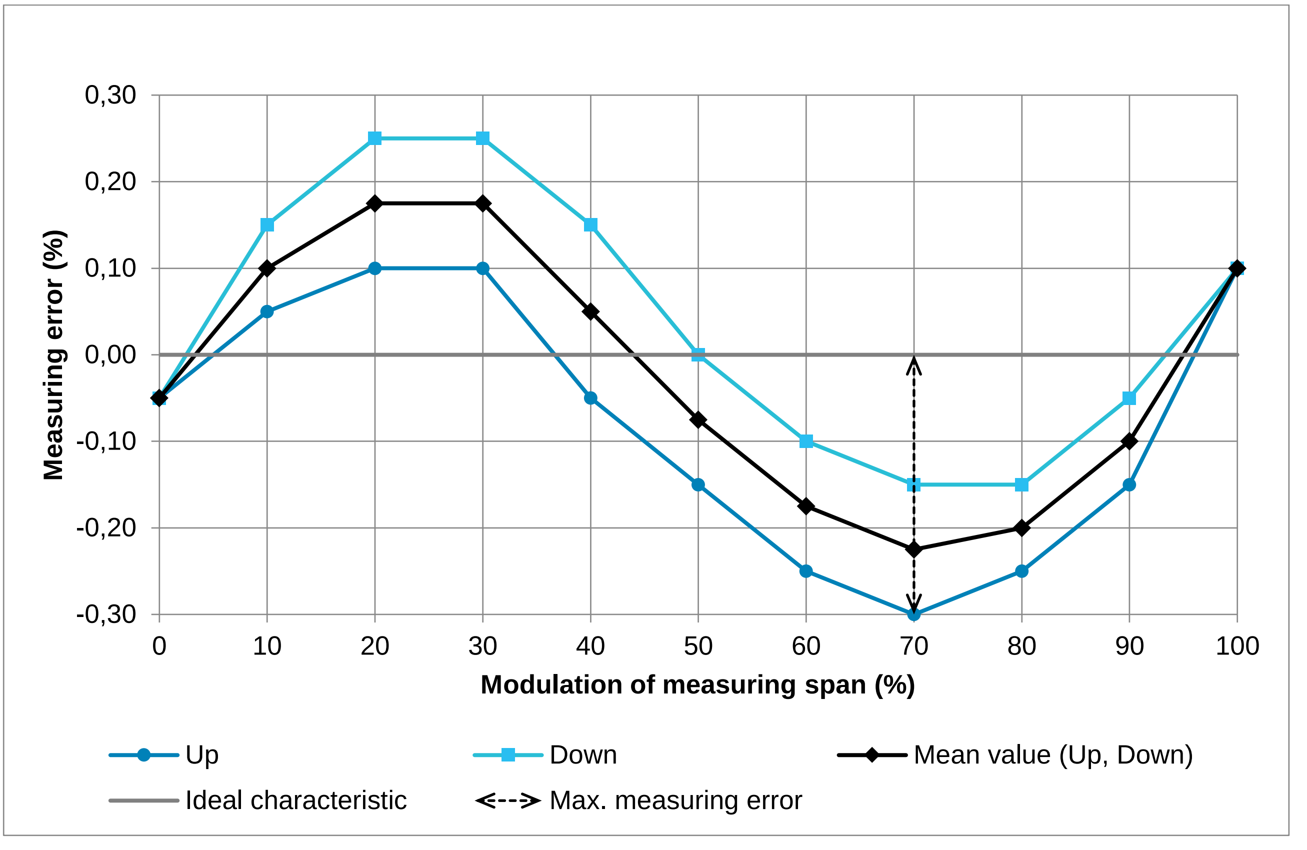



**Figure 12: Specification of the max. measuring error**

#### 2.1.5.9 Specification of measurement errors

To indicate the accuracy of an instrument, it is necessary to specify exactly what type of measurement error is meant. Even without a sign, the values are normally considered to be plus/minus, i.e. the range of the max. measurement deviation is twice the value.

Example 1:

| | |
|---|---|
| **Max. Measuring error**<br>Including zero point and span error, nonlinearity (by terminal base line), hysteresis and non-repeatability (EN 61298-2)<br>(Tamb = 20 °C)<br>For turndown, multiply this value by the applied turndown ratio. | 0.5 % FS |

Example 2:

| | |
|---|---|
| **Standard error of measurement (BFSL)**<br>Including non-linearity, hysteresis and non-repeatability according BFSL (best fit straight line).<br>For turndown, multiply this value by the applied turndown ratio. | 0.2 % FS |

Example 1 guarantees seriously with indication of the max. measuring deviation all measuring errors, in particular zero point (offset) and end point error (span).
Many manufacturers specify only the standard measuring error (BFSL) as in example 2. This allows supposedly better values to be specified. There is no statement about zero point and end point error. Any offset or span error may be present. This is still acceptable if the application allows zero point and span adjustment and the sensor has sufficient long-term stability.
Both types of information are only valid at a constant ambient temperature Tamb = 20 °C. The temperature and long-term drifts are listed separately (see below).

### 2.1.6 Temperature drift

#### 2.1.6.1 Temperature coefficient

The temperature coefficients (TC) indicate the temperature drifts of the zero point and span. The values refer to a temperature interval of 10 K each starting from 20 °C. When the measuring span is fully utilized (full-scale), the two TC values for zero point and span can be added directly. If the measuring span is only partially used, the TC value of the span only acts with the percentage of the used span added to the TC value of the zero point. The values determined in this way indicate the maximum measurement error caused by the temperature drift. The graphic representation of the temperature drift over the temperature shows the so-called "butterfly curve" (see Figure 13).
For the design of the compensated temperature range, the larger of the two values process temperature or operating temperature range (ambient temperature) must be considered.
The calculation of the temperature drift is only valid for a constant steady-state temperature of the sensor, i.e. without spatial temperature gradients. Since this case does not exist in practice during changes of the medium temperature, the validation of such a process is recommended.
Depending on the sensor signal processing and specification, the temperature coefficients can be specified separately for the acquisition of the measured value and for the analog output (see 1.2).

Example for a pressure sensor:

| | |
|---|---|
| Temperature coefficient | ≤ 0.03 % FSR/10 K , measuring span<br>≤ 0.03 % FSR/10 K , zero point |

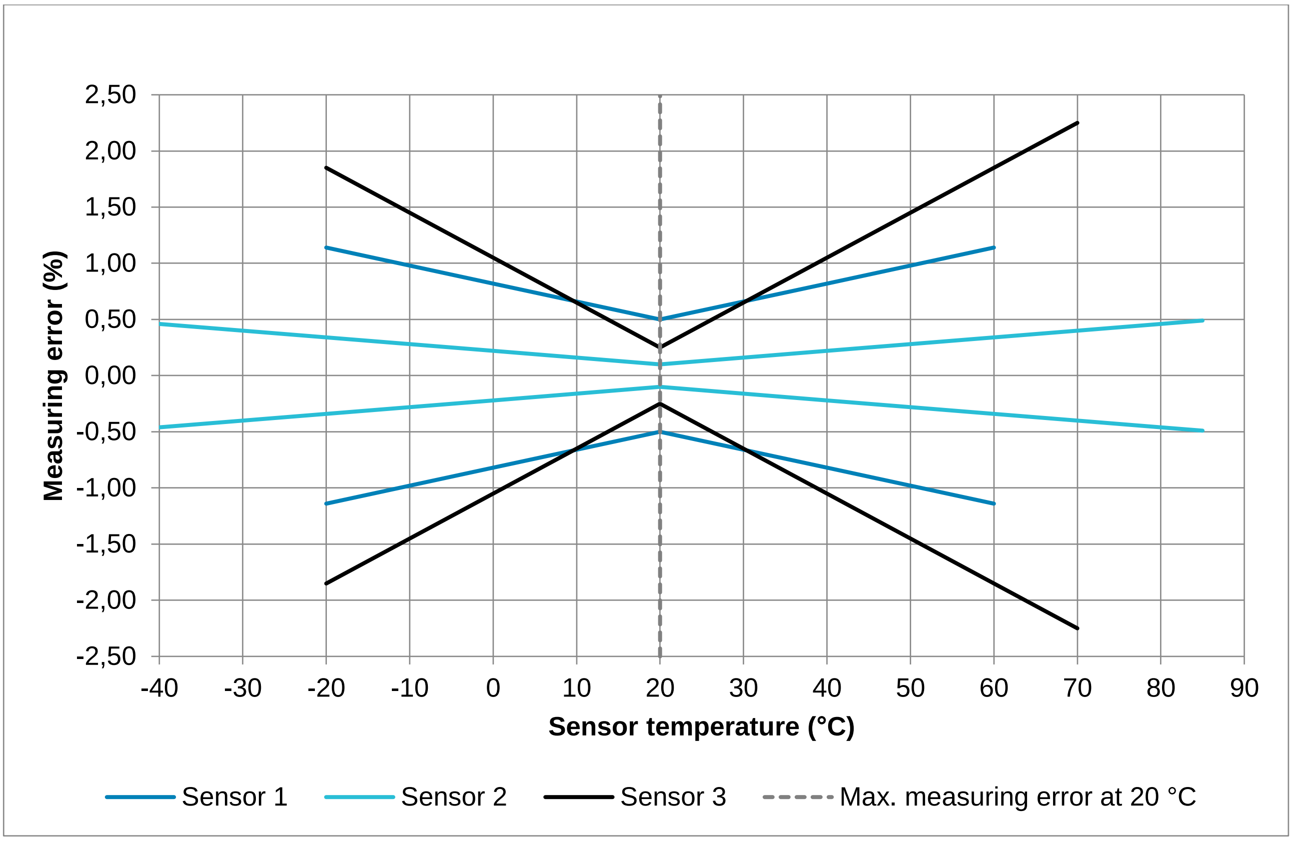



**Figure 13: Example of max. measuring errors of different sensor types vs. the sensor temperature**

Specifications for example in Figure 13:

| | **Sensor 1** | **Sensor 2** | **Sensor 3** |
|---|---|---|---|
| **TC offset (%/10 K)** | 0.08 | 0.03 | 0.20 |
| **TC span (%/10 K)** | 0.08 | 0.03 | 0.20 |
| **Max. measuring error at 20 °C (%)** | 0.5 | 0.1 | 0.25 |
| **Compensated temperature range (°C)** | −20 … 60 | −40 … 85 | −20 … 70 |

Figure 13 clearly shows the influence of the temperature coefficients. Sensor 3 has a smaller max. measurement deviation than sensor 1, but it is only valid at a sensor temperature of 20 °C. As soon as this temperature deviates from 20 °C, the temperature coefficients take effect. Below 10 °C and above 30 °C sensor 1 has a smaller max. error than sensor 3 and measures more accurately, although its max. error specification is 0.5 % instead of 0.25 %. Sensor 2 is a highly accurate precision sensor with excellent temperature stability. It significantly improves the stability of processes in demanding applications with large temperature changes, e.g. autoclave control.

#### 2.1.6.2 Compensated temperature range

In the compensated temperature range, the sensor automatically corrects its temperature drift using a stored correction table. It learns this in a calibration process at different temperatures during production. This reduces the specified temperature coefficients considerably. These are valid within the specified temperature limits. If the sensor temperature leaves these limits, the sensor still outputs measured values, but without ensuring accuracy.

Example for a pressure sensor:

| | |
|---|---|
| Compensated temperature range | -20 … 125 °C |

### 2.1.7 Long-term drift

By definition, long-term drift is only caused by the time factor. A laboratory observation must be made over at least 30 days at constant ambient conditions. The specification of the long-term drift is valid with a percentage deviation of the measuring span per year. Typically, the greatest long-term drift takes place in the first year after production. For the following years a decreasing tendency of the annual drift is to be expected.

Example for a pressure sensor:

| | |
|---|---|
| Long-term drift | < 0.1 % FSR/a |

### 2.1.8 Dead time

Due to internal processing chains, the output signal of sensors is delayed to a change of excitation. The time span between the excitation and the first detectable output change is the dead time (see Figure 14).

### 2.1.9 Rise time

The change of the output signal following an abrupt change of the excitation (after the dead time has elapsed) is practically not abrupt but with a decreasing gradient until the steady state is reached. In a first approximation most systems show the course of an exponential function, as it is also known as charge curve of capacitors (PT1 behavior). The amplitude of the excitation step is between 0 % and 100 %. The rise time is between reaching one of these small and large percentages, fixed at 10 % and 90 % (see Figure 14).

### 2.1.10 Step response time

The step response time is the time span from the beginning of a step excitation until the output signal reaches 90 % of the step amplitude. The step response time is theoretically different from the sum of dead time and rise time, because there is another small time difference between the first reaction of the output signal and reaching the small percentage (10%) (see Figure 14).

