Whitepaper

Endress+Hauser
People for Process Automation

Drift-free flow measurement for utility gases

Proline t-mass F/I 300/500's of Endress+Hauser with innovative sensor design for greater stability even when exposed to process influences

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Abstract

The patented drift-free sensor technology used in Proline t-mass 300/500 from Endress+Hauser is based on a unique design. It utilizes the benefits of traditional sensor technologies without adopting their disadvantages, such as, aging-related drift or diminished sensitivity to flow changes. A completely in-house manufacturing process and full sensor probe quality assurance ensure that flowmeters leaving the factory meet their specification even after extended use in demanding applications. Heartbeat Technology's diagnostic, verification and monitoring functions also provide increased reliability and safety, as well as documented device functionality, without process interruption.

Proline t-mass F/I 300/500

The Proline t-mass family of instruments makes up one of the five modern electrical measuring methods in Endress+Hauser's flow portfolio. The method is based on the thermal mass measuring principle, which is particularly suitable for measuring utility and process gases at low pressures and in small quantities. It is characterized by a high turndown and direct mass measurement. This versatile measuring principle is available as an inline version, t-mass F, for typical pipe sizes from DN 15 to 100 (½ to 4") and as an insertion version, t-mass I, for large circular pipes and rectangular ducts. In addition to measuring accuracy, the long-term stability of a measuring system plays an important role in industrial use. For example, thermal mass meters are used to measure the natural gas consumption of steam boilers. Were the measurement to drift, the customer would likely interpret this as increased natural gas consumption and question the efficiency of the boiler. Only a stable, drift-free measurement supports the monitoring of such important "Energy Performance Indicators" (EnPI).

Figure 1: Inline device in compact version and insertion device with stainless steel remote connection housing (left) of the Proline t-mass 300/500 family of instrument

Basics of the thermal mass measuring principle

As the name suggests, the thermal mass flow measuring principle is based on heat transfer. A certain amount of thermal energy is emitted by a heated sensor probe (resistance element) and carried away by a flowing fluid. The heated sensor probe then replenishes the dissipated energy, and the measuring system determines the amount of energy required for this replenishment. The higher the flow rate at the sensor probe, the greater the energy required to replace the dissipated heat. To make it possible to relate the energy consumption of the sensor probe to the flow rate, a constant must be introduced into the measurement. This consists of the temperature difference between the heated sensor probe and the fluid. A second sensor probe is used to measure the fluid temperature. If the goal is to maintain a steady temperature difference of, for instance, 10 °C (50 °F), flow changes can be determined from the thermal energy expended.

One difficulty of determining flow by means of heat transfer is that the heat transfer is not dependent on flow alone. The heat transfer is also influenced by the type of fluid, the process conditions (pressure and temperature), as well as the sensor probe’s shape and design. All of these factors must be taken into account in order to achieve a reliable result with the thermal mass measuring principle. For example, if the composition of the fluid changes, a measuring error will occur if no correction for this is undertaken by the software. The same applies to physical changes in the sensor probe, a phenomenon referred to as “drift”.

Conventional sensor technology with and without potting material

Various sensor technologies on the market are used by manufacturers of thermal flowmeters. For the purposes of this article, sensor technologies with and without potting material from manufacturers of industrial thermal flowmeters will be considered. The most common sensor probe setup consists of two resistance temperature detectors, usually made of platinum (for example Pt100) and either as a wound wire or thin film sensor. These resistance temperature detectors are packed into metallic protection sheaths, usually made of stainless steel, and potted with a thermally conductive paste to remove insulating air pockets and secure the resistance temperature detectors in the protection sheaths. Finally, the protection sheath is welded shut to physically separate and protect the sensor probe interior from the process. Manufacturers of thermal mass flowmeters often refer to these as “wet” sensor probes because the structure includes potting material.

