Absolut zero invasion

Noninvasive temperature measurement keeps things tight

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The majority of measurements made in the process industry are of temperature and pressure. Around half of the temperature measurements are used for monitoring purposes to secure product quality, increase process efficiency and ensure plant safety. There are virtually no chemical processes in which temperature measurement is not required. Suitable conventional temperature measurement instruments are widely available and the cost of these has decreased over time due to high volumes, technological progress and competition. However, these devices are mostly intrusive in nature. ABB's noninvasive, wireless and energy-autonomous temperature sensor is now changing the face of industrial temperature sensing, as has been illustrated in a recent pilot installation in The Absolut Company's vodka distillery in Sweden.

1 First transmitter for mounting inside the sensor head (TR01)

2 First autonomous temperature instrument TSP331-W

The heyday of technological advancement in temperature measurement was in the 19th century. Thomas Johann Seebeck (thermoelectric effect, 1820) and Carl Wilhelm Siemens (platinum resistance thermometer, 1871) were two of the most prominent pioneers. ABB's activities in industrial temperature measurements date back to 1881 when Wilhelm Siebert melted platinum in his family's cigar-rolling factory in Hanau, Germany and mechanically worked the material into wires. Though subjected to continuous improvement, the main design – with a measuring inset, protected from the process medium by a strong thermowell and a connection head – changed little over the years and many of today's devices are based on these early discoveries.

A game changer was introduced in 1978 by ABB (Degussa at that time) with the implementation of an electronic transmitter inside the connection head → 1. This allowed the measuring circuit and the sensor element to be combined – even in harsh environments – thus reducing the need for long sensor wires, which tend to be sensitive to electromagnetic interference that impacts sensor accuracy and introduces signal noise. This major innovation paved the way for today's distributed smart sensors that deliver standardized and linearized measurement values to a central control system [1].

Almost 40 years later, ABB has now transformed the temperature sensor once more, making it autonomous by introducing wireless communication as well as an energy-harvesting power supply that feeds the instrument from the temperature gradient between the process and its surroundings → 2. ABB has integrated these two technologies into the fully autonomous temperature instrument TSP300-W series. This ABB innovation was a major milestone in temperature sensing and an enabler for wireless communication in process automation.

One remaining shortcoming of industrial temperature measurement devices, however, was the thermowell.

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Thermowells

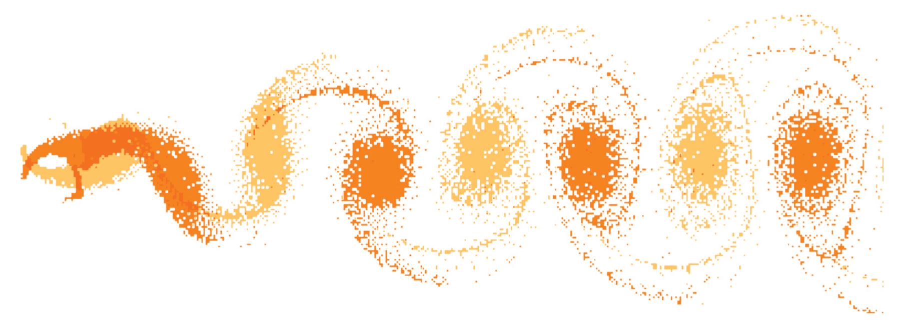
The thermowell protects the sensitive measuring inset from the hot, chemically aggressive, abrasive or pressurized flow inside pipes, boilers and vessels → 3. However, the thermowell obstructs flow, leading to a pressure drop. This phenomenon creates low-pressure vortices downstream of the thermowell → 4. Vortex shedding causes the thermowell to vibrate and if the vortex shedding rate matches the eigenfrequency of the assembly, resonance occurs and dynamic bending stress increases substantially.

In terms of plant safety, thermowells are the most critical part of a temperature instrument: At high flow speeds and pressures, thermowells can easily burst if they are not designed properly. Accordingly, standards have been developed by organizations such as ASME (American Society for Mechanical Engineers) to assist engineers in selecting suitable designs. However, for applications where the standard is not applicable, the engineer is fully responsible for the proper design of shape, length, diameter, coating and interface type. Altogether, this leads to a greatly enlarged number of variants – resulting in higher cost, stock levels and logistic effort.

Title picture
Noninvasive temperature measurement in industrial processes brings a multitude of advantages. However, how is it to be accomplished?

3 Thermowells typically used for heavy-duty oil and gas applications

4 Alternating vortex shedding – vortices occur at one side of the thermowell, then the other. The effect is also seen in a flag waving in the wind.



Besides the safety issues, a thermowell is a nuisance to the process: It reduces the effective pipe cross section and the pressure drop it causes may result in higher pump power consumption.

