



# Evaluation Of Long-Term Metrological Stability Of Smart Sensor Manometers

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## Abstract

This article comprehensively analyzes the long-term metrological stability of smart sensor manometers during operation, their static characteristics, and the factors affecting measurement accuracy. The study investigates drift processes in digital pressure measuring instruments, aging of sensitive elements, environmental influences, and the efficiency of automatic compensation systems. In addition, the influence of microprocessor-based control systems used in smart sensor manometers on metrological reliability is theoretically and experimentally substantiated. The article also discusses the advantages of adaptive verification methods, digital monitoring systems, and long-term calibration strategies. The obtained results contribute to improving the reliability of pressure measuring instruments in industrial enterprises and reducing calibration costs.

**Keywords:** smart manometer, sensor system, metrological stability, static characteristic, drift, calibration, pressure sensor, digital metrology, automatic monitoring, industrial measurements.

**Introduction.** At present, the rapid automation of technological processes in industrial enterprises has significantly increased the requirements for measuring instruments. In particular, accurate monitoring of pressure parameters is essential for the energy, chemical, oil and gas, pharmaceutical, and food industries. In these sectors, deviations in pressure from established limits may lead to technological failures, energy losses, or emergency situations.

Although traditional mechanical manometers were widely used for many years, in recent years they have gradually been replaced by smart digital sensor manometers. Modern smart manometers are characterized by high sensitivity, automatic compensation, remote data transmission, and self-diagnostic capabilities. However, maintaining measurement accuracy over a long operational period remains an important scientific and practical issue.

During operation, temperature fluctuations, vibration, humidity, mechanical loads, and electromagnetic fields affect the physical condition of sensor elements. As a result, the elasticity of the sensitive element decreases, additional errors appear in signal transmission systems, and static characteristics change. These processes ultimately reduce metrological stability.

Metrological stability is defined as the ability of a measuring instrument to maintain its metrological characteristics within permissible error limits over a long period of time. In modern smart manometers, evaluating this parameter is important not only technically but also economically, since an incorrectly selected calibration interval may lead to excessive costs or increased industrial risks.

## Structure and Operating Principle of Smart Sensor Manometers

Smart sensor manometers operate on the principle of converting pressure into an electrical signal. The main structural components of the device include:

- sensitive element;
- signal converter;
- microprocessor unit;
- analog-to-digital converter;



- display or transmission module;
- automatic compensation system.

Piezoresistive, capacitive, or MEMS-based sensors are commonly used as sensitive elements. Under pressure, the membrane deforms and generates an electrical signal. This signal is processed by a microprocessor and displayed in digital form.

The main advantages of modern smart manometers include:

- high accuracy;
- automatic storage of measurement data;
- remote monitoring capability;
- diagnostic functions;
- temperature compensation;
- low power consumption.

However, during long-term operation, aging of electronic components and fatigue of sensor materials gradually alter the metrological parameters.

### Concept and Importance of Metrological Stability

Metrological stability characterizes the ability of a measuring instrument to preserve its metrological parameters over a certain period of time. This indicator is determined by the following factors:

- zero point shift;
- reduction in sensitivity;
- nonlinearity;
- increase in hysteresis;
- drift processes.

A decrease in metrological stability reduces the reliability of industrial control systems. For example, inaccurate pressure measurements in oil and gas pipelines may result in авария situations and production failures. Therefore, continuous monitoring of the metrological condition of manometers in industrial enterprises is essential.

**Investigation of Static Characteristics.** Static characteristics describe the properties of a measuring instrument under constant or slowly changing pressure conditions. The main static parameters are as follows.

**Sensitivity.** Sensitivity expresses the ratio of the change in output signal to the change in input signal.

$$S = \frac{\Delta Y}{\Delta X}$$

where:

- S— sensitivity;
- $\Delta Y$  — change in output signal;
- $\Delta X$  — change in pressure.

During long-term operation, the reduction in sensitivity is mainly associated with deformation fatigue of sensor materials.

**Zero Point Shift.** Zero point shift refers to the variation of the output signal even in the absence of external influence. This phenomenon is usually caused by temperature effects.

**Linearity.** In an ideal manometer, the relationship between pressure and output signal should be linear. In practice, linearity may deteriorate during long-term operation.

**Hysteresis.** Hysteresis occurs when different measurement results are obtained for the same pressure value during increasing and decreasing pressure cycles. This parameter depends on the mechanical properties of the elastic sensing element.

**Drift Processes During Long-Term Operation.** Drift is the gradual change in the output signal of a measuring instrument over time. The main causes of drift are:



- material aging;
- thermal deformation;
- degradation of electronic components;
- mechanical stresses;
- humidity effects.

The drift coefficient can be evaluated using the following expression:

$$D = \frac{X_t - X_0}{X_0} \cdot 100\%$$

where:

- D — drift value;
- X — initial measurement result;
- X<sub>t</sub>— measurement result after a certain period.

Experimental observations showed that the drift level in manometers operating under high-vibration conditions was significantly higher than that in laboratory environments.

#### **Influence of Environmental Factors**

**Temperature.** Sharp temperature changes reduce the elasticity of the sensor membrane. At high temperatures, the resistance of semiconductor elements changes, resulting in additional measurement errors.

**Vibration.** Continuous vibration intensifies mechanical fatigue, causing zero point shifts and reduced sensitivity.

**Humidity.** Humidity accelerates oxidation processes in electronic circuits, leading to failures in signal transmission systems.

**Electromagnetic Fields.** Strong electromagnetic fields generate noise in signal lines. This issue is especially important in digital transmission systems.

#### **Smart Diagnostics and Automatic Monitoring Systems**

Modern smart manometers are equipped with automatic diagnostic systems. These systems perform the following functions:

- monitoring sensor conditions;
- detecting drift;
- recording deviations from standard values;
- sending remote warning signals.

Some advanced devices also use artificial intelligence algorithms to predict the future metrological condition of sensors.

This significantly reduces calibration costs and prevents unexpected failures.

**Optimization of Calibration Intervals.** In traditional metrological systems, the same calibration interval is applied to all manometers. However, for smart sensor devices, introducing flexible calibration systems based on operating conditions is more effective.

According to the research results, the following recommendations were developed:

- manometers operating in high-temperature environments should be calibrated every 6 months;
- devices used in stable laboratory conditions may be calibrated every 12–18 months;
- adaptive calibration methods should be used in systems equipped with remote monitoring;
- extraordinary calibration should be performed when drift exceeds permissible limits.

**Research Results and Analysis.** During the conducted research, the metrological parameters of several smart sensor manometers were monitored over an extended period. The results revealed:

- gradual reduction in sensitivity;
- zero point shifts;
- increase in hysteresis;
- higher measurement errors at elevated temperatures.



In addition, devices equipped with automatic compensation systems demonstrated significantly lower measurement errors.

**Conclusion.** The long-term metrological stability of smart sensor manometers is an important factor in ensuring industrial automation and technological safety. The study showed that environmental influences and aging of sensor elements lead to changes in static characteristics.

Experimental and theoretical analyses confirmed that drift processes, zero point shifts, and sensitivity reduction are the main indicators of metrological stability deterioration. The application of smart diagnostic and automatic monitoring systems improves calibration efficiency and reduces operational costs. In the future, the implementation of artificial intelligence-based forecasting systems will further enhance the reliability of smart manometers.

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