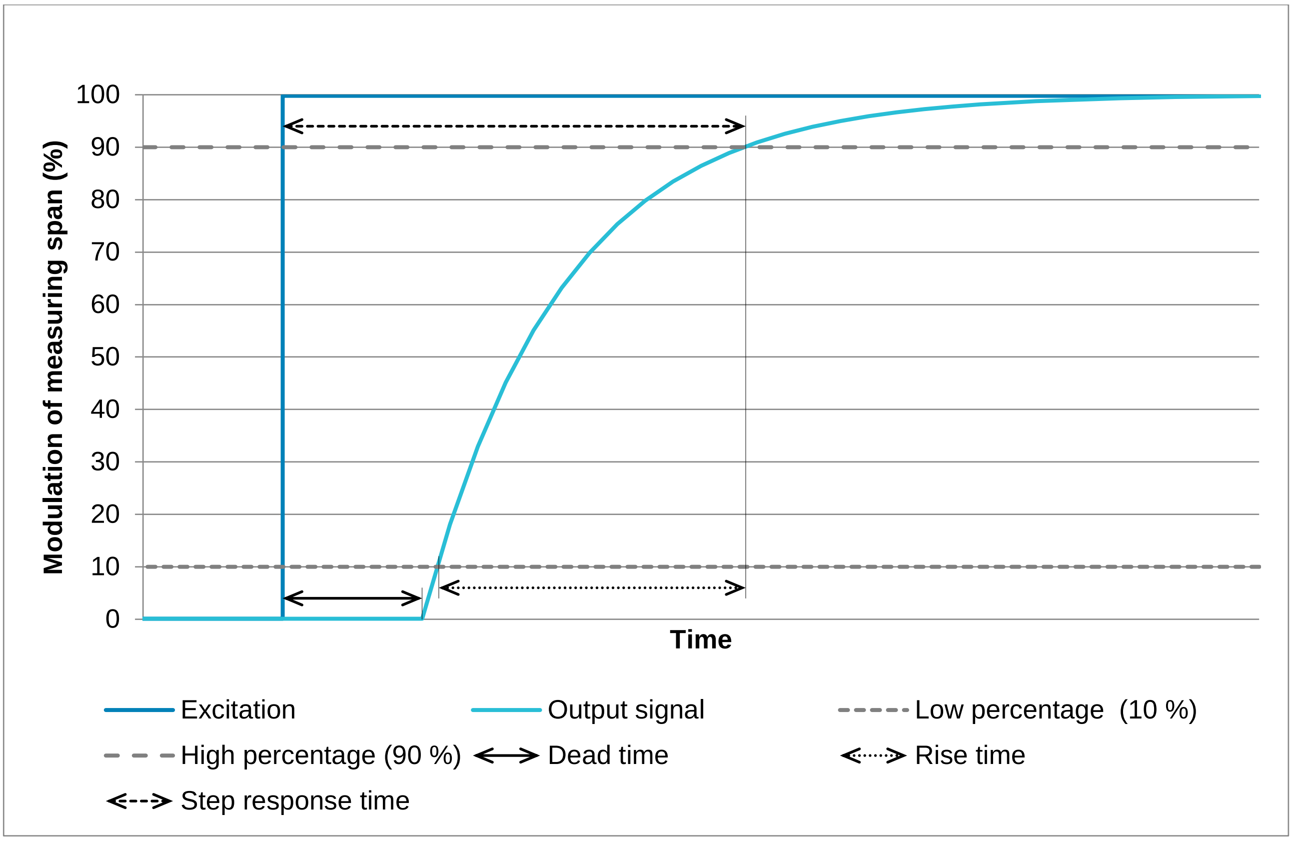



**Figure 14: Definition of dead time, rise time and step response time**

Example for a pressure sensor:

| | |
|---|---|
| Step response time | ≤ 5 ms |

### 2.1.11 Response time

The term "response time" has become generally accepted for level switches, although this should be called "dead time" according to the standard. It applies from immersion in the medium to switching of the output. For the thermal response time of temperature sensors see 3.5.4**Fejl! Henvisningskilde ikke fundet.**.

## 2.2 Process conditions

The sensitive part of a sensor comes into contact with the process temperature and the process pressure of the medium to be measured (liquid, solid or gas).

### 2.2.1 Process temperature

For the extreme values of the permissible process temperature there may be dependencies on the ambient temperature Tamb and the operating voltage Vs (see example in Figure 15). For CIP and SIP cleaning processes there may be higher permissible process temperatures for a limited period of time (see also 2.2.3**Fejl! Henvisningskilde ikke fundet.**).

Example for a level switch:

| | |
|---|---|
| Process temperature @ Tamb < 60 °, Vs ≤ 24 V | -40 … 115 °C<br>135 °C max. (t < 1 h) |

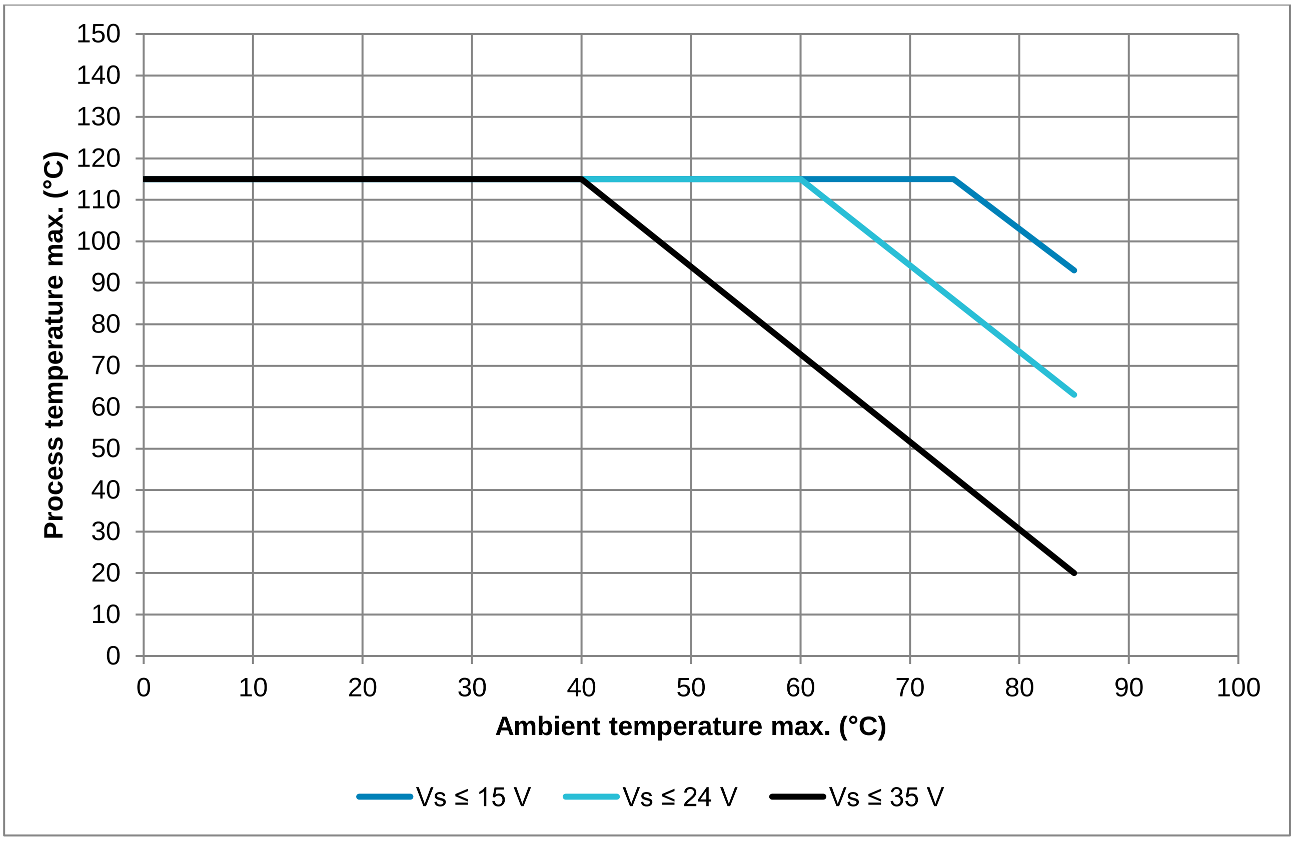



**Figure 15: Process temperature depending on ambient temperature and supply voltage**

### 2.2.2 Process pressure

The process pressure refers as relative pressure to the ambient pressure. A negative pressure (underpressure or vacuum) can cause an increased load for certain sensors. In such cases, the documentation contains appropriate notes. The specification of the max. permissible process pressure can depend on the process connection and the process temperature and/or be limited in time.

Example for a level switch:

| **Process connection (BCID)** | **Continuous Process pressure (bar)** | **Temporary (t < 1 h) Process pressure (bar)** |
|---|---|---|
| G 1/2 A hygienic (A03) | -1 … 10 | -1 … 5 |
| 1/2-14 NPT, with cooling neck (N02) | -1 … 100 | n. a. |

Tamb < 50 °C

For pressure sensors there are further specifications, the overload limit and the burst pressure. These are given in tables depending on the selected pressure range (see 3.1.5).

### 2.2.3 Suitability for CIP/SIP

The suitability for the cleaning processes CIP (Clean-in-Place) or SIP (Sterilization-in-Place) is provided with a maximum time specification, depending on the media temperature.

Example for a pressure sensor:

| | |
|---|---|
| SIP/CIP compatibility | < 35 min @ media temperature up to 150 °C<br>< 60 min @ media temperature up to 135 °C |

The information given here only guarantees the survival of the cleaning process. Whether the sensor still works within the specification under cleaning conditions or whether it can output measured values at all can be seen from the respective documentation. In case of pressure sensors the compensated temperature range is left, unless they are specially designed for this requirement. For this purpose there are versions with an extended compensated temperature range, e.g. for the control of autoclaves.

## 2.3 Process connection

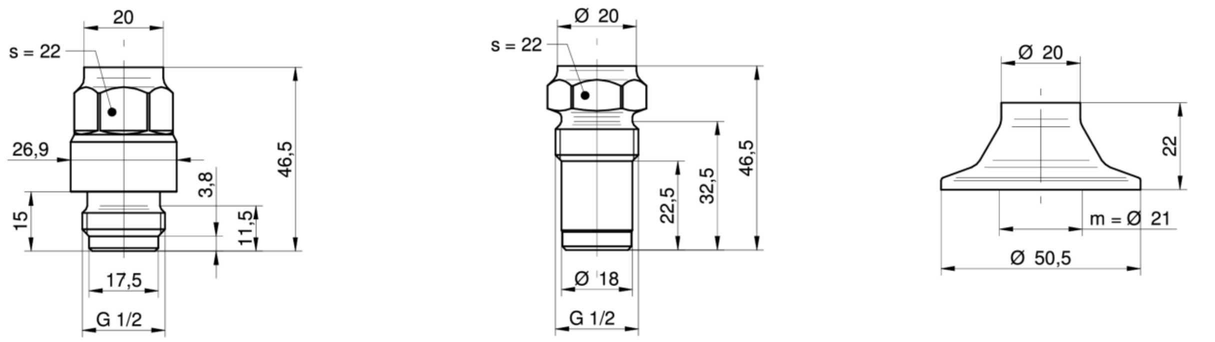
The process connection separates the process from the environment. At the same time it is the mounting part for the sensor, welded into a container or pipe. Process connections are always sealed for use in process technology with fluids or gases. In closed processes, considerable pressure differences to the environment can occur.

**Figure 16: Example for a hygienic process connection on a pipe (sectional view)**

Nowadays, numerous versions of process connections are used. There are standardized and manufacturer-specific designs. Besides the historical development, variants for special applications have been created, e.g. for hygienic assembly in the food industry.

### 2.3.1 Connection variants

Most of the sensors are available with different connection variants as order options. A wide range of adapters extends the flexibility for design-in or exchange of sensors. The BCID code (Baumer Connection Identifier) describes the compatibility between sensor, process connection and mounting aids. Parts with the same code always fit together.




| G51-41 | A03-48 | C03-53 |
|---|---|---|
| G 1/2 A DIN 3852-E (BCID: G51) | G 1/2 A hygienic (BCID: A03) | Tri-Clamp Ø 50.5 (BCID: C03) |

**Figure 17: Examples of different connection variants of a pressure sensor**

### 2.3.2 Wetted parts material

The selection of suitable materials that are compatible with the process media used ensures the best possible results:

- Reliable function and process safety
- Long service interval
- Quality, food safety, etc.
- Compliance with regulations (e.g. FDA, see 2.13.4).

These parts are in contact with the process:

- Welding sleeve or adapter
- Seals (elastomers)
- Wetted sensor material (metal and/or plastic)

Example for a level switch:

| | |
|---|---|
| Wetted parts material | PEEK Natura<br>AISI 316L (1.4404) |

## 2.4 Surface roughness (wetted parts)

For hygienic and pharmaceutical processes, surface roughness is a decisive factor due to good cleanability. Usual designs are Ra ≤ 0.8 µm and Ra ≤ 0.4 µm, some of which can be selected as an option. The specification for weld seams (e.g. for membranes) is specially indicated if different.

Example for a pressure sensor:

| | |
|---|---|
| Membrane | Ra ≤ 0.4 µm |
| Weld seam | Ra ≤ 0.8 µm |
| Process connection A03-48 | Ra ≤ 0.8 µm |
| Process connection C03-53 | Ra ≤ 0.4 µm |

## 2.5 Ambient conditions

The place of use of a sensor determines the requirements for the environmental conditions. These are of climatic, mechanical and electrical nature:

| **Requirements for** | **Remark** |
|---|---|
| Climate | Temperature, humidity, tightness |
| Vibration and shocks | E.g. from pumps and valves |
| Mobility | Stationary or mobile use |
| Transport | Drops with or without packaging |
| Misuse | E.g. resistance to stepping when used as a climbing aid |
| Electromagnetic interference | (see 2.13.2) |
| Specific applications | Railroad, ship |

### 2.5.1 Operating temperature range

In the so-called operating temperature range a sensor works within the specification. The temperature specification refers to the ambient temperature of the sensor (especially its housing). There can be dependencies on the process temperature (see 2.2.1).