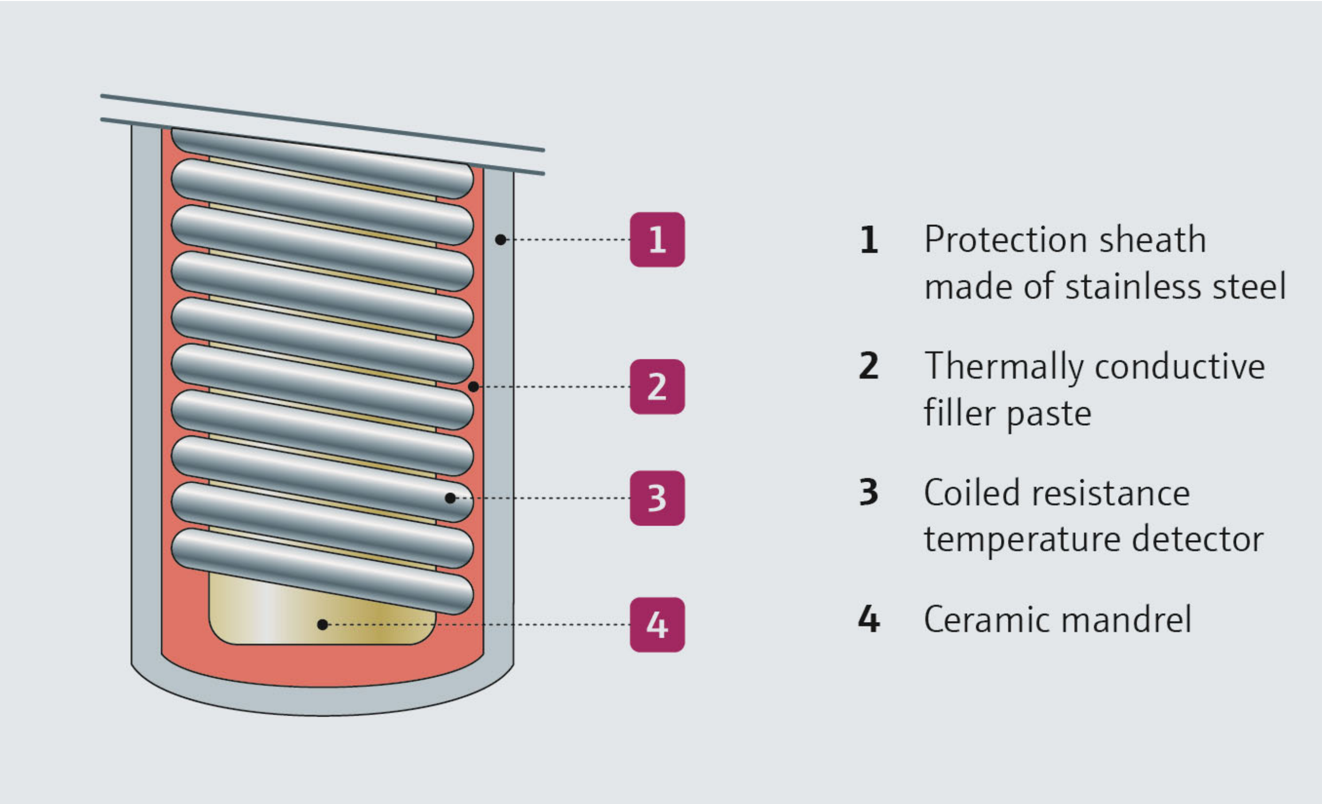

Figure 2: Cross-sectional view of a classic thermal sensor probe setup

Only one manufacturer uses a patented “dry” sensor design. The setup is very similar to the one presented above, the main difference being that no potting paste is used, hence the term “dry sensors”. To ensure a constant, stable heat transfer between the heated resistance temperature detector and the protection sheath, very tight production tolerances are used, and the protection sheath is pressed tightly against the coiled resistance temperature detector by swaging. This effectively reduces air pockets to a minimum. Additionally, in order to prevent the possibility of a short circuit and to increase the contact surface area, a glass coating is used between the protection sheath and the coiled resistance temperature detector.

