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WHITEPAPER

FLOW SENSORS

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IPF ELECTRONIC

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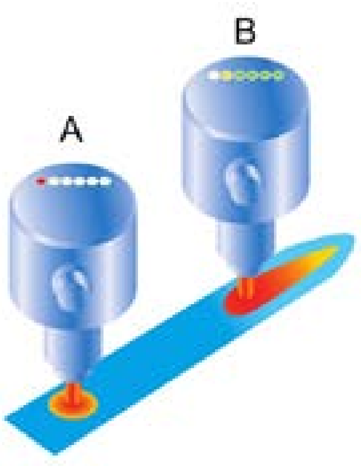
1. INTRODUCTION
Flow sensors – or more precisely, thermodynamic flow sensors – monitor flows or measure the flow velocity of media in closed systems (e.g., pipelines). In the past, so called flap sensors or paddle switches were used for these tasks, whereby the moveable and, thus, mechanically constructed measurement elements (flap, paddle) were located directly in the media flow. As a result, such solutions were extremely susceptible to soiling. If deposits formed on the mechanical measurement elements, the error free function of the devices could be limited or, in extreme cases, fail outright. A flap sensor or paddle switch would then output an IO signal even if, e.g., no flow was present. Thus, an always reliable measurement or monitoring of a media flow could not be realized with such solutions.

Thermodynamic flow sensors, on the other hand, function with no moving parts, thereby excluding the possibility of malfunctions or failures due to soiling or damaged mechanical components. The reliability of such devices is, therefore, greatly valued in many areas of industry. Reason enough to explore this technology in greater detail in this white paper.

2. OPERATING PRINCIPLE OF FLOW SENSORS
The operating principle of flow sensors is based on the thermodynamic principle. Here, the sensor element is heated from within by a few degrees Celsius with respect to the medium into which the sensor element protrudes. The heat produced in the sensor element is transferred to the medium, whereby this heat dissipation – or cooling effect – is greater the faster the medium flows past the sensor element. The resulting temperature in the sensor element is measured and compared with the media temperature, which is also recorded. The flow status can now be deduced for each medium from the resulting temperature difference.
Against this backdrop, the sensitivity of thermodynamic flow sensors is always dependent on the thermal properties (heat capacity) of a medium that is to be measured. This thus raises the following question, stated in general terms: In what time or how fast can a monitored medium absorb heat? In this context, one must consider that flow sensors usually react more slowly than, e.g., flap sensors. To obtain a uniform basis for describing the technical data for flow sensors, the specifications for water are generally used.



Operating principle of flow sensors. Left: The sensor element is located in a medium without flow (A). Right: The sensor element records the flow of a medium (B).

3. CLASSIFICATION OF THE DEVICES

Flow sensors can be classified into two-piece devices and compact devices. Two-piece devices consists of a sensor element that protrudes into the medium and a separate evaluation device. In compact devices, on the other hand, the evaluation unit is integrated in the device. As a result, the limit value can be set directly on site at the measuring point. In addition, cabling is limited to the feed lines for the power supply and the signal output, which are less susceptible to interference. Compact devices can be further divided into solutions with a test prod and so called inline sensors. You can find additional information on this further below.

Thermodynamic flow sensors	
Compact devices	Two-piece devices
Devices with test prod	
Inline sensors	

Classification of thermodynamic flow sensors

Which solution (compact device or two-piece device) is used in a given application is dependent, on the one hand, on the measurement task and, on the other, on the available space as well as the installation situation at the installation location of the flow sensor.
If, for example, media with higher temperatures are to be recorded or measured, two-piece flow sensors are recommended, as the sensitive evaluation electronics are separate from the actual sensor element here. The use of such solutions also always makes sense if the available space for installing a compact device is not sufficient at the installation location, or if, due to the installation situation, the sensor can only be adjusted on site via a separate evaluation unit, or a separate evaluation unit would significantly simplify the adjustment..