Example for a pressure sensor:

| | |
|---|---|
| Operating temperature range | -20 … 85 °C |

### 2.5.2 Storage temperature range

Within the storage temperature range, the sensor is not irreversibly damaged. Besides storage or transport, the installed condition can also be interesting. This information is only valid if no supply voltage is applied.

Example for a pressure sensor:

| | |
|---|---|
| Storage temperature range | -40 … 85 °C |

### 2.5.3 Degree of protection

The degrees of protection for the tightness against foreign objects, dust and liquids or humidity are specified in EN 60529. These only refer to the environment, i.e. the sensor housing. The process-related properties are specified in the process conditions (see 2.2).
Often the weakest element in terms of tightness is the electrical connection, e.g. cable gland, DIN or M12 connector. There are different specified degrees of protection for different types of connection. The accessories used (e.g. M12 cable socket) must also meet the required degree of protection.

Common degrees of protection:

| **Degree** | **Definition according to EN 60529** | **Practical relevance to operating conditions** |
|---|---|---|
| IP65 | Protected against water jets from any angle (jet nozzle) | External cleaning of system parts with hose and nozzle |
| IP67 | Protected against the effects of temporary immersion in water | Humid environment, temporary standing moisture |
| IP68 | Protected against the effects of permanent immersion in water (depth and time to be defined) | Increased requirements according to specification |

| | | |
|---|---|---|
| IP69 | Protected against high pressure and high jet water temperatures | Extremely humid environment, exterior cleaning with high-pressure cleaner up to 100 bar and 80 °C |

| **Grad** | **Definitions according ISO 20653** | **Practical relevance to operating conditions** |
|---|---|---|
| IP69K | Protected from water during high-pressure/steam jet cleaning, especially road vehicles | Extremely humid environment, exterior cleaning with high-pressure cleaner up to 100 bar and 80 °C |

The first digit "6" means complete protection against dust ingress (dust-tight). This is also a requirement for dust ATEX Ex t (protection by housing, see 2.12.2).
The second digit defines the protection against penetration of water or humidity. A higher value starting from digit 7 does not necessarily mean a more robust design, rather the necessary degree of protection must be defined from the operating conditions. For numbers 6 and below, all definitions of the smaller numbers are included. For media other than water, the protection may be impaired.
There are proprietary specifications and test specifications. For example, the requirements of "proTect+" are higher than those of IP69 to ensure a long service life without maintenance in demanding industrial environments[1].

Comparison between IP69 and IP69K:

| **Degree of protection** | **IP69** | **IP69K** |
|---|---|---|
| Standard | EN 60529 | ISO 20653 |
| Focus | Common | especially road vehicles |
| Differences in testing | | |
| Distance test nozzle | 175 ± 25 mm | 100 -150 mm |
| Impact of the water jet | Force measurement | Pressure measurement |

Example for a level switch:

| | |
|---|---|
| Degree of protection (EN 60529) | IP 67 , with appropriate cable<br>IP 69 , with appropriate cable |
| Increased protection requirements | proTect+ |

### 2.5.4 Humidity

The "relative humidity" (RH) is always given. The specification "non-condensing" or "condensing" must be observed for temperature changes where the unit temperature can reach the dew point. This is the case, for example, when a cold process is started, such as when filling a pipe with beer from the storage tank.

| | |
|---|---|
| Humidity | < 98 % RH , condensing |

### 2.5.5 Environmental influences

The EN 60068-2 series of standards contains numerous test procedures for ambient and environmental influences. The most important test methods address the robustness against mechanical stress, such as shock and vibration and changing temperature and humidity. All tests require the determination of test severities. The specifications should be understood as a measure of confidence in the robustness and not as

[1] proTect+: First, the test samples are subjected to either water temperature or air temperature shock tests to simulate the aging effects and thus the life cycle of a sensor in the machine. During this process, the sensors must pass through a total of 50 temperature cycles each. Only then are the tests performed in accordance with the degrees of protection IP x8 and IP x9.

absolute limits of use, since the influences in practice usually cannot be exactly defined or do not behave as they do in the laboratory (e.g. no purely sinusoidal vibrations).

Example for a pressure sensor:

| | |
|---|---|
| Vibration (sinusoidal) (EN 60068-2-6) | 1.5 mm p-p (10 … 58 Hz), 10 g (58 Hz …2 kHz), 10 cycles (2.5 h) per axis |
| Bump (EN 60068-2-27) | 100 g / 2 ms, 4000 impulse per axis and direction |
| Damp heat, cyclic (EN 60068-2-30) | Db: 55°C, variant 1, 2 cycles (2 · 24 h) |

#### 2.5.6 Insulation resistance

The insulation resistance, measured between short-circuited electrical connection lines and the housing or process connection, contains at least an indication of the test voltage and optionally the test time.

Example for a pressure sensor:

| | |
|---|---|
| Insulation resistance | > 100 MΩ , 500 V DC |

### 2.6 Output signal

Different output signals are either integrated in parallel, selectable as order option or programmable.

#### 2.6.1 Current output

The variants depend on the requirements, primarily on the power demand for supply:

- 2-wire (passive current sink, current loop powered)
- 3-wire (additional GND connection for supply, passive or active circuitry)
- 4-wire (separate supply, active current source, normally with galvanic separation)

The output ranges are selectable between:

- 4 ... 20 mA (live-zero)
- 20 ... 4 mA (inverse operation)
- 0 ... 20 mA (dead-zero)
- 20 ... 0 mA (inverse operation)

Optionally, the output span can be ordered pre-configured, especially in case of turn-down of a pressure sensor or OEM adaptation of a temperature transmitter. The required parameters are the two measured values for the signaling end values for 0/4 mA and 20 mA.

The maximum value for the shunt resistance is specified for all output ranges. For passive current output it depends on the supply voltage Vs of the loop power supply. The specification of the operating voltage range refers directly to the sensor connections without considering other current loop devices or shunt resistors.

Example for a pressure sensor with passive current output:

| | |
|---|---|
| Voltage supply range | 8 ... 30 V DC , with current output |
| Current output | 4 … 20 mA , 2-wire |
| Shunt resistance | Rs ≤ (Vs - 8 V) / 0.0205 A<br>Rs ≤ 750 Ω, Vs = 24 V |

Calculation of the supply voltage range Vs of the loop power supply with an additional current loop device, which generates a constant voltage drop Us (see Figure 18):

Vs min. = Voltage supply range min. + Is max. • Rs + Us
Vs max. = Voltage supply range max. + Is min. • Rs + Us

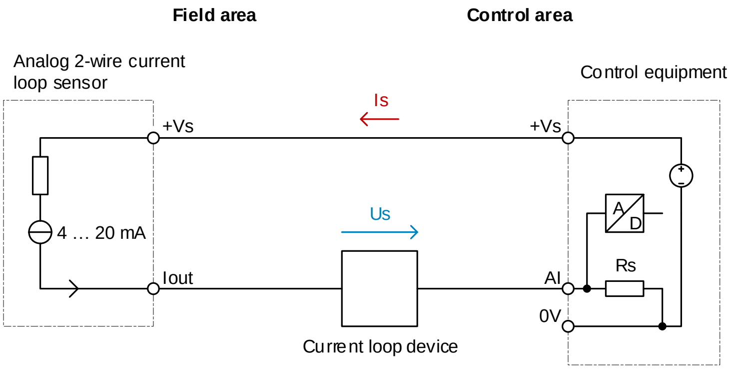



**Figure 18: Current loop with a passive current loop sensor and a current loop device**

The values for the output signal limits Is min. and Is max. can be taken from the configuration (e.g. FlexProgram).

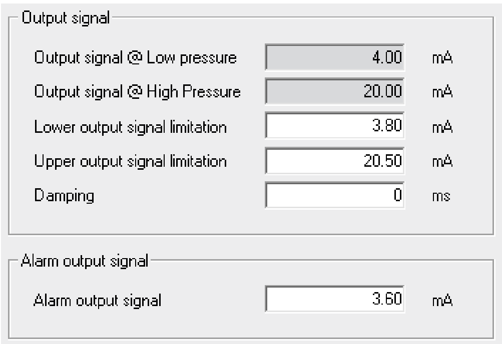



**Figure 19: Example for the configuration of the output signal of a pressure sensor**

For Is min. the lowest value of 3.6 mA configured for the alarm output signal applies here, for Is max. the upper output signal limit of 20.5 mA.

With the example from above and a shunt resistor Rs of 220 Ω and a current loop device (display) with Us = 6 V results:

Vs min. = 8 V + 20.5 mA • 220 Ω + 6 V = 18.5 V
Vs max. = 30 V + 3.6 mA • 220 Ω + 6 V = 36.8 V

Result: A loop power supply with Vs = 24 V is suitable with sufficient reserve.

A detailed description of the current output is contained in the “Baumer Guideline for Analog Sensor Interfaces”.

#### 2.6.2 Voltage output

Examples of output ranges for voltage output:

- 0 … 5 V (dead-zero)
- 0 … 10 V (dead-zero)
- 10 … 0 V (inverse operation)
- 1 … 5 V (live-zero)
- 0.5 … 4.5 V (ratiometric, linear dependent on the supply voltage)
- 0.5 … 4.5 V (absolute, independent of the supply voltage)

A sensor with voltage output is designed in 3-wire technology. To stay within the specified accuracy specifications, the load resistance must not fall below a certain value. The short circuit protection does not destroy the sensor in case of overload or wrong connection.

Example for a pressure sensor:

| | |
|---|---|
| Voltage output | 0… 10 V , 3-wire |
| Load resistance | > 5 kΩ |
| Short circuit protection | Yes |

A detailed description of the current output is contained in the “Baumer Guideline for Analog Sensor Interfaces”.

#### 2.6.3 Switching output

##### 2.6.3.1 Output type

The output type describes the physical design form of switching outputs. The user can configure and/or program this as an ordering option. The following options are available:

- **PNP** Switch to positive voltage supply potential (+Vs)
- **NPN** Switch to reference potential (GND, 0 V)
- **Push-pull** Switch between positive voltage supply potential (+Vs) and reference potential (GND, 0 V)
- **Contact** Potential-free switching contact

##### 2.6.3.2 Logical signal assignment

With binary switching states one speaks of two different logical signal assignments:

- **Normally Open** (NO) Switch in normal (inactive) state open
- **Normally Closed** (NC) Switch closed in normal (inactive) state

A distinction is made between two logical states:

- **Inactive** Normal condition, e.g. no medium detected, pressure ok or no error
- **Active** Triggered or critical condition, e.g. medium detected, pressure too high or alarm

#### 2.6.3.3 Voltage drop

With PNP and NPN outputs, a certain residual voltage across the switching elements is lost, i.e. the potentials of the operating voltage or the reference potential are not quite reached. The values depend on the load, therefore it is indicated under which conditions the voltage drop is specified. For push-pull outputs, both specifications apply to PNP and NPN.

Example for a level switch:

| | |
|---|---|
| Voltage drop | PNP: (+Vs -1.4 V) ± 0.5 V, Rload ≥ 10 kΩ<br>NPN: (-Vs +0.6 V) ± 0.3 V, Rload ≥ 10 kΩ |

#### 2.6.3.4 Current load and short circuit protection

If the permissible current load is exceeded, the correct operation of the switching output is no longer ensured. The short circuit protection switches off the output for protection in case of overload.

Example for a level switch:

| | |
|---|---|
| Current rating | 100 mA , max. |
| Short circuit protection | Yes |

#### 2.6.3.5 Leakage current

Even if the switching output is inactive, a residual current can remain, the so-called leakage current. This must be taken into account when selecting the load resistance in the control unit. If the resistance is too high, the switching threshold for detecting an active state can be reached incorrectly in the evaluation unit.

Example for a level switch:

| | |
|---|---|
| Leakage current | < 100 µA |

For more detailed information see “Baumer Guideline for Switching Outputs”.

## 2.7 Interfaces

The specifications for the IO-Link and HART interfaces are given here separately from the "Output signal" section.

### 2.7.1 IO-Link interface

In addition to operation as a normal switching output (SIO mode: standard I/O), the IO-Link interface offers a bidirectional communication mode. This mode transmits measurement and additional data and enables parameterization of the sensor. A so-called IO-Link master is required for this purpose.
The definitions for each sensor are described in its "IODD". (IO-Link Device Description), which are available as downloads on the manufacturer's website or in the "IODDfinder", see “Publications on IO-Link”.

