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The Five Most Common Mistakes Made in Flow Monitoring

A guide to using calorimetric flow sensors successfully in industrial applications

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Content

In industrially automated fluid applications, the physical parameters of pressure, temperature, level and flow or flow rate have to be recorded precisely and in relation to the particular flowing medium. Provided the right components are used and installed correctly, the measurement processes can be automated precisely, reliably and simply. With their diverse options for integration in existing and new systems, modern automation components facilitate engineering as well as simple, intuitive and fault-tolerant commissioning.

This white paper highlights the pitfalls when implementing industrial flow monitoring technology, helping users to choose the right sensor and install and commission it correctly. To this end, fundamental operating principles and concepts are first clarified

Fundamentals of flow sensor technology

The aim of industrial production processes is to achieve consistently high quality results and flawless operation without downtimes. To achieve this goal, it is not only important to select the right components with appropriate quality characteristics; the correct installation and positioning of these components throughout the entire application network is also crucial.

Electronic flow sensors or flow rate sensors in particular are preferably used to detect critical deviations in the flow speed or flow rate in a timely and reliable manner. A common misconception is that flow sensors and flow rate sensors are one and the same. Flow sensors monitor flow speeds in relation to a relative reference value. Flow rate sensors, on the other hand, measure the flow rate of a medium in absolute terms as a volume or mass flow, based among other things on a defined pipe cross-section.

The choice of the correct operating principle depends on the particular application. In this white paper, we focus on flow sensors with a calorimetric operating principle (also known as a thermodynamic operating principle), which are ideally suited to monitoring flow velocities, for example in the monitoring of pumps (dry run protection) or cooling circuits (e.g. on welding robots). Calorimetric sensors are the first choice for these applications because they are relatively inexpensive and yet sufficiently powerful for these „relative monitoring tasks."

Once the decision regarding a particular operating principle has been made, questions regarding the specific application conditions and the connection to the control environment still need to be clarified. The following must be taken into account:
- Type of medium to be monitored: gaseous or liquid?
- Compact device or version with a remote sensor
- Resistance and material resistance of parts that do and do not come into contact with the media
- Use in potentially explosive or non-potentially explosive areas

- Definition of further requirements such as sensor length, temperature and pressure resistance, type of process connection, ability to communicate, etc.
- Monitoring of individual reference values or reference ranges

The calorimetric operating principle explained in simple terms

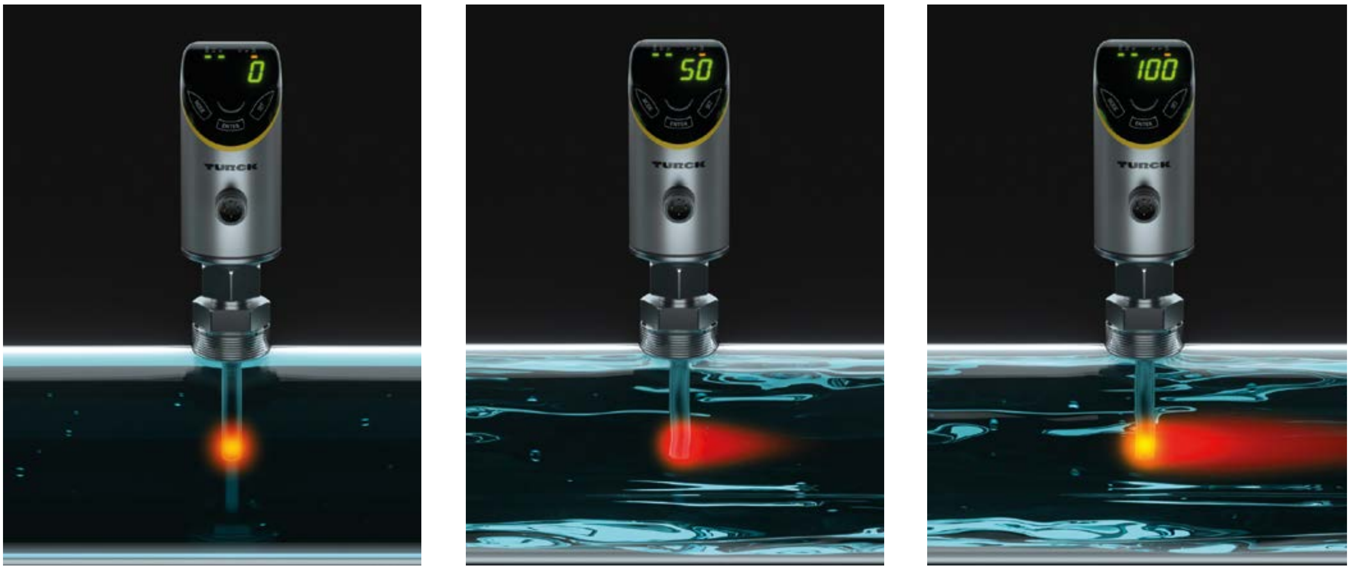
A calorimetric flow sensor works based on the principle of thermodynamics. The principle is that the sensitive element is heated until its temperature is sufficiently higher than that of the flow medium being monitored. This results in an artificially generated thermal energy gradient on the basis of which the flow can be detected. There is a causal relationship between the artificially generated thermal potential and the speed of the medium that flows around the sensitive element: A fast-flowing medium cools the heated sensor down more than a slow-flowing medium. The operating principle can be clearly illustrated with the following two extreme applications