As already mentioned above, compact devices are divided into solutions with test prod and inline sensors. With compact devices with test prod, the sensor element protrudes into a medium. When used in pipes, the test prod is ideally located in the middle of the pipe cross section, as here there is a laminar, uniform flow of the medium..

Flow sensors from ipf electronic: Compact device (upper left), two-piece device without amplifier (upper right) and an inline sensor (bottom)..

Inline sensors consist of a sensor tube (stainless steel) with multiple sensor elements arranged over a large area on the inner side. Compared to solutions with a test prod, the sensor elements thus have a significantly greater contact surface with the medium and also have a faster response behavior. Inline sensors are used primarily if only low media volumes or low flow velocities are to be measured and a very fast device response behavior is necessary.

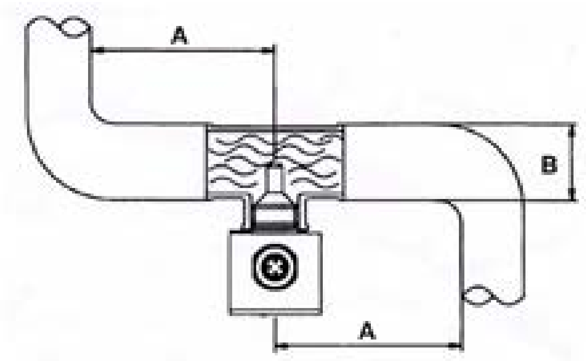
Inline sensors are likewise based on the thermodynamic principle, whereby here the heat generated in the sensor tube by the passing medium is recorded. The flow velocity can be deduced directly from the difference between the media temperature and the sensor element temperature.

4. INSTALLING VARIOUS SOLUTIONS

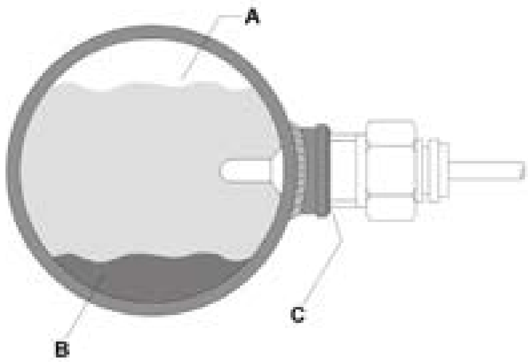
Located in the tip of a sensor element (compact devices and two-piece devices) is the tempered measurement element. The housing tip, which holds the sensor element, and the threaded or mounting components attached to it are, with many sensors, manufactured from a single piece of stainless steel to achieve absolute leaktightness and high pressure resistance. With corrosive media, especially with oxidizing media and caustic media, special materials are used, because stainless steel offers only limited resistance against corrosion or acids (see Chapter 5.2).

In standard applications, flow sensors (compact devices and two-piece versions) can be installed independent of the flow direction of the medium. The sensor element should always be fully surrounded by the medium that is to be monitored. When installing the sensors, also maintain a sufficient distance to constrictions in the pipe or changes in pipe cross section as well as pipe bends. Directly before or after a pipe bend and in the case of changes to the pipe cross section, the medium has a non linear flow. Because the proper function of a device requires a uniform flow of the medium as it passes the sensor element, however, a certain minimum distance must be maintained for the sensors, whereby the distance from the measuring point to a pipe bend or a change in cross section should be five to ten times the corresponding pipe diameter.

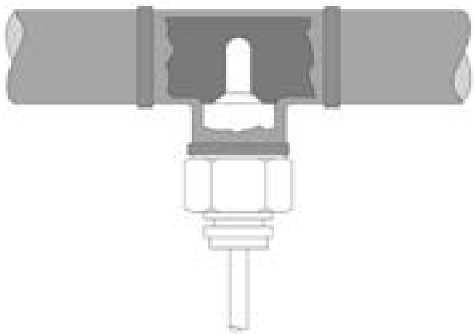
With generally smaller pipe or line cross sections, also bear in mind that the sensor element itself causes a constriction, which leads to a higher flow velocity of the medium in the measuring range. The correct installation of flow sensors, e.g., lateral, from below or in riser lines.



