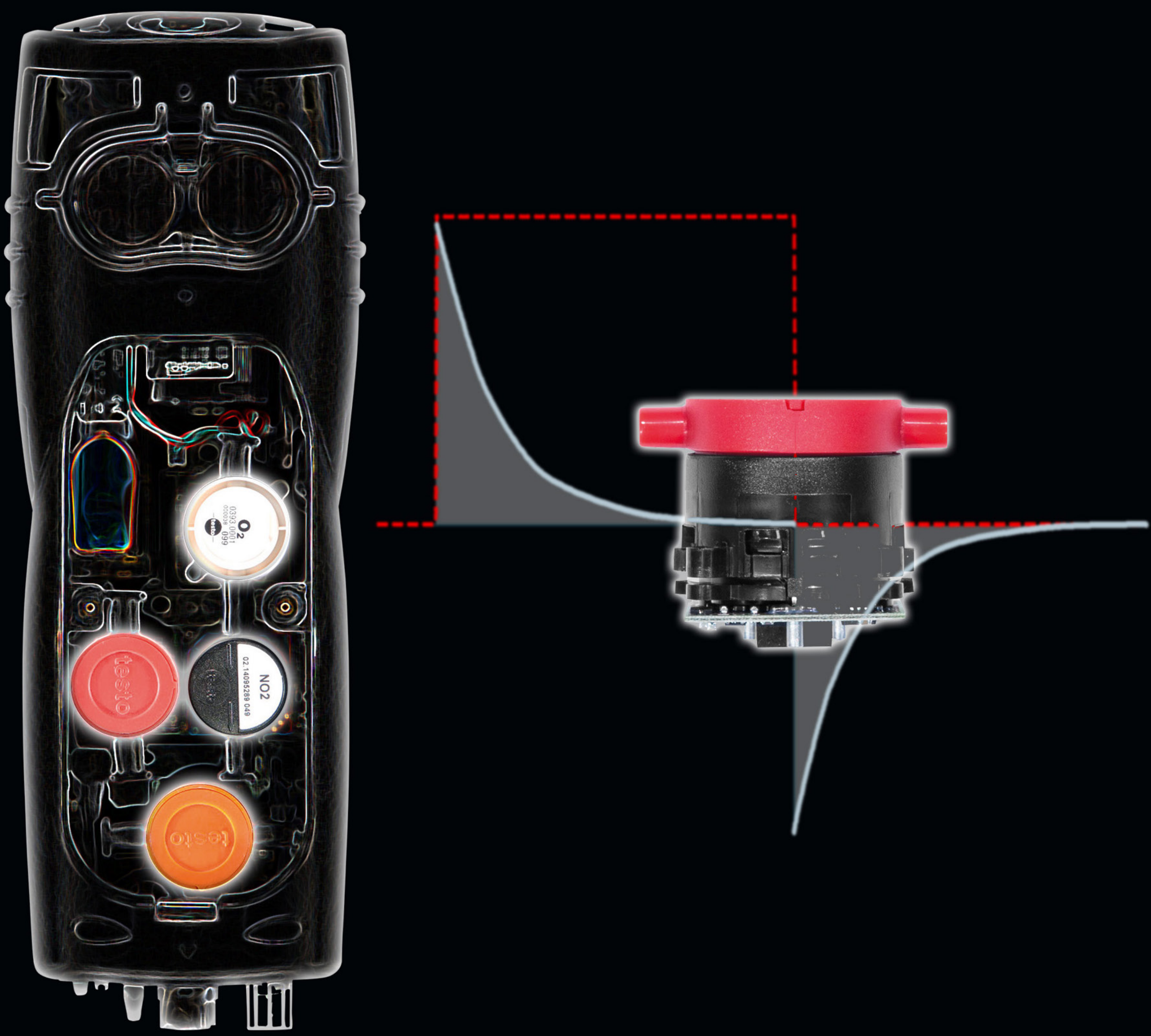
Testo
White paper

Be sure.

be sure – Flue gas analyzers from Testo deliver reliable measurements



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Abstract

Sensors for analyzing gases are playing an increasingly important role in environmental technology and quality assurance. However, mechanical influences and contamination can impair their function. Pulse test analysis provides an integrated self-monitoring system which regularly checks that the sensor is ready for use and ensures that it is working properly.

