

# Keep on running

Field device diagnosis ensures reliable operation

Andrea Andenna, Daniel Schrag, Armin Gasch, Paul Szász



The technological advances of the last decade have brought with them increased expectations from industrial field device customers. Digital signal processing (DSP) and sophisticated communication technologies, for example, have enhanced the information exchange between field devices and the distributed control system (DCS), and devices are now expected to provide in-depth diagnostic information in addition to highly accurate measurement values.

In recent years, ABB Corporate Research has worked tirelessly to meet customer demands by creating multi-functional field instrumentation, and the results of its efforts are now reflected in a string of developments. For example, enhanced diagnostic information, such as automatic redundancy switching and sensor drift monitoring, are major market differentiators for the new head mounted temperature transmitter TTH300. Bubble and electrode coating detection, and conductivity measurement functions will be integrated in the next version of magnetic flowmeters, and future versions of vortex and swirl flowmeters will include an automatic vibration suppression algorithm.

The days when a measurement device was solely used just to measure have long since gone. Cost pressure and the need to improve efficiency by reducing downtime mean customers from the process industry now expect “intelligent” field devices. In fact, many customers want to replace common preventive maintenance by a more efficient and focused predictive maintenance and plant asset management strategy [1] **Factbox**.

ABB and its competitors are acutely aware of this trend and the keyword “diagnosis” is now more or less standard in market requirement specifications for new generations of instruments.

The trends concerning process sensors requirements were recently highlighted in an initiative of NAMUR and VDI/VDE in Germany titled “Technology Roadmap for Process Sensors” [2]. One trend seen from an end customer perspective is the measurement of parameters with even greater accuracy than is currently achieved. The requirements for process sensors extend from the measurement of purely process parameters towards intermediate and trend information about product properties for control purposes (eg, yield and yield trend, by-products, contamination-like content of solids in gases, quality).

With digital signal processing (DSP) and sophisticated communication technologies, measuring devices are now also expected to provide in-depth diagnostic information.

#### Signal processing in multifunctional field devices

In the past, the electric signal of a primary sensor was used as input to a readout device. However, the rapid development of digital electronics in recent years now allows meaningful and important information to be extracted

directly from a sensor’s raw signal. The use of microprocessors and digital signal processing (DSP) give better sensor signal quality, reduced noise and higher measurement accuracy. In addition, diagnostic functions, such as device self-monitoring (eg, checking for electronic defects) and process data monitoring (eg, checking if the

impulse lines of a pressure transmitter to the process are open), and advanced functionalities can be realized. Safety features can also be implemented at that level.

Until recently, additional functionality was provided at the plant control-system level where much higher computation power is available. But improvements in electronics hardware and embedded software platforms now enable these functions to be integrated at the field device level. Anyway, some advanced functions can only be integrated in a field device because they require higher sampling rates than are possible with the usual fieldbus communication data rates.

ABB has worked tirelessly to create multifunctional field instrumentation that meet soaring customer demands.

There are two ways in which advanced functions can be realized in a device:

- *Employ a purely signal processing approach.* Sensors become essentially “soft” because the additional functions are implemented by applying mathematical routines and algorithms embedded in the processor of the transmitter. The sensing part or the mechanics of the sensor remain unchanged.
- *Integrate an additional (commercially available) sensor into the transducer.* For example, ABB’s multivariable transmitter, 267/269 can measure differential and absolute pressure, and process temperature. These quantities are then used to calculate mass flow.

In general signal processing technology is used to extract relevant information from the raw signal. This can be accomplished either by straightforward mathematical data analysis or more complex physical modeling. If the former method is used, the time series of the raw signal can be analyzed by

#### Factbox Industrial sensors in harsh environments

Industrial sensors, such as pressure and flow sensors are often exposed to extreme process and environmental conditions. Aggressive media cause corrosion and abrasion while other substances tend to form deposits **picture**. A device eventually gets to a point when it can no longer function properly and needs to be repaired.