5 TSP341-W noninvasive temperature measurement

Besides the safety issues, a thermowell is a nuisance to the process: It reduces the effective pipe cross-section and the pressure drop it causes may result in higher pump power consumption. It also forms an obstacle to pipe cleaning. Food, beverage and pharmaceutical plants are reluctant to use thermowells due to increased risk of contamination. In brownfield installations, the plant has to be shut down and the pipes emptied prior to the installation of intrusive devices. Thermowells also have a detrimental effect on the measurement itself as they introduce a temperature drop between medium and sensor, and latency. Last but not least, they are often the most difficult and expensive part to install as they frequently require welding.

In 2010, in response to some these challenges, ASME updated its basic standard for thermowell calculation [2], resulting in more robust thermowells with larger diameters, stronger materials and shorter lengths. These changes merely amplified the measurement disadvantages mentioned above.

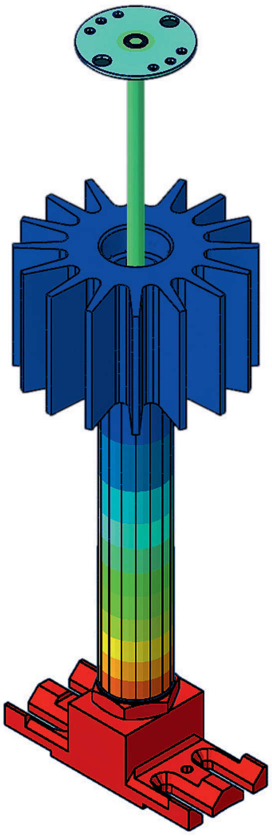
Noninvasive methods

Thermowells can be eliminated by using a noninvasive temperature measurement. Noninvasive instruments leave pipes and vessels unaffected, with many advantages:

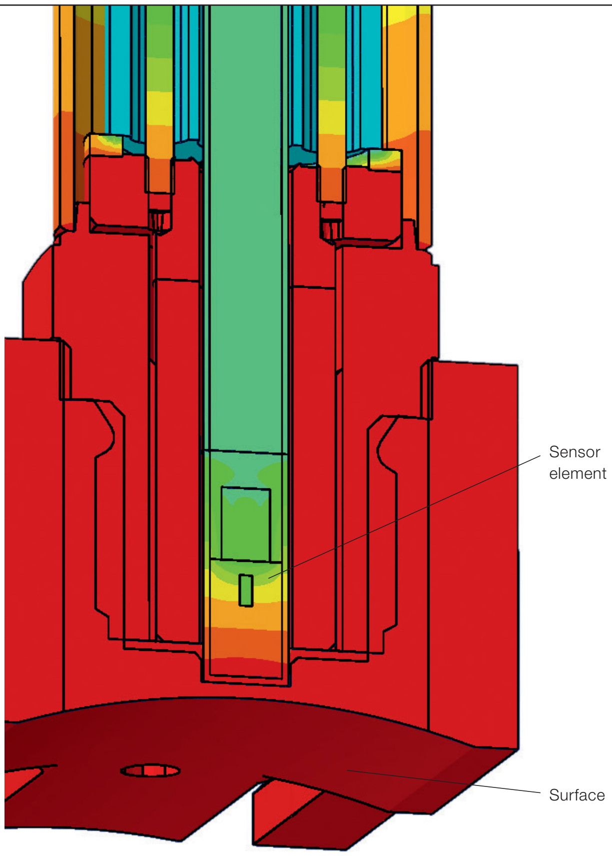
- The shells of pipes and vessels are not penetrated.
- There is no need to empty the pipe for installation.
- No welding is required on site and no special permission for hazardous areas is needed.
- The possibility of contamination is eliminated.

These advantages have considerable implications: Measurement points are now easy to install and can thus be used on a temporary basis – eg, during setup and test of a new process or, if there are issues in production, for root-cause analysis. As soon as a satisfactory situation has been arrived at, the number of measurement locations can be reduced to an economically and technically appropriate long-term value.

6 Finite-element result for the temperature field in a typical setup before optimization



6a Entire device



6b Interface to target surface

Why have noninvasive methods not been used before?

There are good reasons why noninvasive technology has not been used in the majority of temperature measurement installations so far.

The easiest way to obtain a noninvasive temperature measurement would be to attach an existing instrument to the surface of a pipe or vessel instead of introducing it into a thermowell. However, the temperature sensor is then further away from the process medium so that the response time would be impaired, and ambient conditions would have a bigger influence on the measurement.