As a leading manufacturer of measuring instruments, Testo develops and produces both the actual gas sensor technology and the evaluating electronics for the instruments. Comprehensive expertise and access to all aspects of the measurement process are thus available for research into new sensor functions.

Testo is currently working on developing a pulse test analysis system that is built into the measuring instrument. To this end, gas sensors were subjected to accelerated ageing in an extensive series of tests using targeted stress tests. The change in the pulse signal was considered in relation to the sensitivity of the sensor. The results show a clear correlation between the two variables: The stability of the pulse signal is a strong indicator for the functionality of the sensor. The automatic sensor self-monitoring runs in the background and has no effect on instrument operation. Even when test gas is not used, users are kept informed about the sensor's functionality.

Introduction

Measuring instruments are often exposed to demanding or harsh environmental conditions during everyday use. It is not uncommon for gas analysis sensors to be temporarily overloaded by extreme temperatures or gas concentrations beyond the specified measuring range. Mechanical impacts, such as dropping the instrument, cannot be ruled out either. Moreover, dirt and material deposits can impair its function over time. Pulse test analysis is used to determine whether the instrument is still fully capable of performing measurements following these types of events. The sensor is given the ability to independently check its functionality at regular intervals.

The electrochemical sensor

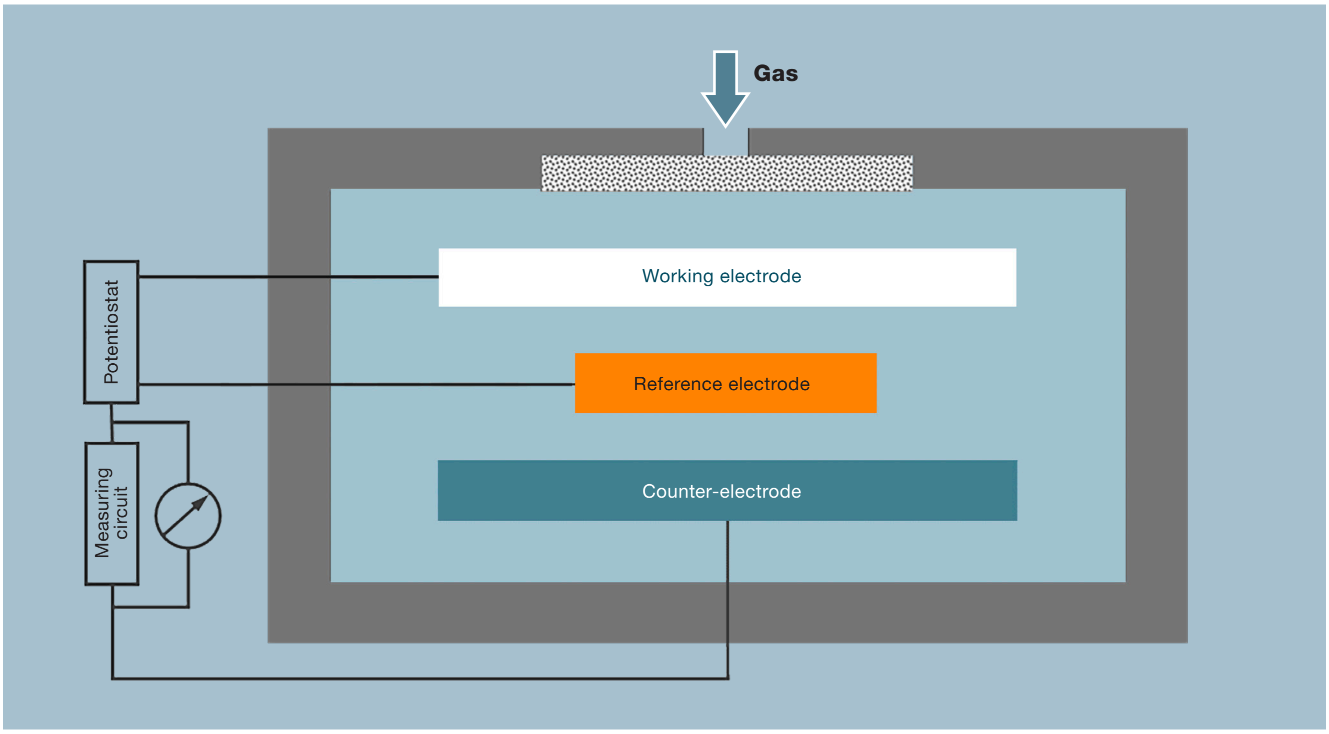

Figure 1: Schematic structure of an electrochemical sensor

As a rule, the gas to be analyzed is a mixture of different components. In the flue gas of a gas boiler, for example, carbon dioxide (CO_2), water vapour (H_2O), oxygen (O_2) and nitrogen (N_2) dominate. In addition, incomplete combustion produces toxic carbon monoxide (CO), the proportion of which needs to be monitored in the flue gas. The gas to be measured enters the sensor through a diffusion barrier, which can be designed as a capillary or membrane. Depending on the sensor type, this may be followed by a filter which retains interfering mixture components.