Example for a pressure sensor:

| | |
|---|---|
| Version | 1.1 |
| Port type | Class A |
| Transmission rate | 38,4 kbaud (COM2) |
| Min. cycle time | 6.4 ms |
| SIO-Mode | Ja |

### 2.7.2 HART® interface

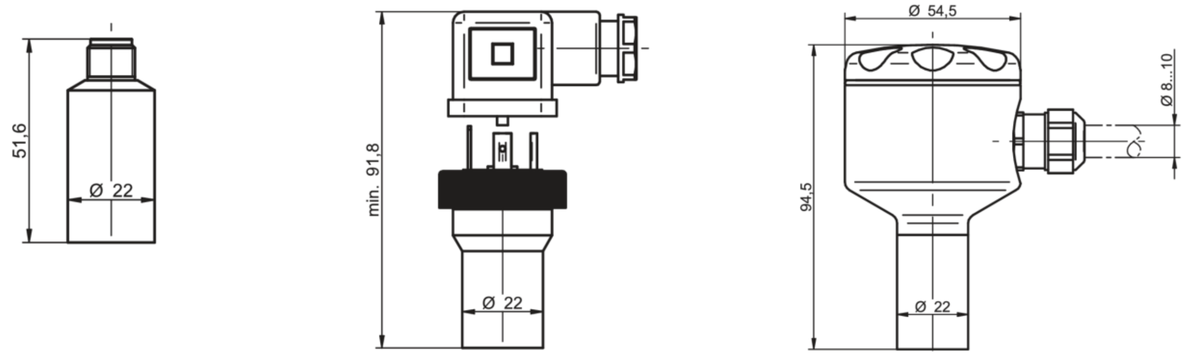
HART® stands for "Highway Addressable Remote Transducer". The bidirectional interface is based on a current signal (0/4 ... 20 mA). Two different frequencies encode the binary digital information by modulation on the current signal (FSK: Frequency Shift Keying). If the analog information of the current signal is omitted, several devices can be interconnected as a bus in the so-called “multi-drop” architecture. Generic standard functions are defined and it is possible to implement manufacturer specific functions. In this case you need the "DD" (Device Description) in the communication device. For further information see “Publications on HART®” and “Baumer Guideline for Analog Sensor Interfaces”.

Example for a temperature transmitter:

| | |
|---|---|
| Properties | Read serial number<br>Read/Change user ID<br>Read/Change configuration<br>Read input signal value<br>Read output signal value<br>Input signal logging<br>2-point sensor-trim |
| Protocol | HCF standard, Rev. 7 including „Temperature Device Family“ commands |

## 2.8 Housing

Certain sensor types can be configured with different housings, e.g. compact housing or field housing. The design of the housing may depend on other properties, e.g. electrical connection or process connection.




Housing with connector M12-A, 4-pin | Housing with connector DIN EN 175301-803A, 4-pin | Field housing with cable gland

**Figure 20: Example of different housing versions of a pressure sensor**

Check the suitability of the housing material for cleaning agents (e.g. Ecolab). For sensors where the housing and the process connection are made of one piece, the housing material can be configured simultaneously with the material for the process connection.

Example for a pressure sensor:

| | |
|---|---|
| Material | AISI 316L (1.4404) |

## 2.9 Electrical connection

The standard choices for electrical connections are provided where applicable:

- Connector
  - M12-A, 4-Pin
    - Plastics
    - Nickel-plated brass
    - Stainless steel
  - DIN EN 175301-803 A (DIN 43650 A), 4-pin
- Cable gland
  - Plastic M16 x 1.5, M20 x 1.5
  - Stainless steel M16 x 1.5, M20 x 1.5
- Cable outlet with configurable cable length

Dependent specifications or availability can arise for the different variants, e.g. for degree of protection or explosion protection.

Example for a level switch:

| | |
|---|---|
| Connector | M12-A, 4-pin, polycarbonate<br>M12-A, 4-pin, stainless steel |

## 2.10 Power supply

### 2.10.1 Voltage supply range

If the power supply to the sensor is outside the voltage supply range, deviations from the specifications or permanent damage may occur. An adapted fuse protection is required. Current loop powered sensors are to be fused with max. 100 mA.

Example for a level switch:

| | |
|---|---|
| Voltage supply range | 8 … 35 V DC |

### 2.10.2 Current consumption

The current consumption may depend on:

- Copy
- Supply voltage
- Operating status (start-up, configuration, etc.)
- Signaling (output inactive/active, current signal)
- Load of outputs

When dimensioning power supplies, the max. current consumption of the sensor applies. If "no load" is specified, the load currents of all outputs are added together.

Example for a level switch:

| | |
|---|---|
| Current consumption (no load) | 25 mA , typ.<br>50 mA , max. |

### 2.10.3 Reverse polarity protection

Reverse polarity protection means that no damage is caused to the sensor if the polarity of the supply voltage is accidentally reversed. Outputs with short-circuit protection are protected in combination against accidental connection to supply voltage or ground potential.

Example for a level switch:

| | |
|---|---|
| Reverse polarity protection | Yes |

### 2.10.4 Power-up time

The power-up time indicates the time period after applying the supply voltage until the sensor is completely ready for operation and provides a valid output signal.

Example for a temperature transmitter:

| | |
|---|---|
| Power-up time | < 3 s , RTD, Ohm, mV<br>< 5 s , T/C |

## 2.11 Factory settings

The specification of factory settings are intended for sensors that contain programmable parameters. In particular, a "factory reset" restores these if provided for the user.

Example for a level switch:

| | |
|---|---|
| qTeach | Activated |
| Switching logic SW1 | Normally open (NO) |
| Switching logic SW2 | Normally closed (NC) |
| Switching range (dielectric constant DC) | < 75 % , DC > 2 |

## 2.12 Explosion protection

In the “Baumer Explosion Protection Guideline” you will find a detailed description of the ignition protection types and the field application. At this point only the terms used in the specifications are referred to.

The information on explosion protection certification is listed separately in data sheets for each protection type. Protection types used by Baumer and their associated data are:

### 2.12.1 Intrinsic safety (Ex i)

Internal values for selecting the associated apparatus (barrier):

- Ui: max. input voltage
- Ii: max. input current
- Pi: max. input power
- Ci: max. internal capacitance
- Li: max. internal inductance

### 2.12.2 Tight enclosure (Ex t)

- Rated voltage, Un: max. permissible supply voltage
- Rated current, In: max. current consumption in normal operation
- Degree of protection for cable accessories: ensuring dust-tightness, esp. for M12 cable sockets
- Max. surface temperature: for calculating the reserve to the ignition and glow temperature (when complying with the working temperature range)

### 2.12.3 Non-sparking (Ex nA)

- Rated voltage, Un: max. permissible supply voltage
- Rated current, In: max. current consumption in normal operation
- Degree of protection for cable accessories: ensuring dust-tightness, esp. for M12 cable sockets
- Temperature class of the device (if the working temperature range is observed)

Will be replaced by Ex ec in the future

### 2.12.4 Increased safety (Ex ec)

The same specifications apply as above for “Non-sparking (Ex nA)”.

## 2.13 Compliance and approvals

Certain countries or unions make directives mandatory for placing products on the market. The manufacturer confirms conformity, e.g. in the EU with the "CE Declaration of Conformity". Certain conformities may only be confirmed by so-called "notified bodies", e.g. ATEX by TÜV or DEKRA with the issue of a type examination certificate.
Conformity with proprietary guidelines, e.g. 3-A and EHEDG for the hygienic industry, is awarded by specialized institutions after prescribed tests or assessment of the design. Compliance with specific standards, such as EN 50155 for rolling stock applications, can be confirmed by appropriate laboratory tests. The applicable standards for a product are listed in the data sheets.
Users may request additional non-legal standards, guidelines and certificates to confirm the suitability of the product for specific applications.
For simplicity, this section does not address specific editions of standards, guidelines and certificates, but provides a general overview.

### 2.13.1 CE (Conformité Européenne)

Compliance with European directives. By attaching the CE mark, Baumer declares the relevant product-specific compliance:

- 2014/30/EU: Electromagnetic compatibility (EMC) (replaces 2004/108/EC).
- 2011/65/EU: Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS) (replaces 2002/95/EC).
- 2014/68/EU: Making available on the market of pressure equipment (Pressure Equipment Directive, see 2.13.3.5).

The directives and any standards applied are to be specified in the “Declaration of Conformity” with the type designation of the device and the manufacturer’s address. With this document, which is to be presented on request, the manufacturer declares compliance on his own responsibility.

### 2.13.2 EMC (Electromagnetic compatibility)

EMC is a decisive criterion for trouble-free cooperation with devices and systems. In Europe, for example, the conformity of equipment to certain standards is legally regulated by the EMC directives. On the part of the manufacturer, certain conditions may apply, e.g. installation of a sensor is only permitted in a metallic container in order to use it as a shield.
EMC is divided into two categories according to the direction of action, radiation and immunity.

#### 2.13.2.1 Radiation

In particular, electronic circuits with microcontrollers or fast logic components unintentionally emit high frequencies. Connected lines can amplify this extremely, as they act like antennas. Radiation with too high power interferes with radio receivers, in the simplest case TV and radio sets. The relevant directives specify standards with test severities to keep the max. radiated power below a certain limit. The limits, some of which are frequency-dependent, vary according to the place of use and the product category. In the industrial sector, a higher radiated power can be tolerated than in the private sector if sensitive receiving devices are not located in the immediate vicinity.

#### 2.13.2.2 Immunity

EMC immunity is primarily not about resistance to EMC radiation from other devices as described above, since the limits there are extremely low so as not to interfere with radio receivers. Transmitters intentionally radiate a power that is many powers of ten higher.
Unintentional interference potentials are caused by discharge events, switching operations, lightning strikes and magnetic fields.

EMC immunity ensures trouble-free operation of wanted and unwanted interference potentials. The applicable standards are divided into several categories. The most important for sensors are:

- High frequency radiated or coupled onto lines (e.g. by cell phone)
- Electrostatic discharge (ESD)
- Fast transients (burst, e.g. due to sparking at switching contacts)
- Surge voltages and currents (surge, e.g. due to secondary effects of lightning strikes or switching inductors)
- Low-frequency magnetic fields (e.g. from motors)

### 2.13.3 Safety

#### 2.13.3.1 ATEX (Atmosphère Explosible)

European directive 2014/34/EU: Equipment and protective systems intended for use in potentially explosive atmospheres (replaces 94/9/EC). Compliance is to be examined by certified body and confirmed with a type examination certificate (e.g. TÜV). Baumer declares the compliance of appropriate sensors with the directive in the CE Declaration of Conformity.

#### 2.13.3.2 IECEx (International Electrotechnical Commission Explosive)

System provided by a voluntary organization to harmonize standards worldwide. An approved IECEx "Certification Body" (ExCB) issues the "Explosion Protection Test Report" (ExTR) and the “Quality Assessment Report” (QAR) for production. This body also issues the declaration of conformity (CoC). Recognition in IECEx member countries, but country-specific certification required; direct legal recognition only in Australia, New Zealand, Singapore and India (with some restrictions where applicable).

#### 2.13.3.3 UL (Underwriters Laboratories)

Independent organization in the US. Issues standards and tests products for compliance with special requirements, for example safety. Canadian Standards Association (CSA) is the counterpart in Canada. The “cULus” pictogram indicates the recognition of the relevant test for both countries. After successful testing, the laboratory issues a certificate (UL listed). The test is largely required by European OEMs that supply machines to the US. Their testing costs are reduced if individual components are already listed. Listing is not mandatory for the simple sale of sensors in the United States and Canada, since our devices do not use voltages or currents that pose the risk of electrical shock or fire.

#### 2.13.3.4 China Compulsory Certificate

Listed product groups, e.g. IT equipment, have had to be CCC certified for sales to and in China since 2002. Since 01.10.2020, CCC has also been mandatory for certain types of sensors for use in potentially explosive atmospheres. An ATEX or IECEx certificate is no longer sufficient, but it supports CCC certification. CCC requires a factory inspection and regular supervisory audits.

#### 2.13.3.5 PED (Pressure Equipment Directive)

The European Directive 2014/68/EU defines the requirements for pressure equipment to be placed on the market within the European Economic Area (EEA). It replaces 97/23/EC and applies to equipment above certain volumes and pressures.

#### 2.13.3.6 CRN (Canadian Registration Number)

The CRN system is the Canadian method of inspecting and registering the design of pressure vessels, piping systems and the armatures used to manufacture them. To date, different provinces require their own registration numbers, but efforts are underway to harmonize these across the country.

### 2.13.4 Food and Beverage

There are both government and voluntary guidelines for the use of sensors in food and beverage manufacturing.

#### 2.13.4.1 European Regulation 1935/2004/EC

Materials and articles intended to come into contact with food.

- 10/2011/EU: Plastic materials
- 2023/2006/EG: Good manufacturing practice

With the “Safety for contact with food” certificate, Baumer declares its compliance with these regulations. For bought-in parts we require appropriate evidence from our suppliers.

#### 2.13.4.2 EHEDG (European Hygienic Engineering & Design Group)

European, non-profit consortium of users, suppliers and health care bodies. Assessment of the cleanability of hygienic components on the basis of a laboratory test in which the test object is compared to a reference tube. If the test is passed, EHEDG issues a certificate. The consortium also issues guidelines. The cleanability of the outside of devices (cases etc.) is referred to as “washdown”, which is used particularly in location sensors (e.g. light barriers). This can also be used for cable connections and connectors.

#### 2.13.4.3 FDA (U.S. Food & Drug Administration)

Supervisory authority in the United States for the protection of humans and animals. In process technology, responsible for the selection of materials. Certain materials such as high-alloy stainless steel and various synthetic materials (e.g. PEEK) are listed for safe medium contact. These are given a specific “CFR” number. Baumer declares compliance with FDA requirements on its own responsibility with the “Food Regulatory Declaration of Harmlessness”.

#### 2.13.4.4 3-A Sanitary Standards, Inc.

Independent, non-profit company in the US. Representation of the interests of public and state health bodies, machine and food manufacturers. Establishes standards for materials and design for use in the beverage, food and pharmaceutical industries. The assessment of the compliance of a test object is carried out by an inspector on the basis of the design drawing and a visual inspection. If this is positive, 3-A issues a certificate. In addition to the parts coming into contact with the process, the exterior design (case etc.) must comply with certain guidelines, for example, no liquid may remain on flat surfaces.