Devices that recognize and report failures or degradation using so-called “self-diagnosis” are key elements of effective maintenance strategies. Very often new generation instruments not only discover internal faults, such as drift or ageing, but they can also recognize changing process conditions, like those from pulsating flow and bubbles in the flow, as well as the condition of other components connected to them. The detection, or even the compensation, of most of these effects is possible through appropriate signal processing algorithms.



1 Temperature sensors and a TTH300 transmitter



Productivity solutions

running a correlation, spectrum or noise analysis to find characteristic features and indications of dysfunctions. Another factor that broadens the spectrum of possible applications and functionalities is the emergence of novel and more efficient signal processing algorithms and techniques, such as statistical signal analysis, non-linear data analysis, adaptive filters, neural networks and wavelets. In the latter method, a physical model of the sensor system is developed either by a set of equations describing the scientific principles underlying the respective sensor or by simulations. The decision regarding the suitability of advanced data analysis or the more elaborate physical modeling strongly depends on the application, the integrity of the measuring data and the available computational power [3].

Devices that recognize and report failures or degradation using so-called “self-diagnosis” are key elements of effective maintenance strategies.

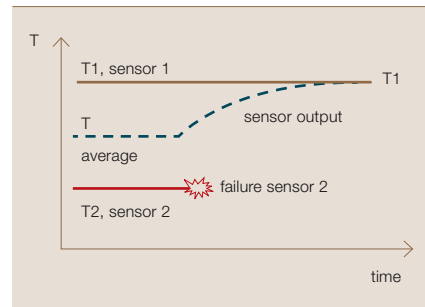
**Constraints of more functionality**

In the industrial instrumentation market, price plays a very important role in keeping or increasing market share. How big a role increased functionality plays depends on different points of view. Operators of big process plants with a multitude of expensive assets – like valves – are willing to pay more for advanced functionality. Device and process diagnostic functions in particular are highly appreciated because they promise to reduce maintenance costs and improve, in general, the reliability of the plant operation. Customers who primarily use the basic functionality only will not accept higher costs. Hence, during the functional-

ity development phase, a trade-off needs to be found between cost and the feasible technical implementation.

ABB Corporate Research has invested consistently in the area of advanced diagnosis and signal processing, and some of the “fruits of this labor” are described in the following sections.

**2** Sensor output with active sensor backup: A sensor failure results in a “soft” transition to the remaining sensor signal.

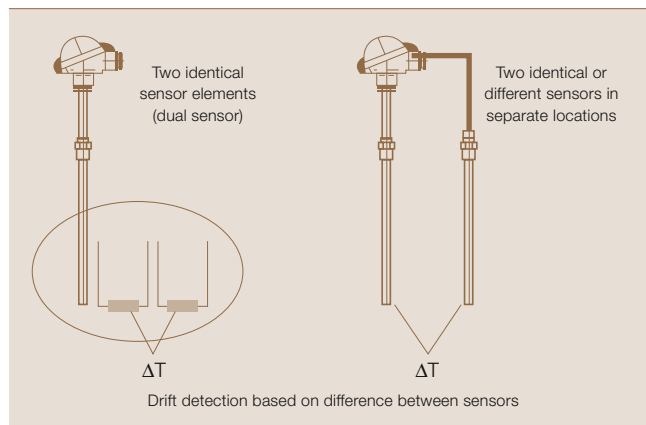


**3** DTM (device type manager) output for active sensor backup function.

Continuously correct temperature measurements

Notification of status and service needed (redundancy active, sensor 1 not available due to wire break, replace failed sensor)

**4** Sensor configurations suited to the use of the drift detection function



**Reliable temperature measurement**

Temperature sensors based on resistance temperature detectors (RTD) or thermocouples are highly accurate with straightforward measurement principles and simple technology. One would therefore assume that signal processing can do little to boost the performance of these temperature sensors. However, daily experience in process applications reveals how conventional plain temperature sensors can drift or even fail due to environmental ageing. While failure is easily detected, sensor drift can lead to wrong process conditions and unnoticed quality loss. Classical preventive maintenance consists of an annual costly re-calibration of temperature sensors in many process applications.