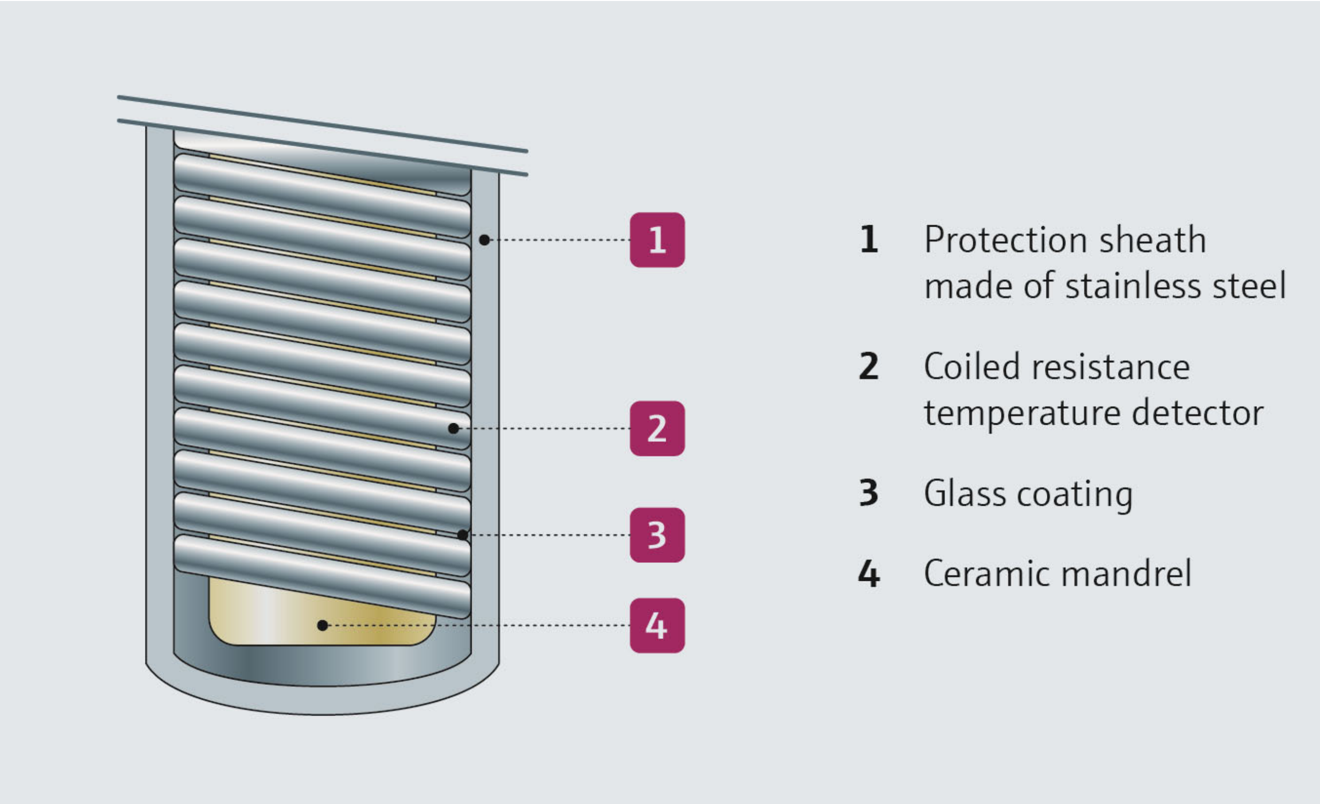

Figure 3: Cross-sectional view of a patented thermal sensor probe setup. Thermally conductive potting paste is not used.

Advantages and disadvantages of conventional sensor technology

Both sensor technologies are characterized by advantages and disadvantages. The main advantage of the classic design (Fig. 2) is good thermal transfer between the resistance temperature detector and the protection sheath thanks to the thermally conductive potting material. Air pockets are also greatly reduced. This is advantageous because air pockets have an insulating effect that prevents good heat transfer. In addition, moisture could form in the cavities, which would interfere with the measurement signal or destroy the sensor probe in the longer term, for example, through corrosion.

One disadvantage of the classic "wet" sensor design is that the organic potting material tends to harden over time and form cracks due to expansion and contraction. These cracks or changes in the structure of the sensor core affect the thermal resistance in the sensor probe and eventually lead to drift of the measurement signal. The more extreme the process conditions are, the faster these aging processes occur. Temperature shocks or rapidly and frequently changing temperatures cause drift in this type of sensor probe more quickly.