- **Application I: stationary medium (v medium = 0 m/s)**
  The thermal potential generated artificially by the sensor can develop to a maximum when the flow is stationary. The image from a thermal imaging camera would show a spherical heat distribution. Due to the thermal conductivity of the medium, only minimal heat exchange takes place between the sensor and the medium.

- **Application II: flowing medium (v medium > 0 m/s)**
  Almost the exact opposite takes place here, as the previously spherical heat distribution is deformed by the current flow into a heat cone shape, which resembles a candle flame rotated by 90 degrees. The faster the medium flows, the flatter and longer the cone becomes until it is a stylized straight line — aligned parallel to the flow.

- The thermal energy is transported away by the flowing medium and the previously strong thermal potential approaches zero. As soon as this point is reached, the flow sensor has also reached the upper end of its working range. All values between the described extremes form the usable operating range available to the user for flow monitoring.

The glossary at the end of this white paper contains alternative operating principles as well as the most important technical terms in flow monitoring.



The probe of a calorimetric flow sensor is heated on one side. Two sensors inside the probe determine the temperatures on both sides. The temperature difference becomes smaller the faster the medium flows.

Immersion vs. inline sensors

A distinction is made between two key designs: immersion sensors and inline sensors. Immersion sensors are mounted as sensing elements in a pipe or other line through which a medium flows. Immersion sensors generally work on the basis of the calorimetric measuring principle and are used for pure monitoring tasks. Inline sensors, on the other hand, form part of the pipe and the medium flows through them. Due to their design, they can also accommodate further physical operating principles, and are therefore usually used in conjunction with a flow measurement. Owing to the geometry, this design already has a predefined pipe cross-section, which can be used for internal calculation of the flow value.

Five mistakes that you should not make when using flow sensors

1. Mistake: Confusing measuring and monitoring

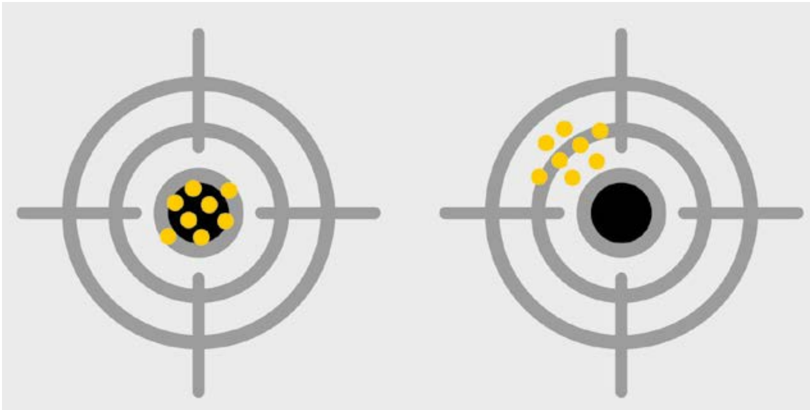
„What is the difference between relative monitoring and absolute measurement?“ This question arises repeatedly, particularly in the field of industrial fluid applications. The scope of functions and the field of application of the respective sensor technology is entirely dependent on the correct definition of measuring and monitoring. The difference between measuring and monitoring is hidden in the adjectives relative and absolute.

Measurement

Measurements provide absolute values. These measurement values refer to an absolute reference. Typically, they are associated with a certain degree of inaccuracy, although this inaccuracy is similar to expenses or weeds. Because in actual fact, none of these three really exists. What do exist, however, are costs, plants and precision. Experts usually talk about measurements when the absolute values also have a corresponding accuracy. Nevertheless, measuring with a lower accuracy can also be referred to as real measuring with a clear conscience.