As the demand for predictive maintenance increases, customers are looking for new solutions. The productivity in processes where temperature control is critical increases significantly with reliable temperature measurements. This in turn drives the development of sophisticated diagnostic functions for temperature transmitters.

In ABB's TTH300 HART temperature transmitter<sup>1)</sup>, a large variety of self-diagnostic features have been implemented within a compact 44 mm diameter housing to enable high accuracy – up to 0.1°C is achievable – reliability and availability **1**. To take full advantage of the high accuracy, the transmitter features two new diagnostic functions: sensor backup and drift detection. The increased computational capacity of the transmitter has enabled algorithms to be implemented at device level without increasing the data load in the communication system.

The TTH300 temperature transmitter can handle two RTDs or thermocouples, or a

**Footnote**  
<sup>1)</sup> The TTH300 HART temperature transmitter was released in April 2006.

combination of both in parallel, and with the sensor backup function in place, the availability of the sensor is greatly increased. Previously, if a temperature sensor failed, a new sensor had to be connected manually to the transmitter, causing significant process downtime and cost. Now once a failure has been recognized by the built-in diagnostic functions, the transmitter automatically switches to the second sensor to ensure a continuous stream of correct temperature measurements **2**. At the same time a message is generated for the device type manager (DTM) **3**. Sensor replacement can be planned for the next routine service date without incurring extra downtime and at minimum cost.

**ABB's reliable and accurate TTH300 HART temperature transmitter contains a large variety of self-diagnostic features in a compact 44 mm diameter housing.**

Drift can occur in all sensors due to long-term mechanical or thermal effects, such as vibrations or overheating. Even though slow drift remains, for the most part, unnoticed in common processes, it can be fatal not only for the process but for the product quality as well. To date this problem has been addressed with regular but costly – in terms of downtime – sensor calibration. However, regular calibration can very often be unnecessary as the sensors remain stable if no severe environmental loads are acting.

Since the beginning of 2007 the new TTH300 offers a solution to this problem by performing predictive maintenance, ie, monitoring sensor drift, and calibrating only when necessary. In this solution, the TTH300 continuously monitors both sensors and compares their data. If the sensors operate within their defined tolerance (ie, without drift), the difference is very small. Drift in one of the sensors, however, causes the difference to exceed a definable threshold, triggering the transmitter to inform the operator that re-calibration or replacement

should be planned for the next routine control. As actions are required only when drift occurs, the number and cost of sensor maintenance operations is significantly reduced.

The standard use-case is drift detection on a dual sensor **4**. Even though drift is a non-predictable stochastic phenomenon, experimental investigations have confirmed that two sensors will not drift identically even if exposed to the same environmental ageing conditions. Alternatively, the drift detection feature can also be applied to sensors in different locations in a process, for example, to detect changes in the total process flow. This in turn allows local problems, such as poor heat transfer due to depositions, to be recognized.

The user can define the threshold level according to the sensitivity of the process to drift. The accuracy of the fit between the two sensors in question determines the minimum applicable alarm threshold. With a one- or two-point fit the detection threshold is about 0.5 – 1 °C because the characteristics of any two sensors will always differ by this amount. The detection threshold can be further reduced with more accurate sensor characteristic information. However, the 0.5 – 1 °C drift alarm threshold fulfils the needs of more than 90 percent of all applications.

**A magnetic flow meter is a reliable and popular device that is applied in the water and waste, food and beverage, pulp and paper, and chemical industries.**

#### Pure MAGIC

The global magnetic flow-meter market is valued at approximately \$700 million. Invented in 1941 by Bonaventura Thürlemann, this reliable and popular device is applied in the water and waste, food and beverage, pulp and paper, and chemical industries.