The patented "dry" design (Fig. 3) eliminates the problem with aging-related drift because no potting material is used. However, even this design has disadvantages. Due to material surface roughness and production tolerances, the contact area, across which the heat flow occurs, can be diminished in comparison with the sensor design using potting material, as it is not entirely possible to prevent the occurrence of air-filled cavities in this design. As a result, the thermal contact resistance increases, thereby preventing an optimal heat transfer. This can increase the response time and degrade the measurement sensitivity of the sensor probe.

According to one manufacturer, the potting material even has shock-absorbing properties, which would theoretically have a protective effect against vibrations. This statement implies that sensor probes without potting material are more sensitive to vibrations and can be more easily damaged by them. However, this is difficult to confirm without real-world verification. Theoretically, an elastic potting material could absorb shocks better, but this would only be the case as long as the potting material also remains elastic. As it hardens over time, this protective effect is lost, and impacts could cause aging-related drift even faster and more effectively.

Another issue with the “wet” sensor design is that the sensor interior consists of different materials: a ceramic mandrel, a coiled wire, an organic potting material and a metallic protection sheath. Each material has a different coefficient of thermal expansion and reacts differently to temperature changes. This behavior promotes aging-related drift.

Patented drift-free flow sensors from Endress+Hauser

The sensor probe used in Proline t-mass 300/500 is a “dry” design, as no organic potting material is used in the sensor core. Unlike the competitor sensor probes presented above, no swaging takes place in Endress+Hauser's patented design. Instead, it relies on an innovative sensor technology that ensures drift-free behavior due to the absence of potting material and the homogeneous, unchanging core structure.

The developers at Endress+Hauser had set three main goals for the design: (1) The sensor probe should exhibit drift-free behavior, (2) its measurement behavior should not be influenced by process or environmental effects, and (3) its manufacturing tolerances should be as small as possible in order to achieve consistent quality by eliminating scatter between sensor batches. All the main objectives were achieved with the newly developed design. The sensor core (Fig. 4) is made of silver, which is bonded to the stainless steel sensor tip (optionally made of alloy C22) by a special process. The result is a homogeneous material without air pockets, as shown in the microsection (Fig. 5).