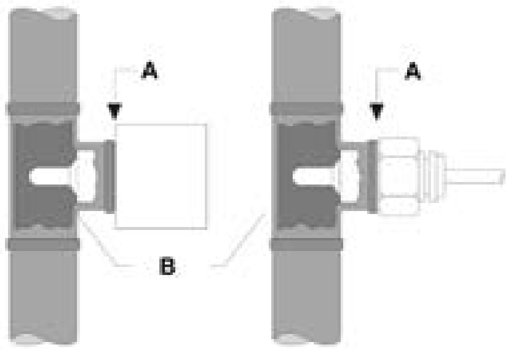
A minimum distance of the measuring point to, e.g., a pipe bend, as shown in this figure, should be maintained.
Where A: A > 5...10 x B. B: Diameter of the pipe.



Lateral installation of a two-piece device. A: Air pocket above the medium, B: Deposits, C: Thread with sealing..



Installation of a two-piece device from below.



Installation of a compact device (left) and of a two-piece device (right) in a riser line. A: Gasket, B: T-piece.

As the description implies, the installation of inline sensors is performed „inline,“ i.e., „in a line“ with a pipeline, whereby the medium flows through the sensor tube. With inline sensors, no potentially interfering element protrudes into a medium, thereby allowing it to flow unimpeded past the measurement or sensor elements. Inline sensors can likewise be installed independent of the direction of medium flow.

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5. APPLICATIONS OF FLOW SENSORS
Thermodynamic flow sensors now cover a very wide range of applications and are used not only in liquid and gaseous media but also in, e.g., specific solid media (e.g., granular or powdery media during dosing operations). As already mentioned in Chapter 2, flow sensors respond slowly due to their function principle, whereby their sensitivity is also always ultimately dependent on the heat capacity of a medium that is to be measured. In this context, some media as well as their specific properties also hamper the proper function of flow sensors or require the use of special materials for the devices. Before going into detail on specific applications areas of flow sensors, a few brief remarks on this topic.

5.1 MEDIA IN PASTE FORM AND OILS
Media in paste form are only conditionally suitable for flow sensors since such media could adhere to or deposit on the sensor element thereby, under certain circumstances, limiting the function of the devices or, in extreme cases, preventing a sensor from outputting a signal.

When using flow sensors in oils, note that the viscosity of such media changes if there are differences in temperature. The viscosity ranges here from high viscosity at low temperatures to low viscosity at high temperature values. This causes the flows at the sensor element to change. In general, the flow sensors are therefore set so that they supply correct results at normal operating temperature (oil is warm and has a higher viscosity).

5.2 CHEMICALS, ACIDS AND CORROSIVE MEDIA
For the use of flow sensors in very specific areas, ipf electronic recommends chemically resistant solutions, whereby special materials including titanium and Hastelloy are used for such devices.

Titanium is a light metal but achieves the strength properties of good structural steels. Titanium forms an oxide layer on its surface, thereby making the metal chemically resistant. Should a titanium surface be damaged through mechanical means in an environment containing oxygen, the oxide layer reforms immediately. Titanium is especially well suited for use in media that contain chloride. Positive experiences have also been made with the use of this material in the chemical and paper industry (bleacheries). Furthermore, titanium is also recommended for sensor elements of flow sensors that are used in sea water cooling systems or sea water desalination plants.

Hastelloy (B-2) belongs to the group of nickel-molybdenum alloys and is very resistant to both corrosion as well as reducing media, e.g., hydrochloric acid (all concentrations). In addition, Hastelloy is very resistant over a large temperature range. Hastelloy can also be used for flow sensors whose measurement elements come into contact with hydrogen chloride as well as sulfuric, acetic or phosphoric acid.