A good noninvasive temperature instrument, therefore, has to have an appropriate design of the thermal pathway from the process to the sensor, which includes all materials and all interfaces through which the heat has to be transferred. It would also be beneficial if the existing (thermowell design) instrument could be adapted to fit as this would reduce the development effort significantly, keep the number of variants and additional parts low, and make it easy for the customer in terms of familiarity and certification retention.

A challenging case

Two autonomous [3], noninvasive temperature instruments were given to The Absolut Company in Nöbbelöv, Sweden so they could explore the device's capabilities without having to interrupt the processes in their vodka distillery → 5. To keep the effort on ABB's side low, adapters were manufactured to mount existing (thermowell design) instruments with adjusted inset length to the pipes.

The sensors were easy to integrate into the existing ABB Extended Automation System 800xA. The System 800xA automation platform has a built-in field device management system. This allows users to have one single system that covers operations, engineering and field device management – including functions such as device configuration and condition monitoring. Such an approach has significant advantages – reduced engineer-

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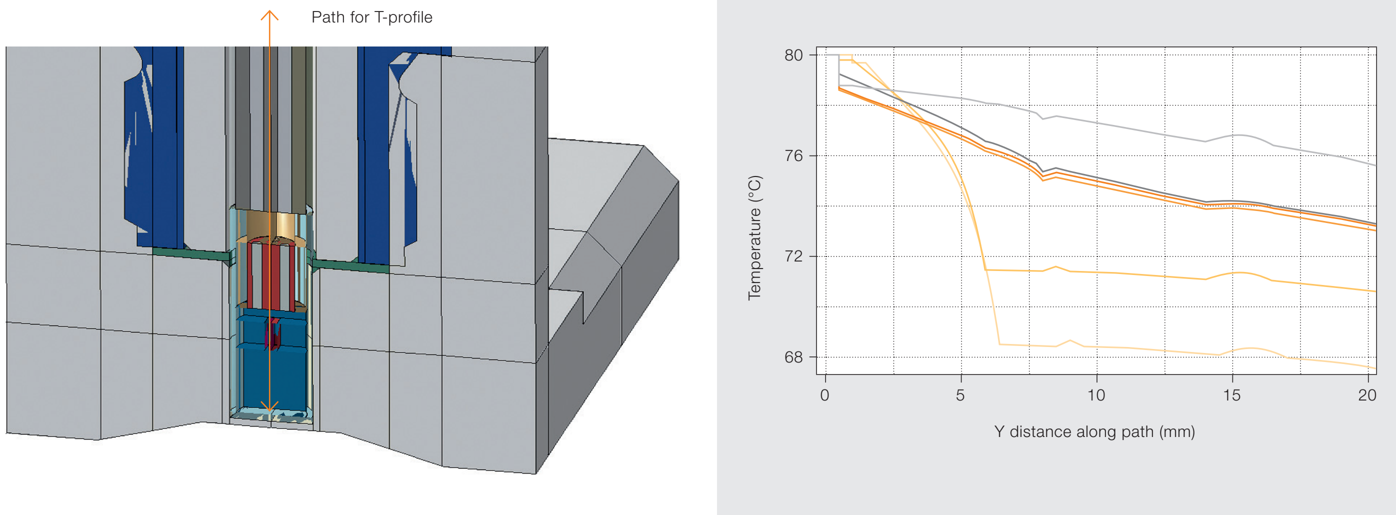
7 Systematic search for relevant design parameters



7a The temperature field is plotted along a path through the device during measurement.

7b Sample temperature profiles across the device for various design iterations

> The sensors were easy to integrate into the existing ABB Extended Automation System 800xA, which has a built-in field device management system.

ing hours, for example – since the complete solution, including field device configuration, is engineered in one system with one common engineering workflow. Another advantage is speedy commissioning as complete signal checkout can be done by one single person from one screen.

After installation, the automation engineers from The Absolut reported that the energy harvesting functionality, as well as the wireless communication, were working well. However, measurement accuracy and the response time of the instruments failed to meet their expectations.

Improving the measurement

A series of measurements at The Absolut revealed a detailed picture of the thermal situation at and around the instrument as well as at the adapter that connects the instrument to the pipe. After determining the cause of the measurement issues, the design of the adapter was improved and tested. The measurement inset and thermal interface materials were also modified. In the final configuration, measurement error was reduced to approximately 1 K (from several degrees Kelvin). At the same time, response time was decreased by 75 percent, such that both performance parameters were close to those of an invasive temperature instrument.