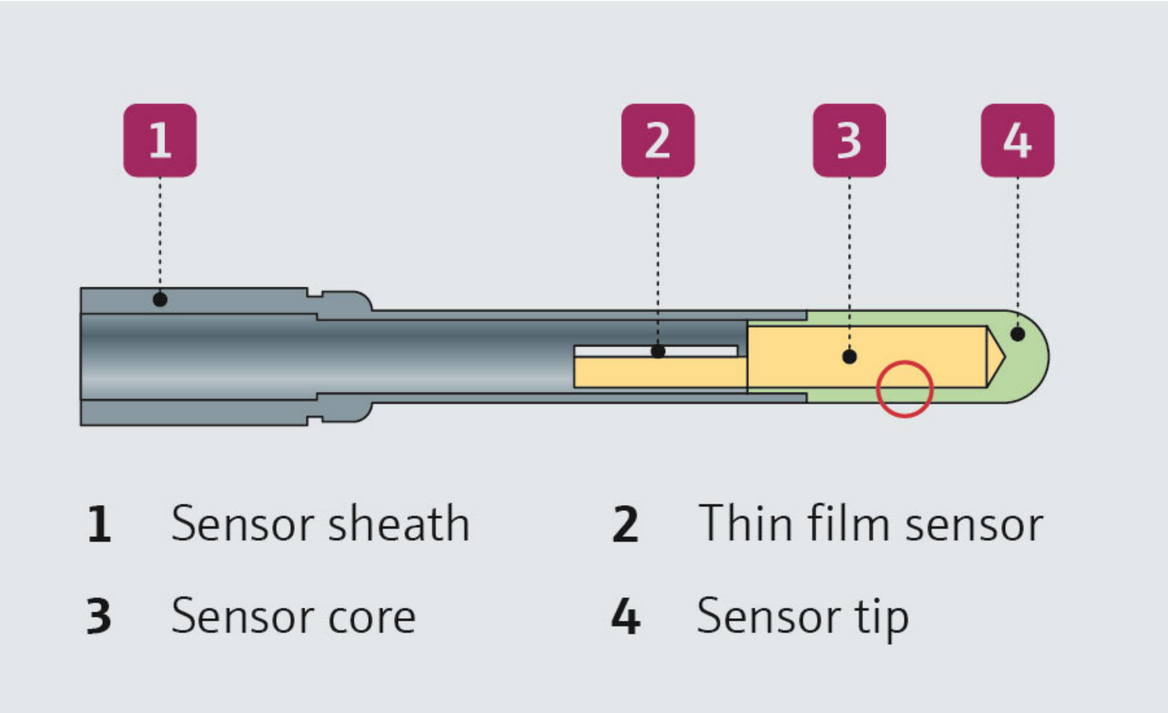

Figure 4: Cross-sectional view of the sensor probe (heater) of t-mass 300/500. The red circle marks the material-bonded connection between the sensor tip and sensor core shown as an enlargement in Figure 5 (below).

