

THE ASPECTS OF CONSTRUCTION AND TECHNOLOGICAL PROBLEMS OF PORTABLE PRESSURE CALIBRATORS

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Abstract - The paper deals with constructional and technological problems connected with designing portable microprocessor-based calibrators for pressure and derived quantities. Microprocessor-based pressure calibrators, with accuracy of 0.05% FSO, designed within a dedicated project at Industrial Research Institute for Automation and Measurements are presented as an example. The discussed device is designated for calibration of pressure transducers directly on an industrial site, as well as for laboratory tests and measurements.

Keywords: pressure sensor, portable calibrators, pressure calibrators

1. INTRODUCTION

Measurements, especially carried out by means of devices working as control elements of technological lines, must be accurate and reliable. The measurement accuracy and reliability at an appropriate high level should be ensured by periodical calibration of used measurement devices, in general, according to a quality management system applied by the user such as ISO, HACCP (Hazardous Analysis Critical Control Point) or GMP Good Manufacture Practice, etc.) [3, 7].

According to the set of definitions [8], the calibration procedure is understood as a set of operations determining, in defined conditions, the relationship between measured values shown by a measurement device or system and respective values realized by measurement standards [1].

Adequate control and measurement equipment is necessary to carry out the calibration correctly. Instruments used for calibration should have much better metrological parameters than devices, which are to be calibrated. In general, it is assumed, that a standard (reference) device should ensure a measurement inaccuracy 3÷5 times lower than the device being tested [8, 9].

In recent years, new solutions for secondary pressure standards have been introduced which take advantage of modern sensor and microprocessor technologies and thus allow to design considerably miniaturized calibrators maintaining at the same time a high accuracy. Moreover, the introduction of new generation electronic circuits allows equipping these calibrators with a range of useful functions.

Constructional and technological problems connected with designing of portable microprocessor-based pressure calibrators are presented in the paper. Furthermore, design and technology of microprocessor-based pressure calibrators developed at Industrial Research Institute for Automation and Measurements PIAP, (Warsaw), as well as respective test results, are presented as an example [3].

2. REQUIREMENTS FOR PRESSURE CALIBRATORS

The main function of calibrators is measurement of characteristics of the tested or calibrated transducer with appropriate accuracy. In the case of pressure calibrators, these are concurrent measurements of pressure (transducer input signal) and electrical signal (transducer output signal), while the required calibrator accuracy currently should not be lower than 0.05% of the measuring range.

A pressure calibrator, to be attractive for the user, should:

- enable measurements with adequately high accuracy,
- enable use in any place of an industrial site while maintaining all its metrological features,
- integrate many measurement and computational functions in a single instrument,
- be user friendly,
- be offered at an affordable price.

A simplified structure of a microprocessor-based pressure calibrator is shown in Fig. 1. The diagram from Fig.1 consists of the following blocks:

- a) a sensor blocks:
 - a pressure sensor, which is used as a standard during external pressure measurement,
 - a temperature sensor for reference temperature measurement, which is used for temperature compensation,
- b) electrical signal measurement block,
- c) microprocessor system realizing control functions, compensation of additional pressure sensor errors and input/output functions (display, internal memory for storage of user data);
- d) output/input blocks.

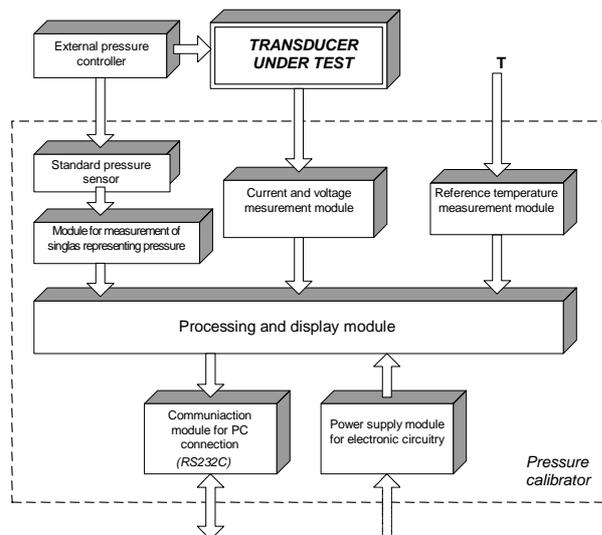


Fig. 1. Structure of a microprocessor-based pressure calibrator structure - general diagram