5.3 SPECIFIC APPLICATIONS
The wide ranging applications of flow sensors primarily include cooling circuits but also the monitoring of various pumped media as well as processes. One lesser known area of application of such devices is filling level inspection.

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5.3.1 MONITORING OF COOLING CIRCUITS

For the monitoring of cooling circuits, flow sensors are always installed in the outlet of a circuit. Fields of use here include, e.g., plastic injection molds, welding machines or welding robots, machining centers, cooling units or motor components. On welding machines, for example, the cooling water flow is monitored with compact devices made of stainless steel to ensure sufficient cooling even at high machine cycle rates. Should the cooling fail, the welding robot is switched off via the sensor. In machining centers, flow sensors monitor the continuous flow of cooling water to protect expensive machines as well as ensure longer service lives.

5.3.2 MONITORING OF PUMPED MEDIA

One very common use of flow sensors is the dry run protection of pumps, whereby here compact devices with integrated turnoff delay (time-delayed output signal in the event of drops in flow) are used. In dosing technology, on the other hand, aggregates are monitored, whereby primarily inline sensors are used for recording the usually very small dosing quantities. The proper function of filters and sieves can also be ensured by monitoring a media flow. If the flow achieves a certain previously set limit value, the filter or sieve must be replaced. An additional safety mechanism in this context can be the switching off of a pump. If a filter or sieve is not replaced, the pump is deactivated should the media flow decrease further. Ideally suited for this application are sensors with two independently adjustable switching points.

5.3.3 MONITORING OF PROCESSES

Another area of use of flow sensors is the monitoring of processes, e.g., the monitoring of cleaning processes. Because aggressive media are often used in such applications, solutions with special materials are usually used.

5.3.4 MONITORING OF FILLING LEVELS

In addition, flow sensors can also be used for filling level monitoring, whereby both compact devices as well as two-piece devices are used depending on the application.

With filling level monitoring, a sensor does not monitor a flow in the strict sense, as only the filling level of a medium, e.g., in a container, is to be queried. Through the special function principle of the sensor element, which transfers the generated heat to a medium that is to be monitored, it is, however, also possible to monitor the filling level in a container provided the medium is able to absorb a sufficient amount of heat. In this case, the sensor element is cooled while in contact with the medium; if there is no contact or if the media level is not sufficient, the effect does not occur. The sensor interprets a rising media filling level as a flow and delivers a switching signal. If the filling level drops below the sensor element, it is now surrounded by, e.g., air in a container. Because air has very good insulation properties, less heat is dissipated via the sensor element, which is basically equivalent to a „missing flow.“ The sensor then delivers no switching signal.

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6. FLOW SENSORS WITH IO-LINK

With IO-Link, a standardized interface was created for a communication system that connects, among other things, sensors for exchanging data on automation systems. In this context, reference is made to the „Sensors with IO-Link interface“ white paper from ipf electronic, which handles the topic in detail. Just a few of the main advantages of IO-Link are listed below:

/ **Cost reduction:** Configurable sensors with standardized interface reduce the otherwise necessary variety of different devices and simplifies procurement.

/ **Fast commissioning:** IO-Link communication takes place via unshielded cables and uses industry standard connectors. The installation location of a sensor can, thus, first be optimized and the device configured in a system at a later point in time. The entire parameter set can be stored and, thus, reused time and again, e.g., for transfer to a replacement device or to other sensors.

/ **Higher productivity:** Sensors with IO-Link identify and configure themselves automatically in the event of a replacement. This not only simplifies device replacement in the event of a defect but also reduces system and machine downtime.

/ **Simple maintenance:** Sensors with IO-Link can be uniquely identified in a system. Furthermore, they offer functions for self diagnosis (e.g., display of the functional reserve) and supply valuable data for better assessing the system functionality. IO-Link sensors use intelligent maintenance and maintenance strategies to thereby enable, e.g., predictive maintenance instead of a preventative or corrective strategy.