The gas reaches the working electrode which, like all components of the sensor interior, is wetted with an electrolyte fluid. The electrolyte is used for charge transport and consists of an acidic or alkaline aqueous solution. Diluted sulphuric acid is often used as the electrolyte substance. When the molecules of the respective target gas come into contact with the surface of the working electrode, a chemical reaction occurs: In carbon monoxide control, for example, CO is converted to CO_2. In the process, charge carriers are released to the electrolyte, which migrate to the counter electrode. At the same time, electrons travel through an external circuit. The resulting current strength in the external circuit is therefore a measure of the target gas content. The more current flows, the more CO is contained in the measurement gas. The reference electrode serves to stabilize the sensor signal, especially at higher concentrations of the target gas.

The pulse test analysis method

Pulse test analysis is a diagnostic procedure that the sensor performs on itself. In this process, the sensor's working electrode is briefly subjected to an increased electrical voltage compared to the reference electrode. In response to this potential shift, a current flows, which is measured. The amount of charge transported Q(t) in the sensor can then be calculated from the strength of the current I(t) and the duration of the signal. It is the crucial variable in evaluating the state of the sensor:

$$Q(t) = \int I(t)\,dt$$

The total charge quantity Q is composed of the sum of two partial charges (Figure 2). Raising the electrode potential first generates a positive sensor current with the partial charge quantity Q1 and then, when the electrode potential returns to its initial value, a negative sensor current with the partial charge quantity Q2:

$$Q = |Q_1| + |Q_2|$$

The total charge Q can be understood as the sum of the two light blue areas in Figure 2.

The above procedure is triggered when the measuring instrument is shut down. The pulse test analysis therefore runs in the background and without interfering with the application.