Monitoring
As soon as physical variables, such as flow speed, are observed with regard to their tendencies, the term ‚monitoring' is typically used in the field of industrial fluid technology — in this case, flow monitoring. This defines the main task of a classic flow sensor: It monitors the flow conditions of a medium in terms of an increase or decrease in its speed. The reference points used are either provided directly via the sensor itself or are made in relation to a relative reference in the controller.

Summary
An absolute measurement can also be used for monitoring purposes and is ‚downward compatible' so to speak. However, relative monitoring cannot replace ‚real' measuring.

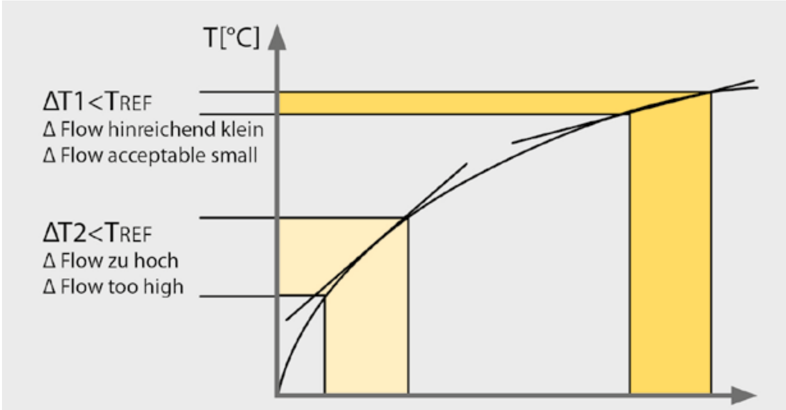


The difference between measurement and monitoring: The left target shows values of a measurement that are not only close to each other, but are also all centered with respect to the target. Right: A monitoring provides sufficiently precise values only in relation to each other, which have a good repeatability, but are not meaningful in relation to the absolute value (the center point).

2. Mistake: Setting an incorrect reference point

The user must take into account the application conditions at the time of commissioning and setting the sensor. This is because the state at the time when the reference value is set is decisive for the informative value of the subsequent flow monitoring.

This can be illustrated with the example of a medical thermometer: If we suspect that someone has a raised body temperature, we take their temperature using a thermometer. We know from experience that you only obtain a valid result for the person's body temperature when the thermometer beeps to indicate that the temperature can be read from the display. If the thermometer is read too early, the temperature shown will usually be too low. Although reading the thermometer too late does not cause the temperature to rise further, it does lead to a degree of uncertainty in the interpretation of the result. In addition, reading the temperature too late takes more time than necessary. It is therefore important to read the value on the thermometer as early as possible and as late as necessary.



If the change to the delta is too high (steep curve), then there is either still no constant flow or the sensor is still heating up. The sensor does not permit teaching until the delta flow is sufficiently flat.

Delta-Flow

On the flow sensors in the FS+ series, a comparable function helps the user to rule out systematic errors when setting the reference point. This delta flow monitoring activates all teach-in functions only when a constant flow speed is reached. In this way, delta flow automatically prevents the sensor from being taught in at a time when the flow conditions are still changing significantly due to system inertia.

3. Mistake: Purchasing a superfluous temperature sensor

Each of the physical parameters in fluid applications—pressure, level, flow, flow rate and temperature—are usually measured by a dedicated sensor. If we look back at the operating principle of a calorimetric flow sensor (see chapter ((INSERT LATER))), we see that such sensors always also record—almost as a by-product—the media temperature in order to detect the flow. This means that in addition to monitoring the flow, it is possible to monitor the temperature of the medium using the on-board means of the calorimetric sensors.

In many fluid applications, which also require an indication of the media temperature, this is an enormous advantage, as it usually renders the use of separate temperature sensors unnecessary. In many cases, when monitoring a cooling circuit, precise temperature readings are not necessary. It is sufficient to know whether the temperature of the medium is 20 or 40 degrees. For an accuracy of up to +/-7 Kelvin, the internal temperature measurement is sufficient.

The use of a separate temperature sensor with higher accuracy is only worthwhile in applications for which more precise temperature values are required, which the calorimetry cannot provide.