### 2.13.5 Maritime

#### 2.13.5.1 DNV GL-Maritime

Amalgamation of the classification companies “Det Norske Veritas” (Norway) and “Germanischer Lloyd” (Germany). DNV-GL certifies equipment for the maritime sector, mainly for use on ships. Before a certificate can be issued, increased vibration resistance in particular must be demonstrated in laboratory tests..

#### 2.13.5.2 Lloyd‘s Register

Classification company with headquarters in London (UK). It issues certificates on the basis of laboratory tests complying with the Lloyd's Register Quality Assurance system. In addition to the shipping sector, the company is also active in the railway sector.

### 2.13.6 Rolling stock applications

EN 50155 refers to electronic equipment for railroad applications, which also includes sensors. In particular, interference immunity, power supply, environmental conditions (e.g. vibrations) and other design requirements are included.

## 2.14 Inspection documents

For orders or certain products these inspection documents according to EN 10204 are available:

### 2.14.1 Declaration of compliance with the order “type 2.1”

Statement of compliance with the order. No specific test or measurement.

### 2.14.2 Test report “type 2.2”

Statement of compliance with the order, with indication of results of nonspecific inspection. Confirmation with regard to selected quality characteristics, e.g.:

  - Material
  - Ferrite content
  - Surface roughness

- No specific tests or measurements of the delivered products
- Production standards confirm the quality characteristics, e.g. random samples
- If several characteristics are confirmed at the same time, a single test report is sufficient

### 2.14.3 Inspection certificate 3.1 “type 3.1”

Statement of compliance with the order, with indication of results of specific inspection. Confirmation with regard to certain properties (e.g. relating to materials and products, such as materials of wetted parts).

- Specific testing, e.g. material analysis
- For multiple products of the same type, listing of all serial numbers in a single inspection certificate
- Gapless traceability based on the serial number of each individual product possible

## 2.15 Calibration documents

### 2.15.1 Calibration protocol

Calibration protocols are created as standard or optional.

- Different number of measuring points
- Measurements with production-internal test equipment that is subject to ISO 9001

### 2.15.2 Calibration certificate

In contrast to the calibration protocol according to 2.15.1, the calibration takes place in an accredited laboratory.

# 3 Specific definitions of measurement technologies

## 3.1 Pressure measurement

### 3.1.1 Definition of pressure

The pressure $p$ is defined as force $F$ per area $A$:

$$p = \frac{F}{A}$$

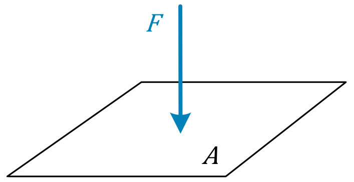



Figure 21 shows a cuboid which exerts a greater pressure $p_2$ on the supporting surface when placed on its front side with a smaller area $A_2$ than when placed on its broad side with a larger area $A_1$. The pressure is greater for the same weight force if the latter acts on a smaller area.

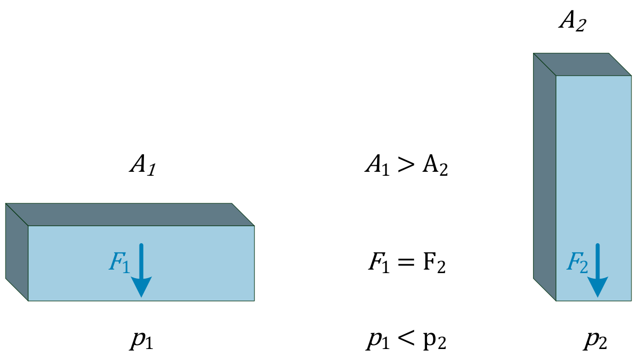



**Figure 21: Illustration of the pressure dependence on the supporting surface**

### 3.1.2 Units for pressure

#### 3.1.2.1 Pascal

The Pascal is named after the French mathematician and physicist Blaise Pascal (1623 - 1662). The pressure unit Pa is derived from the SI units:

$$1\ \mathrm{Pa} = 1\frac{\mathrm{N}}{\mathrm{m}^2} = 1\frac{\mathrm{kg}}{\mathrm{m} \cdot \mathrm{s}^2}$$

Despite its definition as an SI unit, it is rarely used in the practical language of automation technology. In meteorology, the hectopascal (hPa), which has the same number, has replaced the earlier millibar (mbar) for indicating barometric pressure.

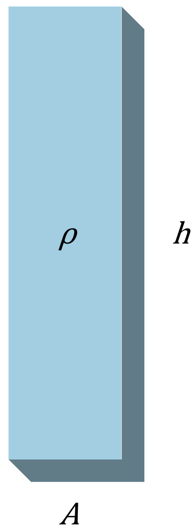
#### 3.1.2.2 Bar

The bar, literally derived from the Greek word for "heavy," is a legally permissible unit along with the pascal. 1 bar corresponds exactly to $10^5$ Pa. As a rule of thumb, the average air pressure or a water column 10 m high exerts a pressure of 1 bar. "bar abs" stands for the specification of absolute pressure.

### 3.1.2.3 Meter water column

A column of liquid with height $h$ exerts a so-called hydrostatic pressure $p_{Hyd}$ on the base surface $A$ via its weight force, also referred to as "gravity pressure". The weight is determined by the density $\rho$ of the liquid and the acceleration due to gravity $g$.

Water column




$$p_{Hyd} = \frac{F}{A} = \frac{m \cdot g}{A} = \frac{\rho \cdot A \cdot h \cdot g}{A} = \rho \cdot h \cdot g$$

For water, the density at 4 °C is exactly 1000 kg/ m³. Together with the international unit value of the acceleration due to gravity

$$g = 9.80665 \frac{\mathrm{m}}{\mathrm{s}^2}$$

the quantity equation is obtained:

$$p_{Hyd} = 9806.65\ \mathrm{Pa} \cdot h[\mathrm{m}] = 0.980665\ \mathrm{bar} \cdot h[\mathrm{m}]$$

For a pressure of 1 bar, a water column of approx. 10.2 m is required:

$$h = \frac{p_{Hyd}}{9806.65\ \mathrm{Pa}}\ \mathrm{m} = \frac{10^5\mathrm{Pa}}{9806.65\ \mathrm{Pa}}\ \mathrm{m} = 10.197\ \mathrm{m} \sim 10.2\ \mathrm{m}$$

There are different notations for the unit designation of "meter water column":

$mH_2O$, $cmH_2O$, $mmH_2O$, $inH_2O$, $ftH_2O$, mWS, cmWS, mmWS.

These units are no longer legal, but the hydrostatic level measurement and tightness specifications still use them.

A detailed formula derivation also in imperial units can be found in the “Baumer Guideline for Hydrostatic Level Measurement”.

### 3.1.2.4 psi

The unit psi, which originates from the imperial system of units, means "pound-force per square inch". One Anglo-American pound (lb) exerts a pressure of 1 psi on an area of one square inch (in²). For conversion to other units, the acceleration due to gravity $g$ is necessary. Depending on its definition, this results in different figures. For the unit value of the acceleration due to gravity from 3.1.2.3 results:

$1\ \mathrm{bar} = 14.503773773\ \mathrm{psi} \qquad 1\ \mathrm{psi} = 0.068947573\ \mathrm{bar}$

The unit can also be found with extensions psia for absolute and psig (gauged) for relative pressure specifications.
The use of psi is primarily widespread in the USA in everyday use (e.g. for tire pressure specifications).

### 3.1.2.5 Torr

The Torr goes back to the Italian physicist and mathematician Evangelista Torricelli (1608 - 1647). He invented the mercury barometer in 1644. In principle, the same derivation applies as in 3.1.2.3, but with a different density of mercury of 13,595 kg/m3 (at 0 °C) for a liquid column of 1 mm height. Practically, 1 torr and 1 mmHg can be equated, although there are slight differences in the derivation via the SI units. In any case, the definition is valid that the mean air pressure of 1013.25 hPa at sea level (1 atm) corresponds exactly to 760 torr and thus:

$1\text{ bar} = 750.062\text{ mmHg} \qquad 1\text{ mmHg} = 1.33322\text{ mbar}$

The torr was formerly used in meteorology, but is no longer an approved unit by law, with the exception of medicine. There, mmHg is used for pressure indications of body fluids, such as blood pressure.

### 3.1.3 Conversion table for pressure units

| | Pa | mbar | bar | $H_2O$ | psi | mmHg | inHg |
|---|---|---|---|---|---|---|---|
| **1 Pa =** | | 0.01 | | 0.102 mm | | | |
| **1 hPa =** | 100 | 1 | | 10.2 mm | | 0.750 | 0.02953 |
| **1 kPa =** | 1000 | 10 | 0.01 | 102 mm | 0.145 | 7.50 | 0.2953 |
| **1 MPa =** | 1000 k | | 10 | 102 m | 145 | 7500 | 295.3 |
| **1 bar =** | 100 k | 1000 | | 10.2 m | 14.5 | 750 | 29.53 |
| **1 m $H_2O$ =** | 9810 | 98.10 | | | 1.422 | 73.556 | 2.896 |
| **1 psi =** | 6895 | 68.95 | | 0.703 m | | 51.715 | 2.036 |
| **1 mmHg =** | 133.3 | 1.333 | | 13.6 mm | | | 0.03937 |
| **1 inHg =** | 3386.4 | 33.864 | 0.033864 | 345.3 mm | 0.491154 | 25.4 | |

(Values partly rounded)

### 3.1.4 Pressure types

"Relative pressure" or "absolute pressure" refers to the underlying reference, i.e. whether the pressure is meant against the "ambient pressure" (generally the air pressure) or against "absolute vacuum". The same pressure is then given different numerical values, such as each of the pressures $p_1$ and $p_2$ in Figure 22.

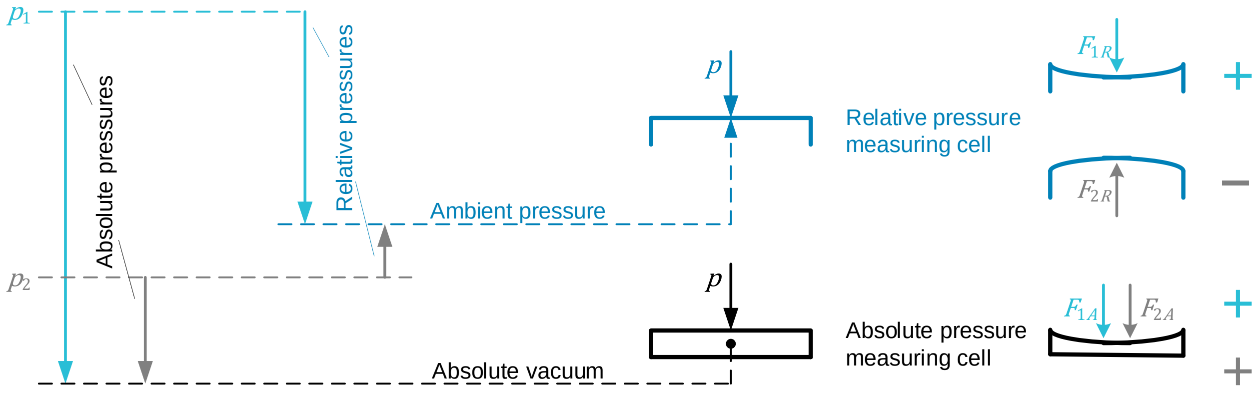



**Figure 22: Pressure ratios for relative pressure and absolute pressure measurement**

The “Baumer Guideline for Hydrostatic Level Measurement” contains a detailed description on this subject.

### 3.1.5 Pressure ranges outside the measuring range

Terms defining the pressure ranges outside the measuring range are:

| Pressure range | Impact |
|---|---|
| Measuring range | Output of the measured pressure within the accuracy specification |
| Overload range | Accuracy specification no longer valid, no damage |
| Destruction range | Non-reversible damage |

**For relative pressure measuring cells at negative pressures:**

In the pressure range below the start of the measuring range, an overload range and destruction range may be present (see shaded areas in Figure 23).
The property for suitability for negative pressures is called "vacuum resistance". In practice, negative pressures can occur unintentionally in the event of a sudden drop in temperature, e.g. when a cold medium is fed into a tank.

**For absolute pressure measuring cells:**

The pressure can never assume negative values (less than zero). There is no range below the start of the measuring range of 0 bar absolute.

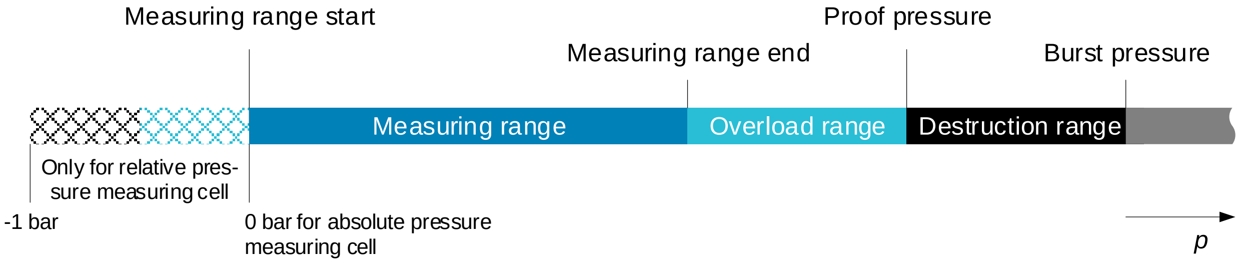



**Figure 23: Definition of pressure ranges outside the measuring range**

The boundaries of the overload range and destruction range are the overload limit and the burst pressure.