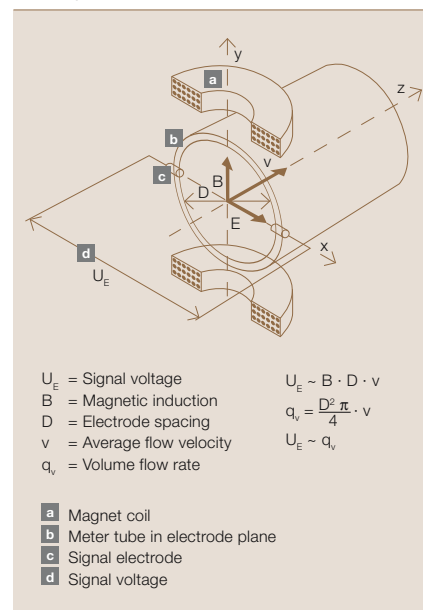
The operation of magnetic flow meters is based on the principle of Faraday's

Law of Electromagnetic Induction **5**. When a conductor passes through a magnetic field, a voltage,  $U_E$ , is induced between the two electrodes, which is directly proportional to the volume flow rate  $q_v$ . Viscosity, density, temperature and pressure do not influence the flow velocity reading of a magnetic flowmeter.

The development of coating diagnostics for a magnetic flow meter is an interdisciplinary problem that relies on a thorough understanding of the process.

Project MAGIC focused on realizing a magnetic flowmeter with multivariable

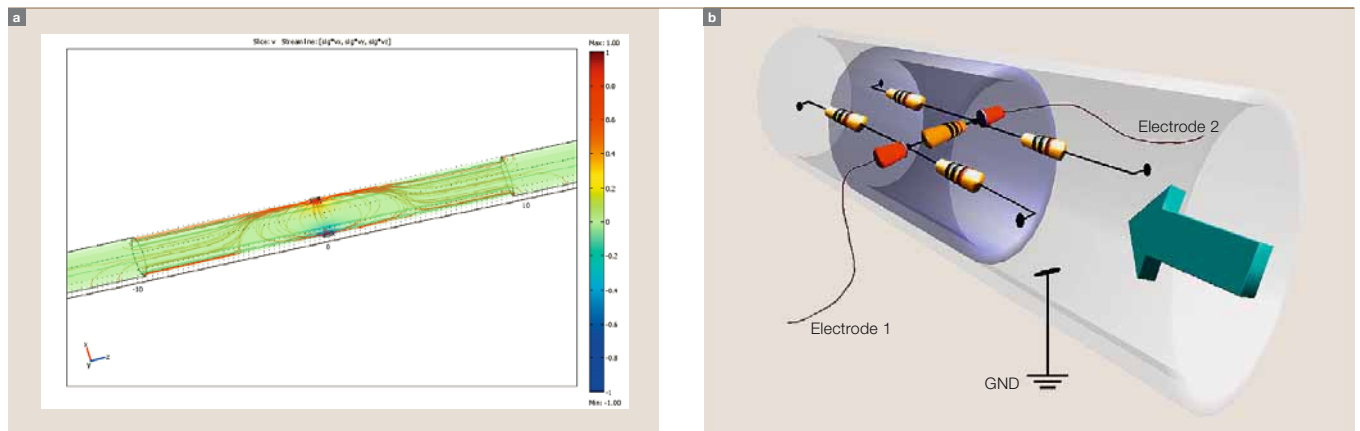
**5** Magnetic flow-meter principle



**6** Coated magnetic flow meter in a pulp and paper application



7 Field simulation and flow-meter model with electric impedances



measurement, device and process diagnostics to detect gas bubbles in the medium and coating of a fabrication system, and to check the conductivity of the liquid.

If coating builds up in the fabrication system, it not only affects the pumps and pipes but also the magnetic flow meter [6]. There are two types of coating, isolating and conductive, both of which affect the flow meter electrodes. Isolating coating continuously reduces the electrode area, eventually causing total flow meter failure, while conductive coating gradually increases the electrode area until a short circuit occurs. Therefore it is vital to monitor the system coating so that failure-prevention measures can be taken.

**Algorithm design**

The development of coating diagnostics for the magnetic flow meter is an interdisciplinary problem that relies

on a thorough understanding of the process. Therefore, the first port-of-call was the theoretical aspects of electrode-electrolytes interfaces. Device measurements in the flow lab under different conditions, followed by field measurements with ABB customers in different processes allowed an analysis of specific process coatings.