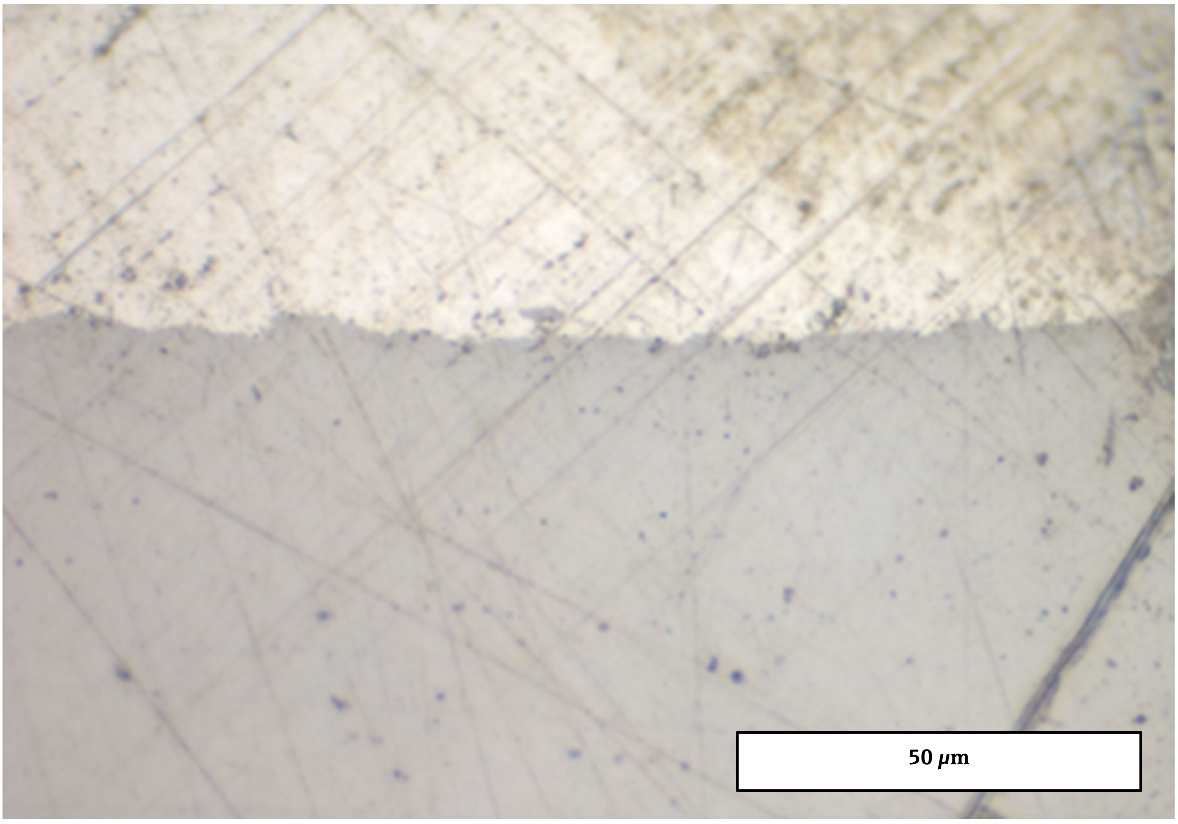

Figure 5: Enlargement of the material-bonded connection in Figure 4

Optimal heat transfer

The sensor core ensures efficient thermal conduction of the heat energy generated by the thin film sensor (Fig. 4). Heat is conducted along the sensor core towards the sensor tip and then transferred radially outwards to the surrounding fluid. The thin film sensor is permanently bonded to the sensor core. This process takes place within a defined period under specified temperature and pressure conditions to achieve an optimal and secure bond. Since the sensor core forms a material-bonded connection with the sensor tip (Fig. 5), it cannot detach from it. The homogeneous structure and the lack of air pockets in the sensor core enable optimum heat transfer from the inside to the outside and vice versa. Due to this solid and unchanging core structure, a drift-free measurement is ensured – even in the presence of plant vibrations and process temperature changes. Finally, the sensor probe is completely protected from external influences (from the process and the environment) by welding to create a gap and seal-free system. Endress+Hauser's unique sensor technology unites the advantages of the herein presented wet and dry sensor designs without assuming, however, the disadvantages associated with other manufacturers' designs. The sensor probes are characterized by a homogeneous and immutable core due to the absence of potting material, whose properties may change over time.

Proof of long-term stability

The development process of t-mass 300/500 included a number of tests intended to prove the long-term stability and robustness of the sensor probes. In the following, we introduce two of these tests and their results. A batch of 40 sensor probes was exposed to temperatures of 180 °C (356 °F) in a temperature test chamber for a period of one year, and during this time, their drift behavior was analyzed at multiple intervals. To achieve this, the sensor probes were taken out of the temperature test chamber for short periods and tested on a flow calibration rig to determine the measuring error at different flow rates. For all sensor probes, this error was within the specified ±1% of the measured value over the entire measurement range for each check. The black bars in Figure 6 represent the control days and the bandwidth of measurement errors.

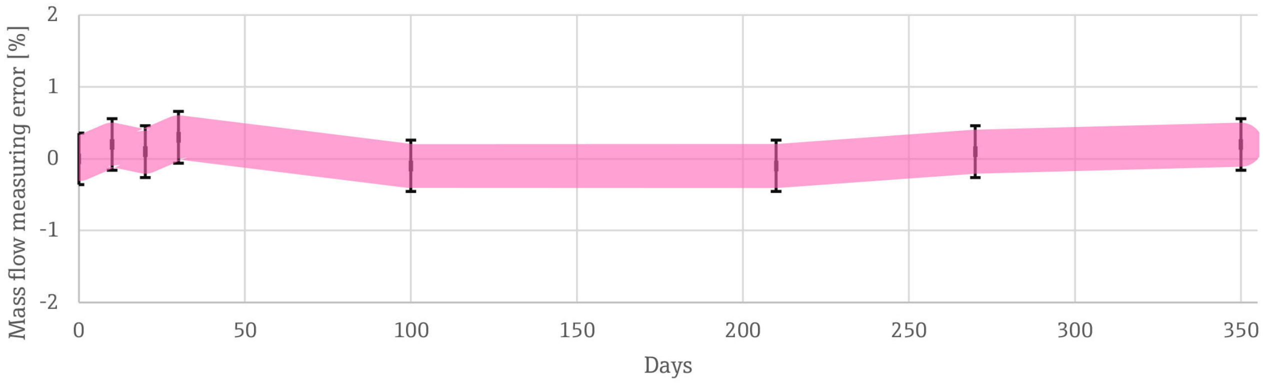

Figure 6: Test results on sensor drift behavior at 180 °C (356 °F)

Another batch of 40 sensor probes was exposed to a temperature shock test in a climatic chamber for the purpose of studying their drift behavior. A total of 500 cycles were run in the chamber. In each cycle, the temperature was initially maintained at –50 °C (-58 °F) and then heated up to 180 °C (356 °F) as quickly as possible. The temperature of 180 °C (356 °F) was again maintained for a specific period of time. Afterwards, the temperature was cooled again to –50°C (-58 °F) for the next cycle. The tests were briefly interrupted several times, and the sensor probes were tested at different flow rates on a calibration rig. The graph in Figure 7 shows the drift behavior of the sensor probes expressed in percent error of the mass flow. The recorded measuring errors are all within a fine tolerance band of the specified ±1% of the measured value.