3. PRESSURE SENSORS FOR APPLICATION IN PRESSURE CALIBRATORS

The pressure sensor block is the main module of the calibrator structure, which in connection with pressure sensor non-linearity and temperature compensation procedures determines the instrument accuracy.

3.1. Selection of pressure sensor

One of the goals of carried out works was to develop such design and technology of a calibrator, which would enable the use of commonly available pressure sensors with average metrological parameters. Currently, piezoresistive sensors are most often used in pressure measurement technique. The main features of these sensors are:

- a wide measurement range (from 10 kPa to 30 MPa),
- long life and high parameters stability,
- relatively high accuracy,
- small overall dimensions,
- low power consumption,
- easy access to high quality measuring amplifiers adapted to work with sensors of this type,
- relatively low price.

Protection of silicon sensor structure against measurement environment is required to enable operational use of a calibrator in any part of installation regardless of the measurement medium.

Pressure, differential pressure and derived quantities sensors designed for operation in difficult conditions are provided with hermetic housings. An example of a hermetic housing of the pressure sensor is shown in Fig. 2.

The housing and membranes are made of stainless steel. Separating membranes are mounted using electron beam welding. Thin separating membranes can be coated with protective materials, such as Teflon

or titanium nitride, to obtain higher resistance against aggressive media and longer lifetime.

The measured signal (pressure, differential pressure) is applied to the separating membranes, then passed to the sensor structure by silicone oil, which is encapsulated in the sensor head.

The basic requirements that should be fulfilled by pressure sensors for application in accurate measurement instruments are: a small non-linearity error and a high long-term stability of parameters. Leading manufacturers of sensor heads with analog output obtain errors of the basic measurement characteristic on the level $0.1 \div 0.2\%$ FSO, which imposes the necessity of additional parameter improvement by conditioning of sensor signals in a programmable microprocessor-based calibrator system.



Fig. 2. Design of a sensor housing with a separating membrane

3.2. Compensation of errors in sensors for accurate calibrators

Most of the measurement sensors and measurement instruments based on them require a compensation of additional errors, because, without such procedure, errors exceed values expected by users.

The methods of sensor parameters compensation can be generally divided into two groups: analog and digital. In the case of accurate microprocessor-based measurement instruments, both compensation methods can be used. The methods of analog compensation have been known and used for many years. In many cases, the analog compensation is carried out by sensor producer during the manufacturing process. This consists of introducing an external thick-film passive compensating resistors to the sensor bridge circuit. Values of individual resistors are selected individually for each sensor during the testing process performed by the manufacturer. Precise values of resistors are achieved by laser trimming. A more detailed description of analog compensation is presented in [10-14]. As next in the sequence, additional compensation is carried out in which numerical methods are applied. The second method, digital compensation, can use various algorithms. One of them is the straight-line segment approximation of calibration characteristics. A detailed description of numerical algorithms is presented in [6].

The efficiency of the compensation algorithm depends on the number of calibration points. The accuracy of output signal approximation to the real value of measured quantity increases with the number of measurement points, however the following problems should be taken into account:

- a) tests, which last for a longer time, significantly increase the price of an instrument,
- b) a large instrument memory is necessary to store many measurement points, which can pose a design and economic problem especially in the case of portable instruments,
- c) an increased time of signal processing in a calibrator during a measurement (time necessary to make corrections) can cause such slow-down of the instrument that the time between one measurement and displaying its result can exceed limits accepted by users (the delay becomes noticeable).