The effects of different liquid properties and coating materials were analyzed using measurements and simulations. The measurements and simulations were then used to develop physical device models that were extrapolated to aid the design of bigger flow-meter diameters.

Vortex flow meters have been successfully used as industrial flow-rate sensors for about thirty years and still they represent a growing business.

tional to the liquid conductivity in the flow meter.

Laboratory measurements were carried out using different coating liquids. The conductivity of the medium (water) between 200 and 2,000  $\mu\text{S}/\text{cm}$  hardly influences the electrode-electrolyte interface [8]. A conductive coating with cream or an isolating coating with oil or  $\text{MoS}_2$  changes the constant phase element. This effect allows coating to be measured independently of the conductivity of the medium.

In addition to coating detection, ABB's flow-meter platform was successfully enhanced – in collaboration with customers in Germany and Sweden – to measure conductivity and detect gas bubbles.

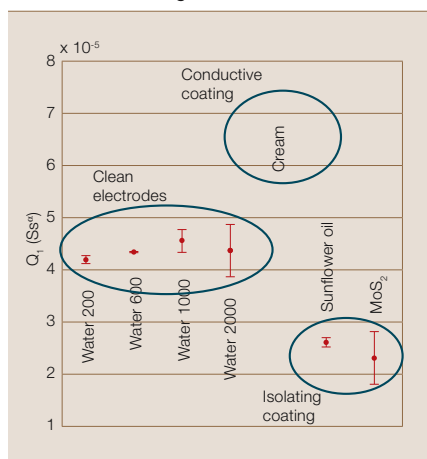
**Vibrations-immune vortex flow meters**

Vortex flow meters have been successfully used as industrial flow-rate sensors for about thirty years, and after all this time they still represent a growing business.

ABB's flow-meter platform was successfully enhanced to measure conductivity and detect gas bubbles.

The working principle of this type of flow meter is shown in [9]. When the fluid flows through the pipe and passes the bluff body, vortices are generated which then hit a paddle mounted directly after the bluff body. Within the paddle a piezoelectric sensor detects the movements caused by the

8 Coating detection based on physical device modelling



The effect coating has on a magnetic flow meter is modelled with frequency dependent impedances positioned between the electrodes and the flow meter ground [7]. Constant-phase-elements accurately approximate the electrode-electrolyte interface characteristics, which in turn provide important information about the actual coating condition of the magnetic flow meter, (ie, clean, conductive or isolating) and therefore about the process system. The reciprocal value of the resistance between the electrodes at higher frequencies is strongly propor-

vortices passing by. The frequency of the paddle oscillations is proportional to the flow rate.

To ensure stronger noise immunity, ABB's vortex flow meters are equipped with a second piezoelectric sensor.

Because the sensor is based on a frequency measurement, disturbances, such as pulsating flow and vibrations (from rotating machines working near the vortex meter), may have a significant impact on the performance of the instrument. To solve this problem, ABB reviewed the computation algorithms and signal-processing concepts of Vortex and Swirl flow meters.

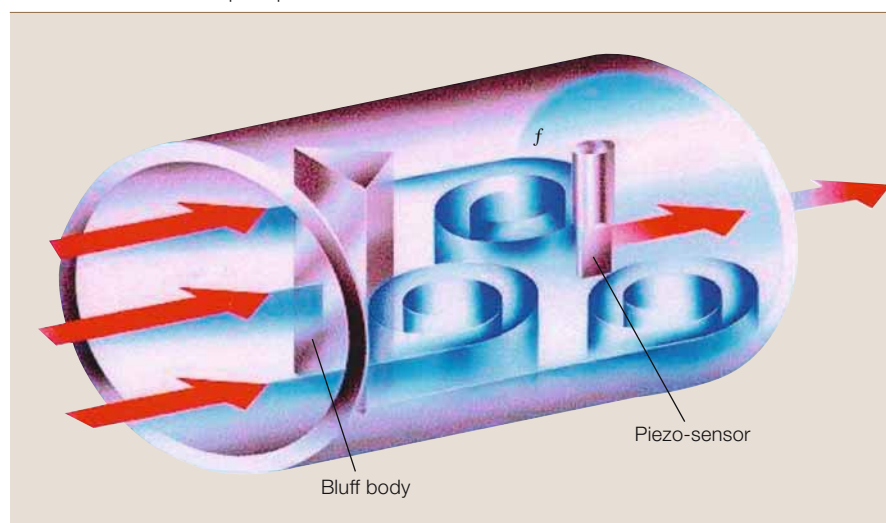
Under normal conditions and without significant noise, the frequency spec-