4. Mistake: Double mounting

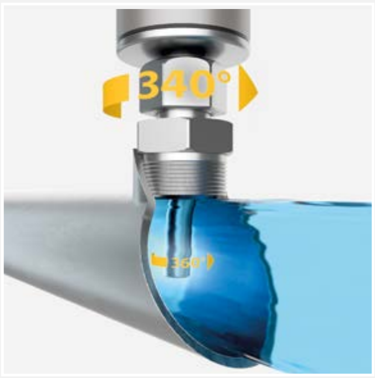
Classic immersion flow sensors have a cylindrical, metallic sensor tip, which houses the sensitive element that is immersed in the flow to be monitored. Typically, immersion sensors have special process connections that allow the flow sensor to be integrated easily into the actual process.

When measuring the flow, the position of the sensor tip in relation to the monitored flow would have to be taken into account. This is because the internal arrangement of the sensitive element in the immersion tip specifies an alignment. The sensor must be precisely aligned in order to use its full performance to measure flow.

For relative flow monitoring, however, the rotary alignment plays a negligible role. This is because during the setting process for the sensor (teach process), the sensor is linked to its specific position in relation to its direction of flow and thus detects the flow with sufficient sensitivity. The source of error for immersion sensors is therefore not due to incorrect mounting, but rather due to a subsequent change in the sensor alignment without teaching in the reference value again.

FS+

Only at very low flow velocities (below 3 cm/s) the FS+ has to be mounted aligned to the direction of flow according to the marking on the sensor. In all other cases, the orientation of the sensor is not relevant. The sensor head, which can be rotated by 340 degrees, can also be aligned after mounting to suit the user.

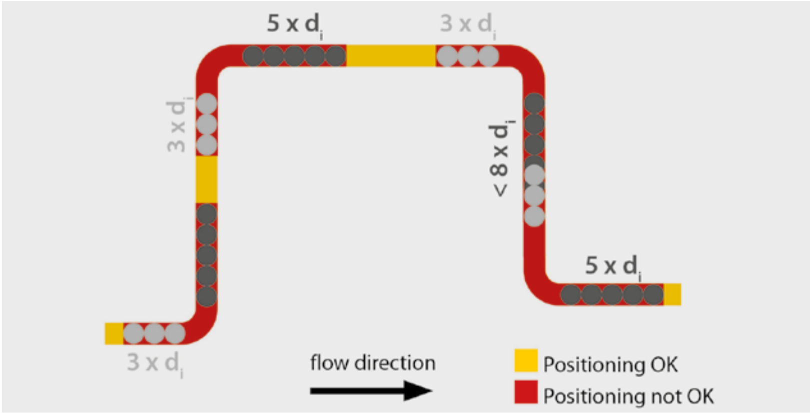


5. Mistake: Incorrect positioning of the sensor during the course of the application

The positioning of the sensor within closed flow systems plays a crucial role. In practice, many factors influence the recording or monitoring result.

Flow profile

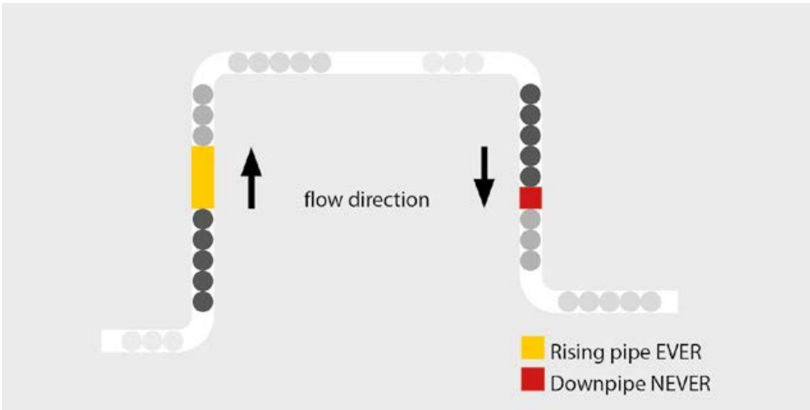
If a medium flows through a pipe without interfering bodies, it results in a laminar flow profile. This is characterized by an inhomogeneous velocity profile. The minimum flow speed is found on the inner wall of the flow channel, while the highest flow speed is present at the center of the pipe cross-section. Turbulent flows form at very high speeds or at interfering bodies such as corners, bends, valves, pumps or filters. This is where turbulence and chaotic flow profiles arise. In case of extreme turbulence, a flow rectifier is used in front of the sensor.



It is advisable to mount the sensor only in the yellow areas.