/ **New machine and system concepts:** Due to the comprehensive networking with every sensor, new, innovative and economical machine and system concepts can be developed.

In the area of air flow sensors, ipf electronic currently (as of September 2018) offers the IO-Link-capable inline sensor **SL430020**.

The **SL430020** is an IO-Link-capable air flow sensor.

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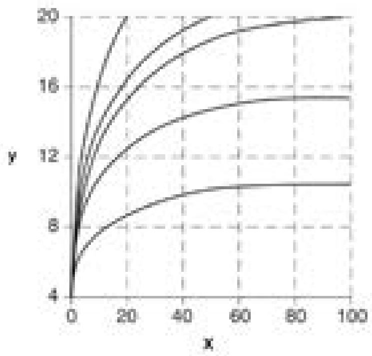
7. GLOSSARY

A number of relevant terms and specialist terms are described below in further detail in the context of flow sensors.

Operating range

Defines the range for which the technical data (specified in the data sheet) of a sensor applies. Outside of this specified operating range, the technical data (e.g., for the accuracy of the sensor) may, under certain circumstances, no longer apply. The detection range of a sensor may, as a result, be significantly larger than its operating range.

Detection range



Devices with analog output deliver a current depend-ent on the flow velocity of the medium in the range from 4 to 20 mA.

x = detection range of the sensor [%]
y = typ. output current [mA]

Specifies the flow velocity of the medium for which the sensor element can deliver an evaluable signal. The relationship between flow velocity and reaction of the sensor element is non linear. This is due to the fact that the cooling effect does not increase proportionally with increasing flow velocity but rather moves toward an end or saturation value. This can easily be seen, e.g., on the curve of the signal output for devices with analog output, as the graphic to the left shows. If one wishes to perform a very accurate measurement, the evaluable range must be limited up to a certain measurement point. The possible evaluation range (x-axis) is thereby reduced.
If the medium is not otherwise specified, the values for water apply.
At the upper and lower limit of the detection range, the influence of the temperature on the switching point drift is higher. Detection range and switching point are, thus, dependent on the medium as different media have different thermal conductivity properties.

Operating voltage

Defines the voltage range for supplying a flow sensor. In the case of a DC voltage supply, it should be ensured that voltage does not exceed or fall below the limits as the result of a possible residual ripple.

Switching current

Indicates the maximum continuous current for the switching output of the device.

Current consumption

Defines the maximum value of the noload current I0 that a flow sensor consumes without load.

Switching voltage

Indicates the maximum voltage including residual ripple that may be placed on the signal output.

Switching capacity

Specifies the maximum voltage including residual ripple that may be placed on the signal output.

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Ambient temperature	Specifies the maximum and minimum permissible temperatures at which a sensor may be used.
Temperature range of medium	Limits the lowest and highest media temperatures at which a sensor still functions properly.
Temperature gradient	Defines the maximum temperature change of a medium in a specific time period that does not affect the sensor principle.
Power-on time	This is the time that elapses after switching on the operating voltage of the sensor before the device has achieved its operational state at nominal flow.
Reaction time (turn-on and turn-off time)	FCombines the turn-on and turn-off time of a sensor. The turn-on time elapses from the beginning of flow of a medium until the display of the flow state on the device. The turn-on time is shortened if a switching point is selected near flow standstill and is increased accordingly at a switching point near the maximum flow velocity. The turn-off time refers to the time that elapses from flow standstill until display of the standstill on the device. The turn-off time is short if the switching point is near the maximum flow velocity and is increased accordingly if a switching point is set near flow standstill for a medium.
Pressure resistance	Refers to the part of the sensor located in the medium, whereby the device delivers a stable signal without being damaged up to the specified maximum pressure. Some applications may require the use of threaded joints that have a lower pressure resistance. These then determine the pressure resistance of the entire system (sensor + installation construction).
Switching delay	This causes a time-delayed output signal during flow standstills (see Chapter 5.3.2)..

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Subject to alteration! Version: January 2019