trum of the piezoelectric sensor output contains one main peak corresponding to the frequency of the vortices. Under vibrating conditions, the frequency spectrum may show additional peaks with high amplitudes <sup>10</sup>. In the graph on the left, the spectrum of the piezoelectric signal shows a peak at 11 Hz caused by the flow. A disturbance peak at 30 Hz, almost three times the flow peak, is caused by vibrations. These types of effects are especially significant at low flow rates where the amplitude of the paddle oscillations caused by the vortices is small. This problem cannot be solved with "blind" noise filtering only.

To ensure stronger noise immunity, ABB's vortex flow meters are equipped with a second piezoelectric sensor mounted outside the flow tube and which is sensitive to disturbances only. The vibration compensation

algorithm implemented is capable of removing vibration peaks without suppressing the flow peak when vibrations are at the same frequency. Referring to <sup>10</sup>, without a vibration compensation strategy, the algorithm would give the wrong output of 30 Hz. The graph on the right shows the signal after vibration compensation – the vibration peak has been completely removed and the main peak remains intact.

9 Vortex measurement principle



**Andrea Andenna**

**Daniel Schrag**

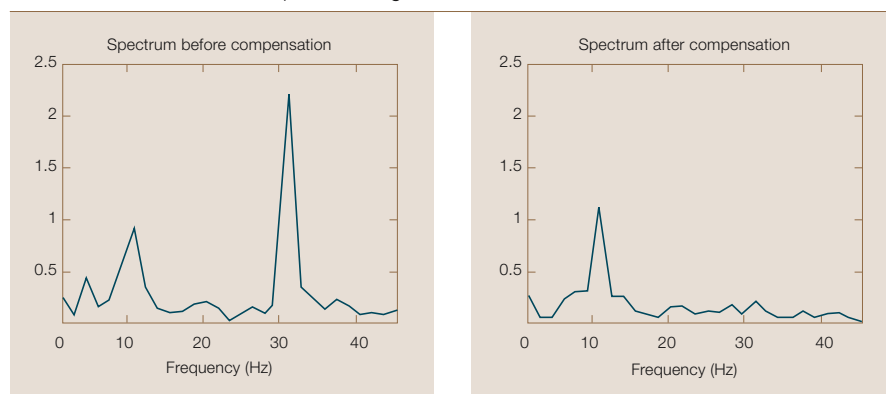
ABB Corporate Research  
Baden-Dättwil, Switzerland  
andrea.andenna@ch.abb.com  
daniel.schrag@ch.abb.com

**Armin Gasch**

**Paul Szász**

ABB Corporate Research  
Ladenburg, Germany  
armin.gasch@de.abb.com  
paul.szasz@de.abb.com

10 Effects of the vibration compensation algorithm



#### References

- [1] Gebhardt, J., Müller, P. O. Watchful eye: Field instrument diagnosis and its efficient use in process plants. *ABB Review* 1/2006, 68–73.
- [2] NAMUR, VDI/VDE (GMA) (2006). Final Report Technology-Roadmap Process-Sensors 2005–2015.
- [3] Riegler, P. (2002). Pitfalls of Advanced Data Analysis for Soft Sensors. 11. *ITG/GMA-Fachtagung Sensoren und Mess-Systeme, Ludwigsburg*, 63–66.

#### Further reading

Keeping, S., Volonterio, E., Keech, R., Johnston, G., Andenna, A. Signaling enhancements. *ABB Review* 4/2007, 12–17.