Deposits and air cushions

In industrial fluid applications, it can be assumed that the media being conveyed may be contaminated or permeated with particles due to the process. Filters are used in many applications, but they cannot be used everywhere and in all cases. Thus, it is entirely possible for sludge and suspended matter to accumulate in the medium over the period of operation and then typically settle at the bottom of the flow channel. Air cushions—the counterpart to heavy particles—can also accumulate in the area of the upper pipe wall in insufficiently ventilated applications and displace the medium. This is essentially the same thing that happens when cave diving or ice diving — air reservoirs accumulate on the underside of the cave or ice cover as a result of the breath expelled by the diver. The sensors for monitoring flow should therefore always be installed in risers, never in downpipes.

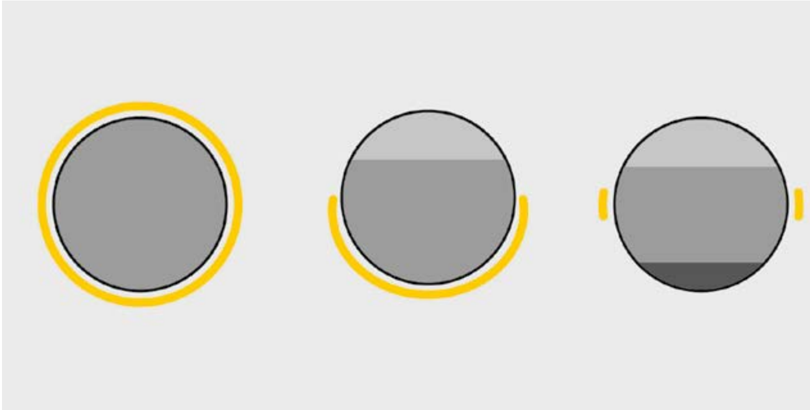


In vertical lines, the installation should be carried out in risers, since the compression of the medium there ensures a homogeneous flow pattern.

Thermal short-circuit

Short-circuits are not only undesirable in the field of electrical engineering. They can also be observed in the area of thermodynamics. These thermal short-circuits occur when a thermal potential finds a direct path to potential equalization. This direct path is called a thermal bridge and is characterized by relatively high thermal conductivity. The potential seeks to balance itself. Applied to the sensor positioning, this means that contact between the usually metallic probe tip and the opposite wall of the pipe must be avoided.

Optimum position of the sensor
For optimum monitoring results, it is advisable to install the sensor at a point in the pipe system where an even distribution of speed can be expected. It is therefore advisable to maintain inlet and outlet sections upstream and downstream of the flow sensor. This means sections in which there are no interfering bodies in the pipe and a sufficient distance from bends or tapers is guaranteed. In addition, the probe tip should be positioned as centrally as possible in the pipe cross-section.



The yellow areas indicate good sensor positions for different pipe conditions. Air pockets and deposits reduce the number of possible positions for the flow sensor.

Summary

Due to their simple, low-maintenance design and their almost universal applicability, calorimetric flow sensors for industrial flow monitoring are superior to other concepts in many respects, especially from a cost perspective. If they are used as intended for flow monitoring, their accuracy is sufficient. If the mistakes described are avoided, they provide extremely reliable results with high economic efficiency.

FS+ flow sensors

As part of the Fluid+ sensor family, the FS+ flow sensors monitor liquid media according to the calorimetric principle and therefore offer the possibility to detect the media temperature in addition to the flow. The 2-color LED bar on the user interface displays either flow or temperature values. Users can choose between devices with two different output functions: either analog (4…20 mA) or as a transistor with automatic PNP/NPN detection and communication via IO-Link 1.1. The switching behavior can be set to either „normally open“ (NO) or „normally closed“ (NC). The FS+ is as easy to mount as it is to operate. For example, the sensor tip can be aligned in any direction in the medium; the sensor will still operate within its specification. Following installation, the sensor housing can also be freely rotated by 340 degrees independently of the sensor. This ensures convenient alignment of the display and electrical connection. The FS+ offers practical features such as a locking mechanism and the option to reset the sensor to previous settings (undo function) as well as to restore the factory settings. There are two modes available for teaching switching points: with Quick-Teach, users can define a reference current within a matter of minutes and set the monitoring of deviations directly on the sensor. Alternatively, maximum and minimum values can also be determined in the application. Delta flow monitoring is a particularly helpful function, activating all teach functions only once a constant flow is achieved. Changes in the media temperature have no effect on the flow measurement due to the internal compensation.

Glossary – technical flow measurement terminology explained in simple terms

Operating range (detection range)
The operating or detection range specifies the range of the process variable for which the sensor provides a standardized output signal. The range is typically dependent on the thermal conductivity of the medium. The detection range limits the evaluable output signal, but not the maximum permissible flow speed.