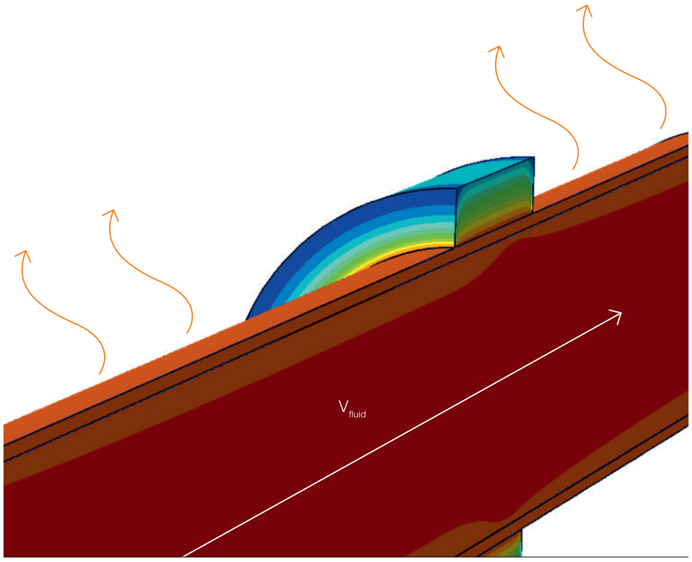
> Finite-element simulations were used to identify the relevant design parameters.

Modeling

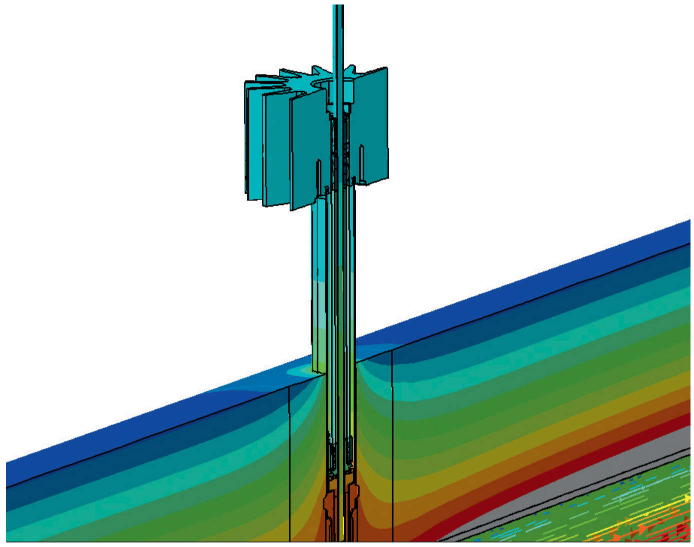
Physical understanding of the measurement point and subsequent modeling and simulation of the thermal situation were important for arriving at a good design. Finite-element simulations and extensive automatic model-tuning [4] were used to identify the relevant design parameters → 6. Geometry, materials and interface properties could be effectively represented in the models → 7.

Furthermore, it was important to understand how the sensor temperature can be affected by details of the measurement situation – eg, by different insulation types or different flow conditions. An understanding of these influences was generated via conjugate heat transfer calculations in which a hot or cold fluid is modeled flowing along a pipe where the instrument is mounted and/or where some axially homogeneous or spatially varying insulation is applied to the pipe. Typical temperature fields generated by these calculations are shown in → 8.

8 Conjugate heat transfer has been analyzed in cosimulations of coupled finite-element and fluid-dynamic calculations.



8a Temperature field distortion in the case of a locally insulated fluid-conveying pipe



8b Temperature field in the structure and velocity field in the fluid for a typical measurement situation

Easy installation

The newly designed adapter can be mounted onto a wide variety of pipe diameters; only the length of the clamps (simple steel bands) has to be adjusted, thus greatly reducing the number of variants and increasing flexibility. The design's lower complexity requires less machining and allows simpler installation, which is especially beneficial in hard-to-reach locations. The installation does not require calibration or extensive parameterization.

Following this optimization, The Absolut Company installed four TSP341-W units and the predicted improvements in measurement accuracy and response time were confirmed.

A new flexibility

Noninvasive, wireless and energy-autonomous temperature measurement ushers in a new era of flexibility. With temperature measurement and the job of engineering it into a System 800xA DCS now made so easy, applications that add a high value – but traditionally have been difficult to justify from a cost perspective – are now well within reach. One good example of such an application is short-term instrumentation of processes during optimization and continuous improvement exercises or energy efficiency initiatives. Another example is to supply ABB's System 800xA heat exchanger asset monitor (HXAM) – a condition monitoring tool that identifies heat exchanger performance changes and operational degradation – with the temperature inputs it requires to guarantee more energy-efficient operation and reduced maintenance costs. In large facilities, improved heat exchanger performance delivers substantial energy savings.

Only applications with extreme spatial or temporal gradients pose a challenge to the complete closure of the gap between the performances of the noninvasive sensor and its invasive counterpart – both in terms of measurement accuracy as well as response time. A next logical step, once the thermomechanical options are exhausted, is to use advanced model-based algorithms that can correct the measurement.

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