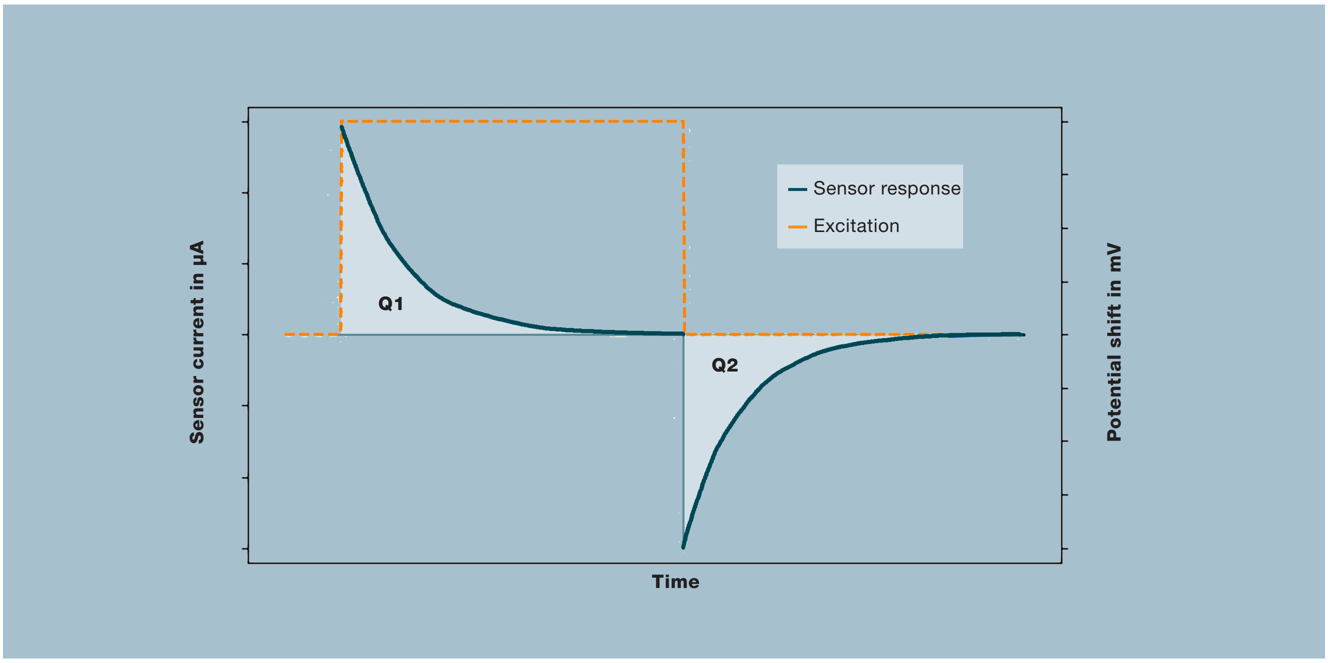

Figure 2: The dashed line represents the excitation of the working electrode as a potential shift in mV. The blue curve shows a typical sensor response. The current/time integral, i.e. the amount of charge transported, corresponds to the light blue areas under the current response of the sensor. This value allows the state of the sensor to be assessed.

Test description

Extensive series of tests were carried out to develop the pulse test method. A total of more than 100 sensors were subjected to intensive testing over a period of three months. The sensors were subjected to controlled, accelerated ageing by means of load tests. The objective of the investigation was the correlation between the ageing process and the loss of sensitivity on the one hand and the pulse test result on the other.

The series of tests were carried out on the flue gas stream of a diesel-powered cogeneration plant. In addition, environmental influences in the form of humidity and temperature stress tests as well as poisoning incidents were examined in the laboratory:

Test series	Application	Stressor
Real gas	Diesel cogeneration plant	High flue gas concentration and exposure
Ambient humidity	High/low humidity	Desiccation, over-humidification
Poisoning	Organic vapours	Assignment of electrodes

Table 1: Series of tests carried out

The flue gas was fed to the sensors via valve control, alternating between flue gas and fresh air cycles. The flue gas components (gas type, gas concentration, particle load) in themselves place increased demands on the sensors. The effective load on the sensors can be adjusted via the ratio of measurement time for the flue gas and measurement time for the ambient air. The distribution in this test was $t_{flue\ gas}$ = 90 % and $t_{ambient\ air}$ = 10 %.