Stand-by time
The stand-by time is a time period during which the sensor reaches its operating state. The sensor is ready for operation only once the stand-by time has elapsed; it can then be set or its output signal can be used for evaluation.

Pressure resistance
The pressure resistance typically refers to the sensor housing. Up to the specified maximum pressure, the sensor delivers a stable output signal without it being damaged. However, application-related screw joint constructions can have different pressure resistances, which may also be lower.

Media temperature
The media temperature range, usually specified as a pair of values, indicates the limits within which the sensor can be used without incurring damage and can provide valid output signals.

Nominal current
Since the output characteristic curve of calorimetric flow sensors is typically non-linear, all other parameters are related to the operating point suitable for the nominal flow.

Response time
The response time is a cumulative value and consists of the switch-on and switch-off time. The switch-on time is defined as the time during which the sensor has detected, processed and output a change in the process variable. Due to the characteristic sensor curve, it shortens at low flow rates and increases at higher flow rates. The switch-off time is exactly the other way round, meaning that the response time can be regarded as constant.

Reynolds number
The dimensionless Reynolds number is used in fluid mechanics to determine the type of flow. Essentially, two different flow types can be differentiated: laminar flow without turbulence and turbulent flow with turbulence.

Laminar flow	Re < 2320
Turbulent flow	Re > 2320

Temperature gradient
The temperature gradient defines the maximum temperature change of a medium per time unit that a sensor can follow without malfunction. It is a measure of the quality of a flow sensor.

Ambient temperature
The ambient temperature indicates the maximum and minimum permissible outside temperature at which the sensor may be operated according to the specification.

Thermal conductivity
The thermal conductivity—also known as thermal coefficient—describes the material property that determines the heat flow through a material based on the heat conduction. The thermal conductivity provides information on how well a material conducts thermal energy.

Magnetic Inductive
The magnetic inductive effect is only suitable for conductive media. When a magnetic field is applied, the moving charge carriers induce an electrical voltage in the flow, which can be picked up perpendicular to the direction of motion and the applied magnetic field at the pipe wall. The magnitude of the tapped voltage is proportional to the mean flow speed (#right-hand rule).

Vortex effect
The Kármán vortex street forms behind an interfering body built into the flow. Vortices detach periodically from either side of the interfering body. There is a direct correlation between the frequency of the vortices that occur and the flow rate. There is a tendency for this to be unfavorable in connection with abrasive media (#bridge pillars in the river).

Coriolis effect
Suitable for measuring the mass flow of flowing liquids or gases in a closed flow system. A pipe bend through which the medium flows is caused to vibrate and the resulting Coriolis force is measured (#garden hose principle).

Doppler effect
By transmitting and receiving ultrasound within the medium, relative frequency shifts can be detected. Shifts in the output frequency with respect to the input frequency detected are a measure of the flow speed of the medium. Reflective particles such as fine air bubbles or dirt particles within the medium are necessary (#red-blue shift in space).

Runtime method
The speed of the ultrasonic signal transmitted is superimposed with the flow speed of the medium. If the ultrasonic pulse runs with the flow, the runtime decreases, while the runtime increases in the opposite direction. The measurement of the runtime difference can be used to determine the measurement of the flow speed. (#driving against the wind).

Bernoulli venturi effect
With the differential pressure method, the pipe cross-section is significantly narrowed in the form of an orifice or nozzle. Since the volume and mass flow must be the same at all points within the piping system, this inevitably results in a pressure gradient from which the flow rate can be derived. (#why does an airplane fly)

SAW method
Interdigital transducers are stimulated by an electrical signal and generate and detect acoustic surface waves. These spread out over the pipe surface and also couple into the liquid at a specific angle. The waves thus generate received signals when they pass through the liquid once and several times. Both occur in and against the direction of flow. The runtime differences are proportional to the flow rate.

Calorimetric method
The calorimetric method is also known as the thermodynamic operating principle. Here, the sensitive element is heated up in relation to the flow medium. As the medium flows, the thermal energy generated in the element is discharged through the medium. This can be measured and the flow speed derived from it.

Author | Raphael Scholzen, Product Manager Flow Sensors Turck

Further Infomation
[At a glance: FS+ flow sensors]
[Flow sensors product page]

Contact
Hans Turck GmbH & Co. KG | 45466 Mülheim an der Ruhr, Germany
T +49 208 4952-0 | F +49 208 4952-264 | contact@turck.com