#### 3.1.5.1 Proof pressure

The proof pressure is the max. pressure at which no non-reversible damage occurs to pressure sensors. After exceeding this pressure, operation is no longer guaranteed within the specification (e.g. non-linearity, zero point deviation, etc.). Even short pressure peaks above the overload limit can lead to permanent deviations. The presence of pressure peaks is often not even known or their peak value is underestimated[2]. If the "water hammer" cannot be avoided, the max. pressure amplitude must be determined and the measuring range selected so that there is a reserve for the overload limit. The span of interest then occupies only part of the measuring range of the pressure sensor[3].

[2] There are pressure sensors that include a pressure peak recording as secondary information.
[3] Water hammers should always be avoided, as they can damage the entire system. They occur with fast-flowing media when a valve closes abruptly in the direction of flow. The cause must be eliminated. Otherwise, the pressure sensor, as the weakest link in the system, will be damaged first.

#### 3.1.5.2 Burst pressure

A pressure above the burst pressure permanently destroys the sensor. It can damage the sensor element as well as cause a rupture of the diaphragm. This poses a risk of medium escaping from the process due to a lack of tightness. The exact knowledge of the max. occurring pressure ensures the correct selection of a pressure sensor.

Example for the specification of the overload limit and the burst pressure:

| **Measuring range (bar)** | | | | **Proof pressure (bar)** | **Burst pressure (bar)** |
|---|---|---|---|---|---|
| 0 ... 0.1 | 0 ... 0.16 | 0 ... 0.25 | | 1 | 2 |
| 0 ... 0.4 | 0 ... 0.6 | 0 ... 1 | | 3 | 6 |
| -0.1 … 0.1 | -0.2 … 0.2 | -1 … 0 | -1 … 0.6 | | |
| 0 ... 1.6 | 0 ... 2 | 0 ... 2.5 | 0 ... 4 | 15 | 30 |
| -1 … 1.5 | -1 … 3 | -1 … 5 | | | |
| 0 ... 6 | 0 ... 10 | 0 ... 16 | 0 ... 20 | 60 | 120 |
| -1 … 9 | -1 … 15 | | | | |
| 0 ... 25 | | | | 70 | 140 |
| -1 … 24 | | | | | |
| 0 ... 40 | | | | 135 | 270 |
| -1 … 39 | | | | | |

### 3.1.6 Turndown

A turndown reduces the measuring span of a pressure sensor. This only has an effect with analog signaling, e.g. with the 4 ... 20 mA signal. The errors of analog signaling by converting between analog and digital are reduced, because the smaller measuring span is distributed over the same signal range. The resolution of measured values in the analog signal improves.
The measurement error of the measured quantity of the sensor still refers to its native measuring span. The absolute measurement error (specified in the unit of the measured quantity) remains the same. The relative measuring error (specified in percent) refers to a smaller measuring span and increases in proportion to the turndown.

Example for a turndown:

| | |
|---|---|
| Measuring range | –1 … 24 bar |
| Max. measuring error | 0.5 % FS |
| Absolute measuring error | 0.5 % × 25 bar = 0.125 bar |
| Output range limits (standard) | 4 mA = –1 bar<br>20 mA = 24 bar |
| Max. turndown ratio | 5 : 1 |
| Turndown applied | 2.5 : 1 (< max. turndown ratio) |
| Measuring range with turndown | –1 … 9 bar |
| Measuring span with turndown | 9 bar – (–1 bar) = 10 bar |
| Max. measuring error with turndown | 0.125 bar ÷ 10 bar = 1.25 % FS |
| Output range limits with turndown | 4 mA = –1 bar<br>20 mA = 9 bar |

Figure 24 shows an Example for a characteristic curve without and with turndown. The significantly larger slope with turn-down already outputs a current signal of 20 mA at 9 bar.

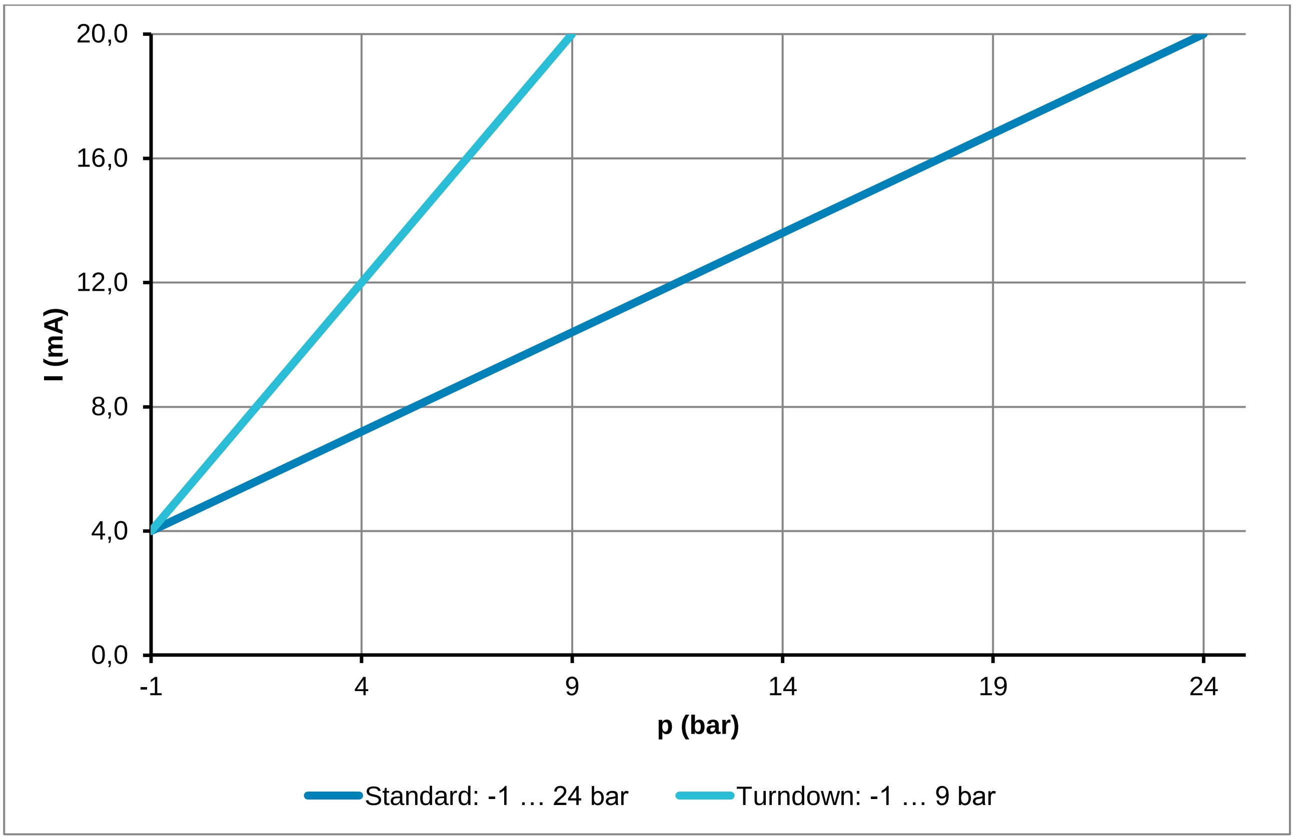



**Figure 24: Example of the characteristic curve of a pressure sensor without and with turndown**

### 3.1.7 Influence of the installation position

Due to the weight of the diaphragm and oil filling, a position-dependent pressure superposition occurs depending on the design in the order of magnitude of up to a few millibars (or a few centimeters for hydrostatic level measurement). High-precision pressure sensors (≤ 0.25 %) with measuring ranges ≤ 2 bar show a relevant influence of the zero point deviation due to the installation position. Manual adjustment of the offset parameter corrects this systematic deviation. The factory adjustment corrects the offset by default for installation from above. For the installation positions from the side and from below, a positive offset is added in the factory setting (see Figure 25).

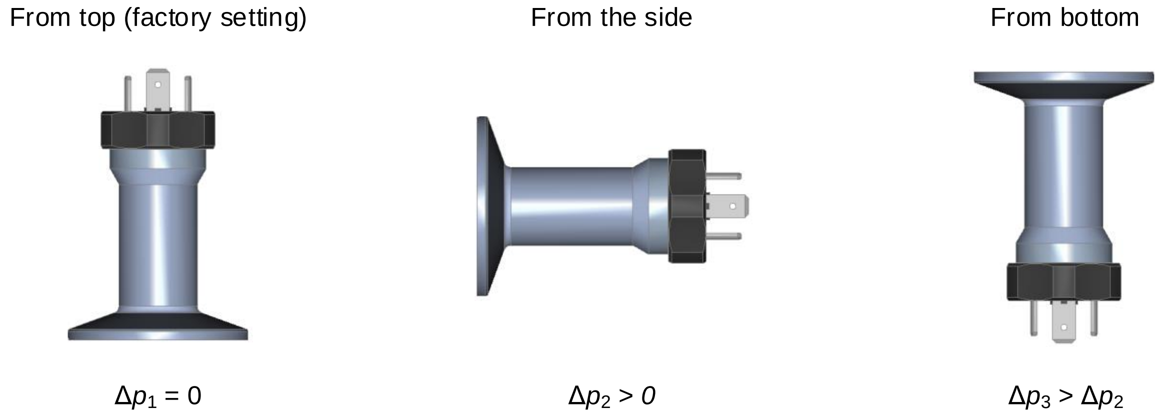



**Figure 25: Pressure superposition or zero point deviation with different mounting positions**

## 3.2 Level measurement

Level measurements determine the level of the surface of a medium to a defined reference point. Conversion by volume or weight provides the filling quantity contained in a container.

### 3.2.1 Units for fill level

#### 3.2.1.1 Meter

The meter, derived from the French "mètre", has been defined since 1799 as the new "original master meter" via the length of a bar of platinum iridium. As early as 1791, there was a decision for a new measure of length, which was to be the ten-millionth part of the distance from the pole to the equator at a given longitude. In the meantime, the first prototype of the original master meter was created in 1795 from cast brass. Today, the meter is defined as the SI base unit with the abbreviation "m" via the speed of light.

#### 3.2.1.2 Foot

The foot has its widespread origin in the use of body measurements as a unit of length, such as "hand" or "cubit". Today, the "English foot" (ft) and the subdivision into 12 inches (in) is valid:

$1\ \mathrm{ft} = 12\ \mathrm{in} = 0.3048\ m$
$1\ \mathrm{in} = 25.4\ \mathrm{mm}$

### 3.2.2 Units for filling quantities

The filling quantity in a vessel is derived from the fill level and the vessel geometry. The volume, together with the information about the density of the medium, provides the mass (or weight).
For a purely cylindrical vessel, there is a linear relationship between standing height and volume. For completely or partially non-vertical vessel walls, e.g. in the case of a cone, dished end or horizontal cylindrical tank, a conversion function or table must be created.

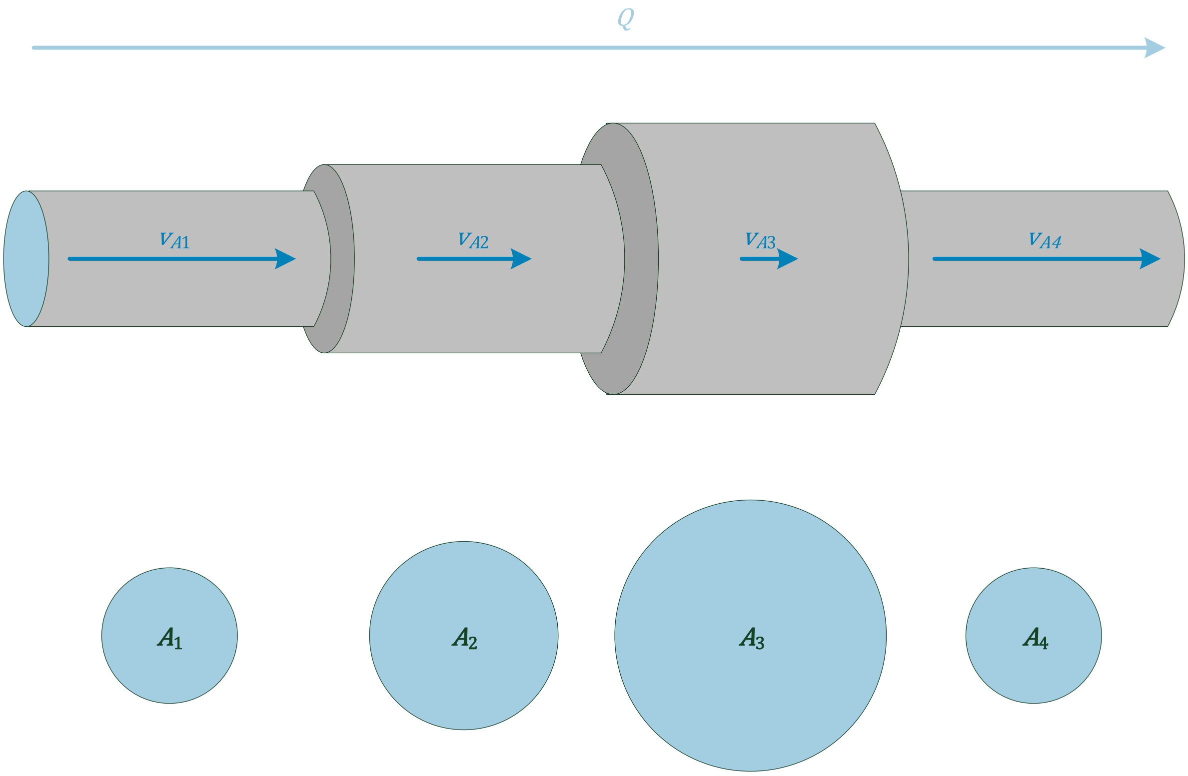
### 3.2.3 Hydrostatic level measurement

The derivation of the units for hydrostatic level measurement can be found in the “Baumer Guideline for Hydrostatic Level Measurement”.