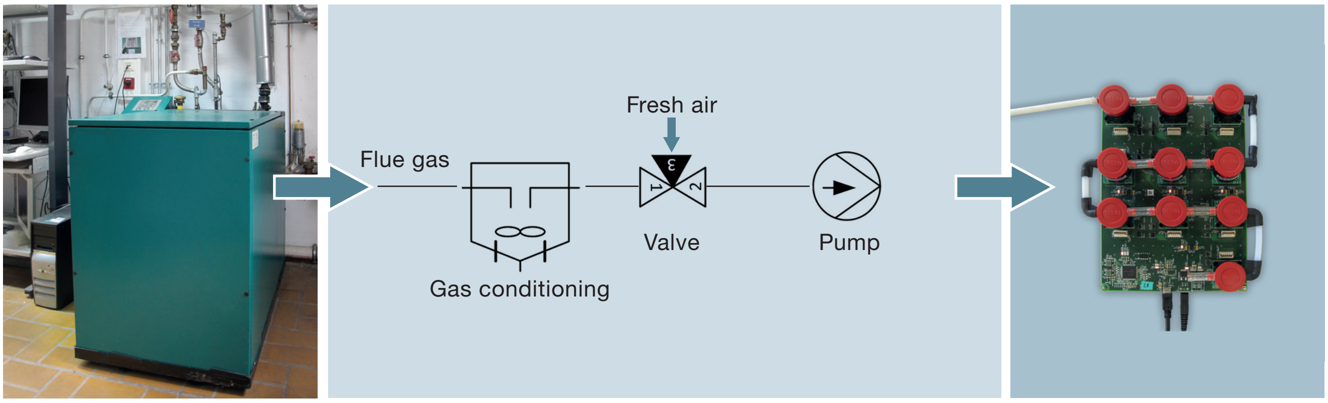

Figure 3 (from left to right): Diesel cogeneration plant, schematic layout of gas sampling, test sensors on evaluation unit.

The humidity and temperature stress tests were carried out in the laboratory. To create different humidity environments, desiccators were provided with different saline solutions, and test sensors were stored in them.

Moisture content	Humidity value	Saline solution
Basic humidity	approx. 55 %RH	above magnesium nitrate hexahydrate
Low humidity	approx. 11 %RH	above lithium chloride
High humidity	approx. 89 %RH	above potassium nitrate

Table 2: Humidity environments

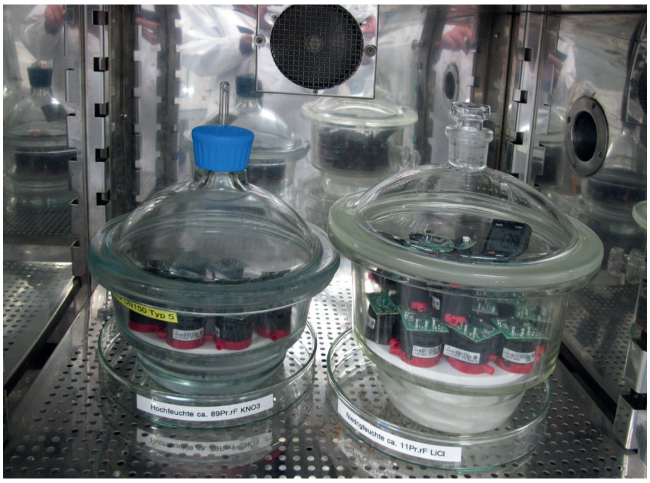

Figure 4: Sensors in the desiccator – humidity stress test

In the so-called poisoning stress tests, the sensors were exposed to alcoholic vapours. This scenario corresponds to the instrument coming into contact with a contaminating atmosphere, for example if there are solvent-soaked cloths in the toolbox. The vapours emanating from them can impair the sensor function; in technical jargon, this is referred to as sensor "poisoning". The symptoms manifest themselves, among other things, as increased zero signal values, which, depending on the degree of poisoning, only subside after hours or several days.

For all test series, the tests were carried out according to the following procedure:

Establish initial values
- Establish sensor sensitivity
- Establish pulse test parameter

Stress exposure
- Flue gas endurance test
- Humidity
- Poisoning

Regular checking
- Determine the sensor sensitivity
- Determine the pulse test temperature

Correlation analysis

Correlation between the parameters
Sensor sensitivity and pulse test

Results and customer benefits

A comprehensive database was created from regular testing of the test sensors. It represents the course of the change in the sensor parameters. There was a clear correlation between the parameters of sensitivity and pulse test signal in both the real gas and the humidity stress tests:

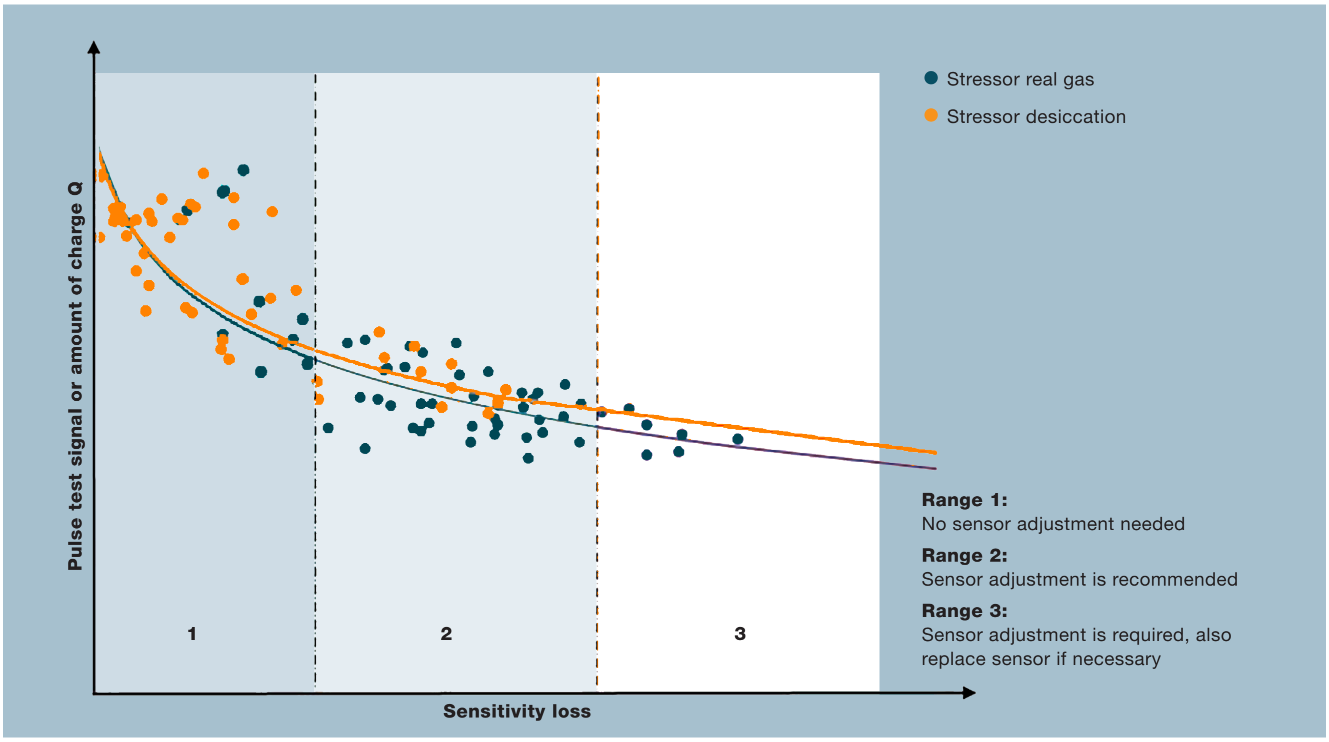

Figure 5: Effect of the stress tests on sensor performance

The loss of sensor sensitivity (x-axis) is accompanied by a reduction in the pulse test signal or the amount of charge Q (y-axis). This relationship can be well modelled: Ranges with perfect sensor function can be clearly distinguished from ranges with decreasing sensor function. This means that it is possible to monitor the sensors in the field without using test gas. Test gas is usually not part of a user's equipment. A functional test that does not require test gas and the associated testing outlay can result in significant simplification and savings.

In range 1, the sensor is fine and provides reliable readings. If the performance of the sensor deteriorates due to environmental or load influences or due to mechanical impacts (range 2), the user receives a timely indication that the sensor needs to be adjusted. Range 3 represents a marked loss of sensor sensitivity, where sensor adjustment is urgently recommended and, if necessary, sensor replacement is advised.

Even without the use of test gas, the user is kept informed about the sensor's function as per specifications.

Summary

The pulse test analysis method is based on a short-term potential shift. This causes a current pulse in the sensor, the time progression of which can be evaluated. Conclusions about the state of the sensor can be drawn from the amount of charge that has flowed.

Extensive series of tests have shown that there is a strong correlation between the sensor sensitivity determined using test gas and the pulse test result. This correlation provides a valid basis for assessing the sensor's functionality and the quality of the measurement results.

The pulse test analysis can be carried out automatically on a regular basis in the measuring instrument. It is designed to run in the background, unnoticed by the user, and does not affect the availability of the measuring instrument. The self-diagnosis replaces the time-consuming sensor test using a specific test gas. It makes using the instruments easier and, at the same time, more reliable.

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