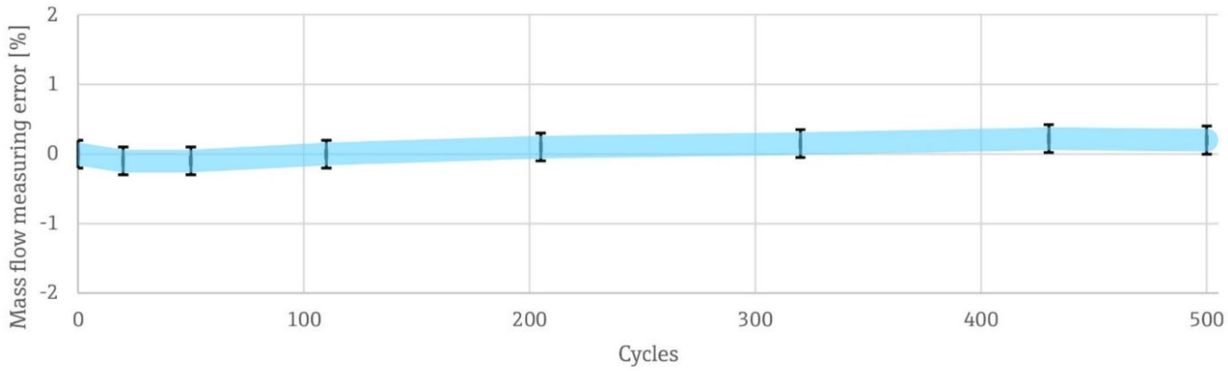

Figure 7: Results of the study in the climatic chamber with up to 500 cycles from –50 °C to +180°C (-58 °F to 356 °F)

In-house quality assurance and traceability

The complete manufacturing process and quality management take place at Endress+Hauser Flow Switzerland (Reinach). To maximize product quality and minimize sources of error, various methods for increasing process reliability are used right at the start of product development, such as the design and process FMEA (failure mode and effects analysis). In addition to the favorable sensor properties already described above, a highly automated soldering process ensures consistent quality with respect to the bonding of the sensor elements. Here, the required temperature-pressure profile is constantly monitored during a production cycle. Each welded seam is leak tested using helium as test gas. All sensor probes are tested for high voltage resistance with a test voltage of 500 V. For the correlation between the resistance value and the temperature, all sensor probes are adjusted in a temperature control system at different temperatures according to EN/IEC 60751. The high-precision reference sensors measure at an accuracy of ±0.025 °C (±0.045 °F).

To ensure consistent quality, all sensors produced are tested on a traceable sensor quality check station using gas flow. Within a brief amount of time, the resistance-temperature correlation and the thermal connection of all sensor probes are checked. The material traceability of the component parts as well as all test results and measuring data are recorded digitally in a database and can be assigned to a specific sensor at any time. These sensors are only permitted to leave the sensor production area when all the necessary documentation is available, and the numerous tests have been successfully completed. When a flowmeter is returned to the manufacturer's factory for recalibration, the new values are added to this data. Thus, it is possible to compare and display the device history at any time.

Checking the sensors with Heartbeat Technology

Heartbeat Technology provides additional options for checking the sensor system in its installed condition. For example, a sensor check is performed during the startup process of the device and during verification using Heartbeat Technology. In this case, the resistance values are measured and a test for electrical short circuits to the housing is conducted. This makes it possible to detect any electrical drift. The sensor status is indicated via a corresponding alarm on the device and in the Heartbeat Technology verification report. This increases safety in plant operation and can be carried out at any time in the installed state.

Although thermal drift is virtually eliminated by the design of the sensor probes, a test routine has been integrated in Heartbeat Verification. Certain prerequisites must be met in order for a thermal drift check to be performed. These include a constant flow and a constant process temperature. More detailed information on the test requirements is described in the Heartbeat Verification manuals for t-mass (SD02477D/06/EN; SD02479D/06/EN). The measuring system recognizes by itself when the prerequisites are fulfilled and carries out the check for any thermal drift. If these are not fulfilled, no check takes place and the message ”Not executed” appears on the log. The verification concept has been certified by an independent body and is traceable according to ISO 9001. The results of the verification are traced back to internal references and factory tolerances. The device function can be evaluated in the installed state at the push of a button and without interrupting the process.

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