## 3.3 Flow measurement

### 3.3.1 Definition of volume flow

The volume flow (also flow rate) indicates how much volume of a liquid or a gas flows through a pipe per time interval. As long as there are no branches, no medium is lost or added anywhere. The volume flow Q remains the same regardless of the cross-section $A_x$ along the pipe. The average flow velocity $v_{Ax}$ varies depending on the local cross-section of the pipe, see Figure 26. The flow profiles (laminar, turbulent) occurring at points along the cross-sectional areas $A_x$ depend on many factors and are not the subject of this description.




| | | | |
|---|---|---|---|
| $A_1$ | $A_2 = 2 \cdot A_1$ | $A_3 = 4 \cdot A_1$ | $A_4 = A_1$ |
| $v_{A1}$ | $v_{A2} = \frac{v_{A1}}{2}$ | $v_{A3} = \frac{v_{A1}}{4}$ | $v_{A4} = v_{A1}$ |

**Figure 26: Relationship between average flow velocity and pipe cross-section**

Most common measuring principles for flow measurement provide as raw signal either a punctual flow velocity $v_p$ or a flow velocity $v_A$ averaged over the cross-section. Taking into account the pipe cross-section $A$ at the installation location of the sensor, it can calculate the volume flow $Q$ from $v_A$ and further the volume $V$ flowed through over a time interval $\Delta t$ by time integration.

$$Q = v_A \cdot A$$

$$V = Q \cdot \Delta t$$

### 3.3.2 Flow measurement units

#### 3.3.2.1 Flow velocity

For the flow velocity $v$, the same SI unit "meters per second" applies as for normal velocity measurements, e.g. that of a vehicle:

$$[v] = 1\frac{\mathrm{m}}{\mathrm{s}}$$

#### 3.3.2.2 Volume flow

For the volume flow $Q$ is derived from the SI units "cubic meters per second":

$$[Q] = 1\frac{\mathrm{m}^3}{\mathrm{s}}$$

In practice, various other units are used for the volume flow $Q$, depending on the quantities conveyed, e.g. for the volume liter, milliliter and for the time minute or hour.

### 3.3.3 Conversion table for volume units

| | $m^3$ (cubic meter) | l, $dm^3$ (liter) | ml, ccm (milliliter) | imp gal (gallon UK) | US gal (gallon US) | $ft^3$ (cubic foot) | $in^3$ (cubic inch) |
|---|---|---|---|---|---|---|---|
| **1 $m^3$ =** | | 1000 | | 219.97 | 264.172 | 35.3147 | |
| **1 $dm^3$ =** | 0.001 | | 1000 | 0.212 | 0.26417 | 0.035315 | 61.024 |
| **1 ml =** | | 0.001 | | | | | 0.061024 |
| **1 imp gal =** | | 4.546 | 4546 | | 1.2 | 0.1605 | 277.42 |
| **1 US gal =** | | 3.7854 | 3785.4 | 0.8327 | | 0.1337 | 231 |
| **1 $ft^3$ =** | 0.02832 | 28.317 | 28317 | 6.229 | 7.4806 | | 1728 |
| **1 $in^3$ =** | | 0.01639 | 16.387 | | | | |

(Values partly rounded)

## 3.4 Conductivity measurement

### 3.4.1 Definition of specific conductivity

The electrical conductance $G$ is the reciprocal of the electrical resistance $R$ and thus the ratio between current $I$ and voltage $U$ according to Ohm's law.

$$G = \frac{1}{R} = \frac{U}{I}$$

Different substances have different specific conductivities $\gamma$. An electrical conductor flowing in the longitudinal direction has the conductance:

$$G = \gamma \cdot \frac{A}{l}$$

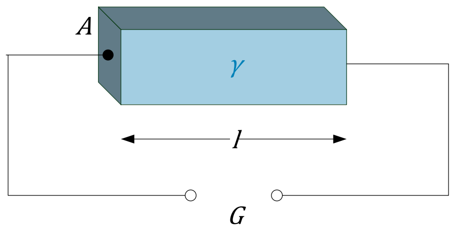



**Figure 27: Conductivity of an electrical conductor through which current flows in the longitudinal direction**

The greater the specific conductivity $\gamma$ of a substance, the greater its conductance for the same shape and size. A conductivity measuring cell for liquids measures their specific conductance. The diameter and spacing of the electrodes determine the sensitivity of the measuring cell, the so-called "cell constant". Compact conductivity meters take their cell constant into account even when preparing the measured value.

### 3.4.2 Units for specific conductivity

The unit of conductance is the "Siemens". The unit of specific conductivity γ taking into account the geometric dimensions area $A$ and length $l$ is "Siemens per meter":

$$[\gamma] = 1\,\frac{\mathrm{S}}{\mathrm{m}} = 0.01\,\frac{\mathrm{S}}{\mathrm{cm}} = 10\,\frac{\mathrm{mS}}{\mathrm{cm}}$$

### 3.4.3 Conversion table of conductivity values

| | **S/m** | **mS/m** | **µS/m** | **S/cm** | **mS/cm** | **µS/cm** |
|---|---|---|---|---|---|---|
| **1 S/m =** | | 1000 | | 0.01 | 10 | |
| **1 mS/m =** | 0.001 | | 1000 | | 0.01 | 10 |
| **1 µS/m =** | | 0.001 | | | | 0.01 |
| **1 S/cm =** | 100 | | | | 1000 | |
| **1 mS/cm =** | 0.1 | 100 | | 0.001 | | 1000 |
| **1 µS/cm =** | | 0.1 | 100 | | 0.001 | |

### 3.4.4 Temperature compensation

The conductivity of any liquid depends physically on the temperature. It increases with +2 %/K for most aqueous solutions. In order to compare measurements, measuring instruments convert the directly determined conductivity back to a reference temperature. This is usually set to 25 °C. In addition to setting the reference temperature, the meters also allow a temperature coefficient in %/K to be entered. This must be set to 0 %/K if temperature compensation is not required.

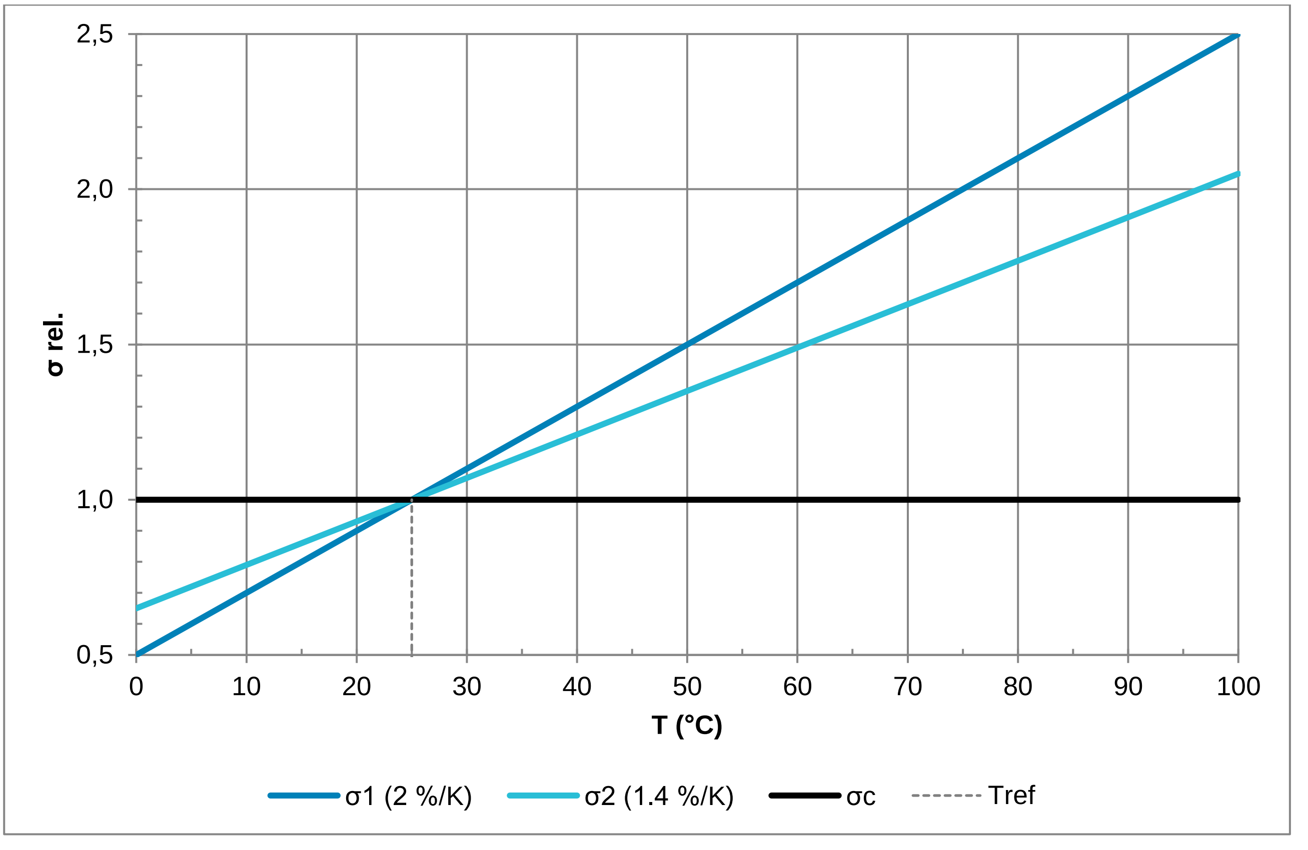



**Figure 28: Temperature compensation using the example of two different temperature coefficients**

The example in Figure 28 illustrates the relationship using a normalized scaling with a factor of 1.0 at a temperature of 25 °C. The liquid with conductivity $\sigma 1$ has a temperature coefficient TC of 2 %/K. The conductivity at the reference temperature $T_{ref}$ is normalized by a factor of 1.0. If the temperature is increased by 50 K to 75 °C, the conductivity doubles:

$$\Delta T = T - Tref = 75\,℃ - 25\,℃ = 50\ \mathrm{K}$$

$$\frac{\sigma_T}{\sigma_{\mathrm{Tref}}} = 1 + TK \cdot \Delta T = 1 + 2\ \%/\mathrm{K} \cdot 50\ \mathrm{K} = 1 + 100\ \% = 2.0$$

At 0 °C the conductivity is reduced to half:

$$\Delta T = T - Tref = 0\,℃ - 25\,℃ = -25\ \mathrm{K}$$

$$\frac{\sigma_T}{\sigma_{\mathrm{Tref}}} = 1 + TK \cdot \Delta T = 1 + 2\ \%/\mathrm{K} \cdot (-25)\ \mathrm{K} = 1 - 50\ \% = 0.5$$

In order to obtain comparable results, the measuring instrument always compensates the measured conductivity for the output as if the temperature were $Tref$, usually 25 °C. The measured conductivity is then displayed as a temperature-compensated value. This results in the characteristic $\sigma c$ in Figure 28 as a temperature-compensated indication of the conductivity.
Conductivity sensors have an integrated temperature sensor for determining the liquid temperature. Chapter 3.5.4 also applies to its specification.

### 3.4.5 Conductivities of different media

| Medium | Conductivity | Remark |
|---|---|---|
| Pure water | 0.055 µS/cm | Only possible under exclusion of air |
| Ultrapure water | ≤ 1.1 µS/cm | According to European Pharmacopoeia |
| Distilled water | 0.5 … 5 µS/cm | Obtained by evaporation |
| Drinking water | ≤ 2790 µS/cm | German Drinking Water Ordinance |
| Beer | 1.2 … 2.3 mS/cm | |
| Milk 3.5 % fat | 4 … 6 mS/cm | Measurement of udder health possible |
| Sea water | 56 mS/cm | |
| Caustic soda (NaOH) 5 % | 223 mS/cm | |

Data related to Tref = 25 °C

The conductivity depends on the concentration. Figure 29 shows this using caustic soda (NaOH) as an example. The conductivity decreases again above a certain concentration. Each medium has its own characteristic property.