For example, the static characteristics of the pressure sensor used in the calibrator in comparison with calibrator characteristics after the linearization procedure (when 10-segment straight-line approximation was applied) is shown in Fig. 3.

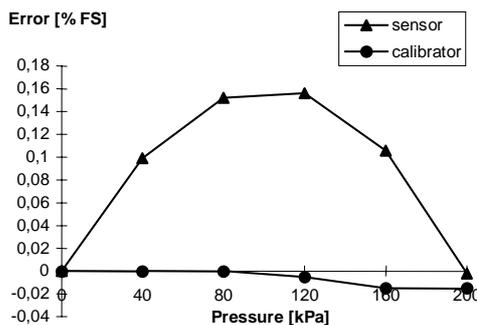


Fig. 3. Static characteristics of the (standard) pressure sensor used in the calibrator in comparison with calibrator characteristics after the linearization procedure

4. INSTRUMENT MINIATURIZATION PROBLEMS

Studies concerning the optimization of industrial installation servicing costs, encompassing maintenance of transducers installed in automation systems, justify the use of portable calibrators, which enable in situ verification or calibration of transducers [1, 5]. Ensuring sufficient calibrator resistance to various ambient conditions imposes high requirements also on calibrator housing. In almost all industrial applications, calibrator circuitry must be protected against dissipated electromagnetic field, which is one of significant external factors limiting instrument accuracy.

Selection of the optimal housing for a calibrator is closely related to instrument design and technology. In case of calibrators, critical elements are pressure sensors and microprocessor-based electronic circuits.

Selection of housing design and material is a difficult compromise task and requires consideration of following aspects:

- circuitry shielding against electromagnetic interferences,
- reduction of level of interferences emitted by the circuitry into the environment,
- ensuring tightness and mechanical strength,
- ergonomics,
- achieving a sufficiently low price. [3].

5. POWER SOURCES FOR PORTABLE MEASUREMENT INSTRUMENTS

In the case of portable instruments, one of the key problems to be solved is power source selection.

A good power source for portable measurement equipment should be characterized by following main features:

- low weight,
- long life time,
- high capacity,
- low temperature dependency,
- environmental friendliness,
- low price.

Generally, power sources can be divided into two basic groups:

- non-rechargeable cells,
- rechargeable cells (accumulators).

Most of the above mentioned requirements are fulfilled by NiMH batteries that owing to relatively small dimensions and a high capacity are an optimal power source for portable equipment. A big advantage of these batteries is that they do not contain heavy metals that pollute the natural environment [2]. On other hand, a disadvantage of the discussed batteries is temperature dependency of cell parameters [7].

6. FUNCTIONS OF PRESSURE CALIBRATORS

Owing to a big diversification of customers, it is difficult to define an optimal set of functions, with which a pressure calibrator should be equipped. Because of this, the best solution is to introduce a modular architecture of the calibrator. Such an approach enables adapting the instrument both to metrological needs and the budget of a specific customer.

A significant advantage of portable calibrators should consist in a user-friendly operation and protection against accidental damages.

The calibrator quality will be determined by following features and functions:

- a large display,
- legible alphanumerical characters,
- easy read out in rooms with poor illumination,
- a legible keyboard,

- functions facilitating carrying out specific procedures e.g. in situ calibration of a transducer,
- possibility of measurements in a wide pressure range (multi-range instrument),
- a pressure sensor overload indicator (preferably acoustic one),
- battery low indicator,
- optimally selected housing, meeting simultaneously requirements of high resistance to mechanical shock, small dimensions and weight, as well as (what is substantial) a low price. Meeting all these requirements simultaneously is difficult, because in general they are mutually inconsistent.

7. MODEL OF THE PC-01 PORTABLE HIGH ACCURACY PRESSURE CALIBRATOR

As an example there is presented the microprocessor-based calibrator with accuracy not worse than 0.05% of pressure measurement range. Typical, commercially available and relatively inexpensive pressure sensors were used in this project. The accuracy class has been achieved by application of adequate methods of pressure sensor errors compensation.

A typical version of piezoresistive silicon sensors from Lucas Co. was used in the discussed calibrators. The sensors selected for application in the calibrator feature low non-linearity errors, precompensated in the temperature range 0÷70°C. The final compensation of temperature influence on zero signal and range span is carried out by a microprocessor circuit using programmable compensation coefficients, that were determined basing on measurements during calibration of the calibrator. Each specimen of calibrators was equipped with two sensors with ranges 200 and 700 kPa.

The module that carried out measurements of signals representing pressure consists of a pressure sensor signal conditioning circuit, an analog multiplexer and an analog/digital converter (A/D).

The conditioning circuit amplifies the sensor signal (0÷100 mV) to obtain a full range of the A/D converter. The analog multiplexer feeds the signal from the sensor selected by calibrator control circuitry into the A/D converter. The system is equipped with a 24-bit A/D converter.

The first step of software linearization of sensor characteristics consists of a primary calibration of the calibrator readout (inaccuracy of standard pressure measurement 0.01%). The characteristics are usually calibrated at room temperature 20±2°C. A 10-segment straight-line approximation was applied for the characteristics in the solution presented further on. The obtained linearity error of pressure measurement characteristics is contained in limits of 0.02% for the 200 kPa range and 0.03% for the 700 kPa range.

However for the purposes of algorithmical compensation of temperature influence, interpolation nodes of correction characteristics are introduced for 4 different temperatures (5, 30, 40, and 50°C), for which 2-segment straight-line approximation was applied. Calibrator temperature monitoring for calibration purposes is realized by an internal temperature sensor that is included in the calibrator measurement system. Additionally, the readout from temperature sensor can be displayed as an independent measurement of calibrator ambient temperature. Tests and calibration of the calibrator were carried out using an automated stand for calibrator rating.

Test results (expected and obtained) for a specimen lot consisting of 5 instruments are presented in Table I.

TABLE I. Test results for the specimen of pressure calibrator (maximal values for the lot consisting of 5 instruments and both measurement ranges)

Parameter	Unit	Assumed value	Obtained value
Pressure measurement range	kPa	0...200 0...700	0...200 0...700
Current signal measurement range	mA	0...20	0...20
Voltage signal measurement range	V	0...10	0...10
Working temperature range	°C	5...50	5...50
Pressure readout intrinsic error	% of measurement range	0.05	0.04
Current readout intrinsic error	% of measurement range	0.015	0.008
Voltage readout intrinsic error	% of measurement range	0.015	0.005
Temperature error of pressure readout	%/°C	0.01	0.0075
Temperature error of current readout	%/°C	0.0015	0.0015
Temperature error of voltage readout	%/°C	0.0015	0.001

Results obtained at the Central Office of Measures (GUM) during verification of tests carried out in Laboratory of Industrial Research Institute for Automation and Measurements were used to evaluate readout uncertainty of PC-01 pressure calibrator [4]. Basing on these tests, it was found that the distribution of pressure readout is a normal one and the determined maximal values of the extended uncertainty (U) amount to:

- $U = 0.02$ kPa for the measurement range 0÷200 kPa,
- $U = 0.04$ kPa for the measurement range 0÷700 kPa, respectively, at confidence level 95% and for expansion coefficient $k = 2$ [9].

SUMMARY

1. Constructional and technological problems connected with designing portable microprocessor-based pressure calibrators were presented in the paper. The description of microprocessor-based calibrator design and the compensation method used in this instrument were presented as an example. Further, results of test carried out on a calibrator prototype were presented.
2. The calibration method presented in this paper allows obtaining instrument accuracy on the level 0.05% of measurement range (with the use of commonly available piezoresistive pressure sensors with average parameters).
3. During work, special attention was paid to calibrator design optimization with the objective to maximize instrument functionality.
4. This paper also contains a set of procedures, which enable to perform correctly a pressure sensor directly on an industrial site or installation, even for persons who are not well familiar with this subject.

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