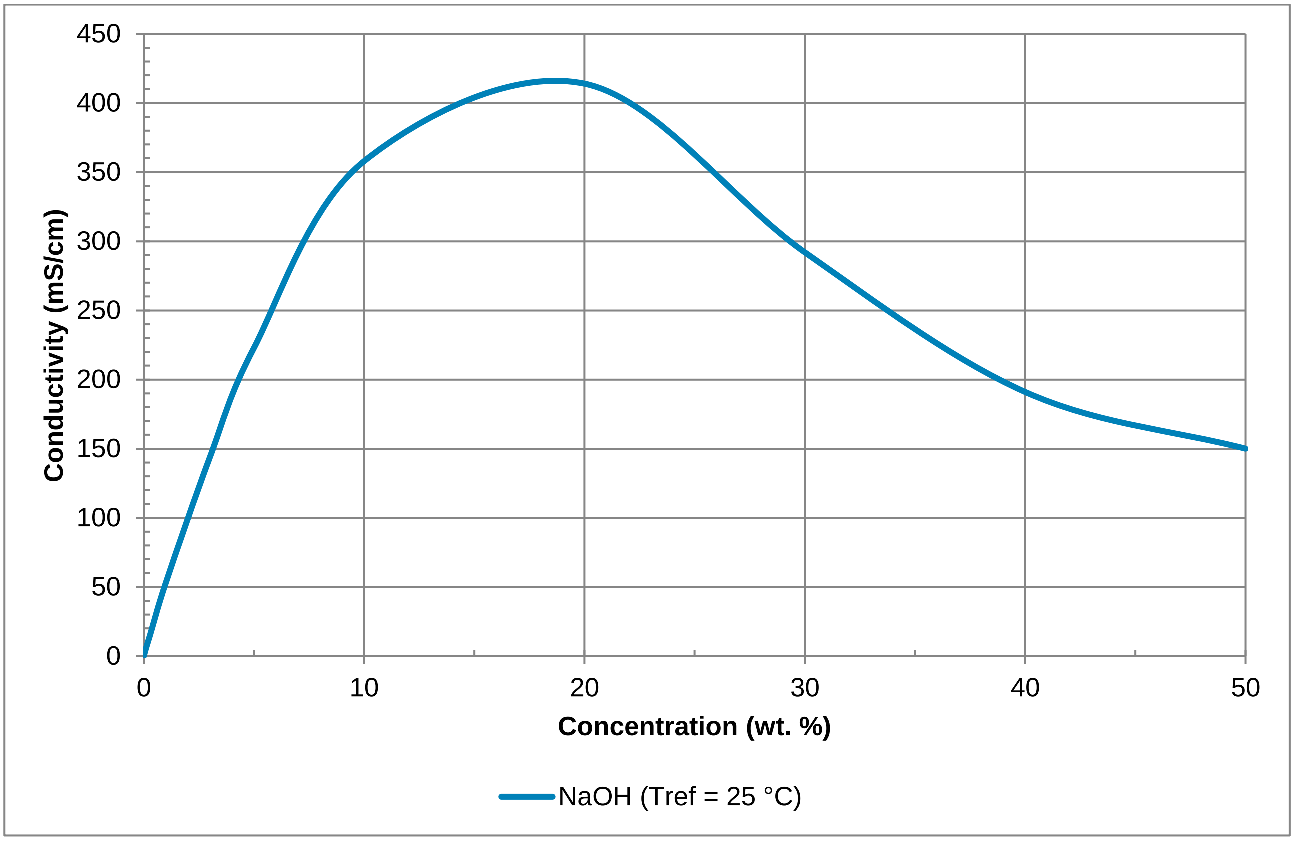



**Figure 29: Conductivity of caustic soda (NaOH) as a function of concentration**

## 3.5 Temperature measurement

### 3.5.1 Definition of temperature

Temperature (derived from the Greek word "thérmis" = warm) is a physical state variable. It describes the measure of heat and thus the proportion of energy due to the disordered movement of particles (atoms or molecules).

### 3.5.2 Units for temperature

#### 3.5.2.1 Degree Celsius

The Celsius scale goes back to the Swedish astronomer Anders Celsius (1701 − 1744).
The freezing point and the boiling temperature of water at normal atmospheric pressure define the scale. Today, these limits define the range from 0 °C to 100 °C (after Celsius had defined the scale in reverse at that time).

#### 3.5.2.2 Degree Fahrenheit

The German physicist Daniel Gabriel Fahrenheit (1686 − 1736) wanted to avoid negative temperature values and fixed the lowest point 0 °F with a solution of ice, water and ammonium chloride. This replica produced the lowest temperature of −17.8 °C that he could measure in his hometown of Gdansk in the winter of 1708 − 1709. Fahrenheit defined the second point as 32 °F at the freezing point of pure water. The third point was to be the average body temperature of a human being, his choice of 96 °F. Later, the boiling point of water was defined as exactly 212 °F; thus, a range of 180 °F corresponds exactly to a difference of 100 °C. In the past, the Fahrenheit scale was used throughout Europe, but today it is predominantly used only by the USA and, to some extent, Canada.

#### 3.5.2.3 Kelvin

The Kelvin defines the absolute zero point as the lower limit 0 K, i.e. the lowest temperature that theoretically exists physically, corresponding to −273.15 °C. At this temperature, the energy of the disordered particle motion is zero. On the Kelvin scale, a difference of 1 K corresponds exactly to a difference of 1 °C on the Celsius scale. Today, the Kelvin is the SI unit of temperature and is commonly used in technical and scientific fields. The Kelvin is preferred for the indication of temperature differences, e.g. for accuracy specifications of temperature sensors.

#### 3.5.2.4 Temperature unit conversions

$t[°\mathrm{F}] = T[°\mathrm{C}] \cdot 1.8 + 32$ $\quad$ $t[°\mathrm{C}] = (t[°\mathrm{F}] - 32) \cdot \frac{5}{9}$ $\quad$ Rule of thumb °F to °C: subtract 30 and halve

$T[\mathrm{K}] = t[°\mathrm{C}] - 273.15$ $\quad$ $t[°\mathrm{C}] = T[\mathrm{K}] + 273.15$

### 3.5.3 Conversion table °C / °F

| °C | -40 | -30 | -20 | -10 | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °F | -40 | -22 | -4 | 14 | 32 | 50 | 68 | 86 | 104 | 122 | 140 | 158 | 176 | 194 | 212 | 230 | 248 | 266 | 284 | 302 | 320 | 338 | 356 | 374 | 392 |
| °F | -20 | 0 | -10 | 20 | 40 | 60 | 80 | 100 | 120 | 130 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 330 | 340 | 360 | 380 | 400 |
| °C | -29 | -18 | -23 | -7 | 4 | 16 | 27 | 38 | 49 | 54 | 60 | 71 | 82 | 93 | 104 | 116 | 127 | 138 | 149 | 160 | 166 | 171 | 182 | 193 | 204 |

(Values partly rounded)

### 3.5.4 Thermal response time of temperature sensors

The thermal response time is due to thermal inertia. In first approximation, the rise follows a step excitation of an e-function. Its time constant T63 characterizes the behavior with specification of only one time value. At this time the function reaches 63 % of the step excitation amplitude. The alternative specifications T50 and T90 can be converted into each other via constant factors. For an existing specification one goes in the following table into the appropriate line and can read off the factors for other time constants or response times in the respective columns. As an example, let us assume T90 with 7 s: The T50 value with 2.1 s is lower by a factor of 0.301.

Table for converting response times:

| | **T50** | **T63** | **T90** | **T99** |
|---|---|---|---|---|
| **T50** | 1 | 1.443 | 3.32 | 6.64 |
| **T63** | 0.693 | 1 | 2.303 | 4.61 |
| **T90** | 0.301 | 0.434 | 1 | 2.00 |
| **T99** | 0.151 | 0.217 | 0.50 | 1 |

The amplitude of the jump excitation is the difference of the excitation between after and before the jump. It can have any absolute measure (e.g. 10 K). Figure 29 shows the amplitude with a normalization to 100 %.

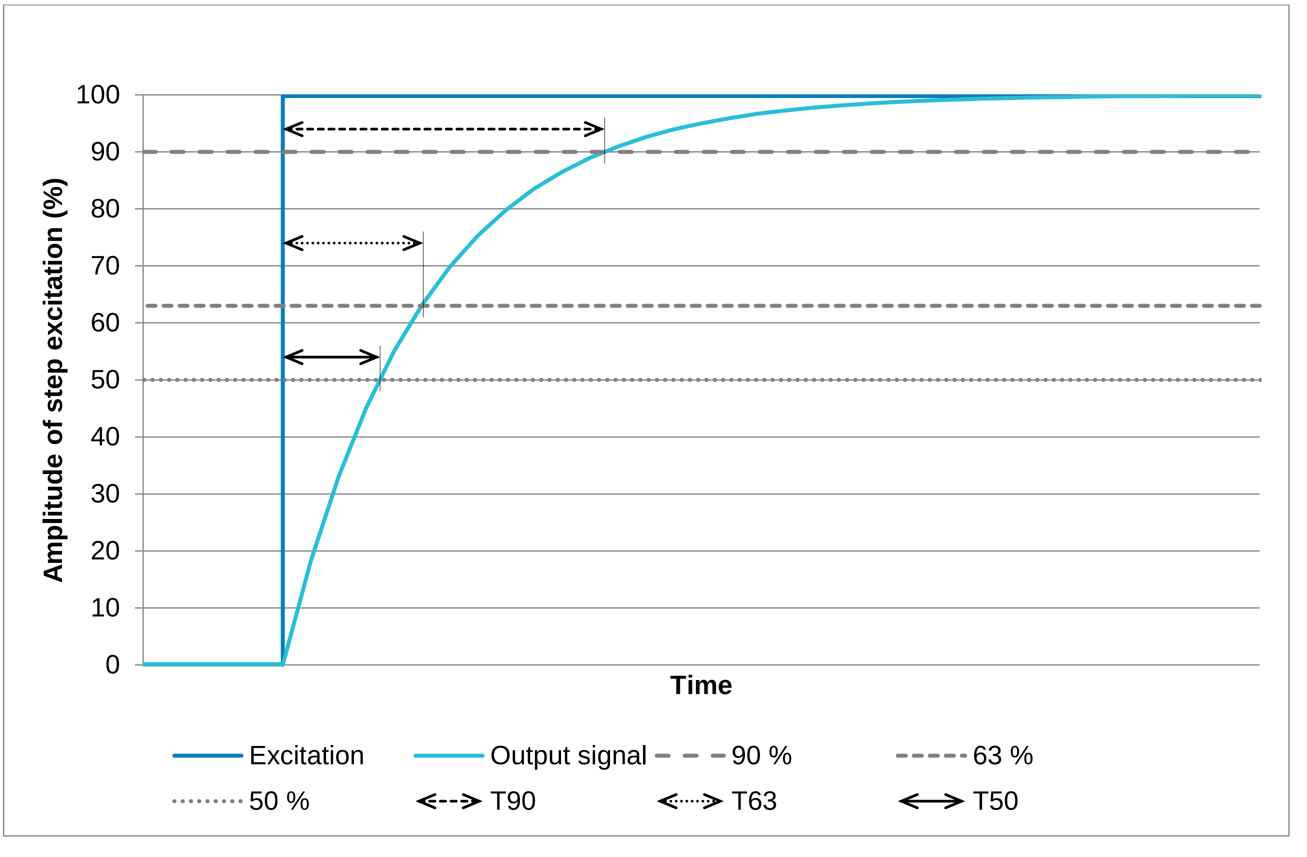



**Figure 30: Definition of the time constant T63 and the response times T50 and T90**

# 4 Appendix

## 4.1 List of figures

## 4.2 Subject index

## 4.3 Additional Literature

### 4.3.1 “Baumer Guideline for Hydrostatic Level Measurement”

This document describes how hydrostatic level measurement works, i.e. the use of pressure sensors to determine the continuous level in a container. It is intended to deepen the understanding of this measuring method and to give the user a check for suitability in his application. Furthermore, it enables him to make the correct selection of suitable sensors and measuring ranges. Furthermore, the attainable accuracy under certain conditions is discussed and instructions for evaluating the measuring signals are given. An appendix with the theoretical derivation of the used variables and formulas allows to deal with the matter in more detail if necessary.
Weblinks: DE, EN

### 4.3.2 “Baumer Guideline for Analog Sensor Interfaces”

This document describes the functionality of active analog sensor interfaces such as current and voltage signaling. It is intended to provide support for the selection of the most suitable analog sensor interface and its implementation.
Weblinks: DE, EN

### 4.3.3 “Baumer Guideline for Switching Outputs”

This document describes the functionality of switching outputs, such as PNP or NPN. It is intended to provide support for the correct selection, parameterization and implementation of sensors with binary signals.
Weblinks: DE, EN

### 4.3.4 “Baumer Explosion Protection Guideline”

This document contains recommendations for ATEX installations of suitable Baumer sensors.
Weblinks: DE, EN

### 4.3.5 “Publications on IO-Link”

In the IODDfinder the IODDs of all manufacturers are normally available for download.
Weblinks: DE https://io-link.com/de/IODDfinder/IODDfinder.php
EN https://io-link.com/en/IODDfinder/IODDfinder.php

Further details on IO-Link are contained in the document "IO-Link System Description" and other publications of the IO-Link Consortium.
Weblinks: DE https://io-link.com/de/Download/Download.php
EN https://io-link.com/en/Download/Download.php

### 4.3.6 “Publications on HART®”

Please refer to the pages of the "FieldComm Group" for corresponding information.
Weblink: EN https://www.fieldcommgroup.org/

## 4.4 Documentation history

| Version | Date | Reviewed by | Amendment / Supplement / Description |
|---|---|---|---|
| V1.00 | 19.01.2021 | fep | Translation from German document V1.00 DE |
| V1.10 | 01.03.2021 | sonp | Figure 4 removed |