Influence function as a metrological characteristic of the digital pressure meter

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Abstract. The influence of external factors and uninformative parameters of the input signal on the measurement results was evaluated. The main metrological characteristics of the digital pressure meter IDC-2-Micro are given and the design features of the pressure measurement system are described in its example. The principle of operation of a strain-resistant pressure sensor is considered. As a result of their deformation, the output voltage of the bridge is generated, which is proportional to the measured pressure. External factors that have the maximum impact on the metrological characteristics of the pressure meter were selected and the limits of their values were set. 8 factors were identified: ambient air temperature and the measured medium, changes in operating overpressure, ambient humidity, vibrations, frequency of the supply voltage and fluctuations in its values, the presence of an external electromagnetic field. A plan for a factor experiment to evaluate the influence function has been developed. When studying the influence of various factors, including their pair interactions, on the parameter under study using the random balance method, a type of regression equation is proposed. When studying the influence of various factors, including their paired interactions, on the parameter under study, the method of random balance was used.

1. Introduction
In modern conditions, it is important to obtain reliable measurement information about the value of the measured physical quantities for the science and technology development. Decisions about the suitability of products and technological processes, the quality of production management, the quantity and quality of materials, and other resources used are made based on measurement information analysis.

Pressure and flow measurement instruments are widely used in the modern industry. They are part of the measurement and control tools for many technological processes in mechanical engineering, heat and electricity, gas and oil production, food processing, and other areas.

It is necessary to determine the metrological characteristics of the measuring instruments used to ensure the reliability of the received measurement information. In this case, the input measured value is evaluated, as well as the influence of external factors and uninformative parameters of the input value on the measurement results. The results of this assessment are presented as an influence function [1-7].

The aim of the work is to evaluate the influence of external factors and uninformative parameters of the input value on the results of pressure measurement represented as an influence function.

2. Methods of study
The input measured value in pressure measurement and control devices affects the sensor's sensitive element, which converts it into a form that is convenient for processing, further conversion, or
transmission in accordance with the requirements of the measurement or control system [8-17]. It is usually an electrical signal (figure 1).

![Figure 1. General view of the measuring system](image1)

The digital pressure meter IDC-2-Micro produced by the group of companies "Teplopribor" (Moscow) is one of the modern measuring instruments. This is an exemplary (accuracy class 0.05) digital strain gauge multi-limit pressure meter (overpressure of compressed air, pressure difference, and used as a reference measurement tool for checking pressure sensors). It is used in testing and measuring laboratories, metrological services, and repair shops (figure 2). The power supply of the device is provided from a 220 V or an autonomous source with a voltage of 8-9 V, so the device can be used not only in laboratory conditions but also directly on the measurement object [18].

![Figure 2. General view of digital pressure meters](image2)

The strain effect phenomenon, which consists of changing the electrical resistance of conductors under the action of their deformation, is used to convert the pressure in the IDC-2-Micro device. The sensor's elastic element is deformed when the measured pressure is applied to it, which leads to a change in the electrical resistance of the strain gages included in the bridge circuit. The output signal of the bridge circuit is converted and amplified to form a unified analog output signal (4-20 mA) or digital type HART, FOUNDATION Fieldbus (figure 3).
The operation of the pressure sensor (figure 4) is based on the fact that the differential pressure is transmitted through the process connection to the silicon sensor. The diaphragm bends and deforms four strain gauges under the influence of the input pressure. The proportional to the input pressure voltage is generated at the output of the bridge as a result of changing the resistance.

The metrological characteristics of pressure meters include uninformative parameters of the output signal because they can have a significant impact on the error of the measuring instrument. These are temperature, external electromagnetic field, voltage fluctuations in the power supply network, thermoelectric power, and spurious electrical voltages.

3 Results and Discussion
The measuring instrument has some effect on the input signal source when the measured value is perceived. The result of this action may be a change in the measured value relative to its actual value.

The influence of external influences and uninformative parameters of the input value is described using metrological characteristics called influence functions. These are functions of the form \( \Psi(\xi_1, \xi_2, \ldots, \xi_q) \), that describe the dependence of the corresponding metrological characteristic on external influencing quantities (temperature, pressure, vibration, etc.). The influence function is usually expressed as an additional error that occurs when a certain value of the factor parameter is reached. Conditionally, the additional error as a function of influence can be divided into two types. The first is a multiplicative error, characterized by a change in the conversion coefficient under the influence of an influencing quantity. The second type is an additive error when the conversion coefficient is constant [19].
Taking into account the high requirements for the accuracy of reference measuring instruments and the design features of the pressure meter, the impact of external factors on the metrological characteristics of such measuring instruments was evaluated. The factors, which have a maximum effect on the output value were selected using an expert and experimental method. The selection criterion was a change of more than 20% of the value normalized for normal measurement conditions. The factors to be assessed were classified into various groups – mechanical, climatic, and electrical. As a result of the selection, 8 factors were identified: ambient air temperature and the measured environment; changes in operating overpressure; environment humidity; vibrations; frequency of the supply voltage; voltage fluctuations in the power supply network; the presence of an external electromagnetic field.

For a measuring instrument with a linear transformation function, the influence function can be represented by a polynomial of the first degree. Therefore, as a result of the experiment, the influence function must be established in the form of an equation:

\[
\Delta = a_1 x_1 + a_2 x_2 + \ldots + a_n x_n + c,
\]

where \(\Delta\) – error of measurement instrument readings;

\(a_1, a_2, \ldots, a_n\) – influence coefficients;

\(x_1, x_2, \ldots, x_n\) – values of influencing factors;

\(c\) – the free term of the equation (\(c=\text{const}\)).

Evaluation of influence functions is performed separately for each influencing quantity. Influence functions are evaluated when the influencing variables change together if the influence function of one value significantly depends on other influencing variables.

Parameters of external influencing factors when using the IDC-2-Micro device as a reference measurement tool should be within the following limits: ambient temperature \((23\pm2) ^\circ\text{C}\); relative humidity from 30 to 80 %; atmospheric pressure from 84 to 106,7 kPa; no vibration, shaking, or bumps that affect the operation of the device; there should be no fluctuations in the supply voltage; there should be no fluctuations in the frequency of the supply voltage; external electric and magnetic fields must be absent; supply air pressure \((140\pm2,8) \text{kPa}\).

When determining the influence of changes in external factors [2] on the device readings, the boundaries of the studied area of their values are selected slightly wider than their acceptable range. Since the influence function should reflect not only ordinary changes in metrological characteristics but also the general trend of changes in metrological reliability of the measuring instrument and the reliability of the obtained measurement results, real deviations of measurement conditions, including those close to extreme ones, should be taken into account. Thus, the following limits are set for the values of influencing factors (table 1).

**Table 1. Values of influence quantities**

| Affecting factors | Identification factors | Limiting value factors |
|-------------------|-----------------------|-----------------------|
| 1. Ambient temperature, °C | x₁ | +19 | +27 |
| 2. Relative humidity, % | x₂ | 27 | 85 |
| 3. Atmospheric pressure, kPa | x₃ | 80 | 106,7 |
| 4. Vibration velocity, m/s, at Mains frequency 30 Hz | x₄ | 1 | 60 |
| 5. Electrical power supply voltage, V | x₅ | 210 | 230 |
| 6. Mains frequency, Hz | x₆ | 45 | 55 |
| 7. The amplitude of the potential stress variable magnetic field at Mains frequency of up to 400 Hz, A/m | x₇ | 0,08 | 80 |
| 8. Process temperature, °C | x₈ | +10 | +38 |
The full factorial experiment (FFE) according to plan $2^8$ would have included 256 single experiments [3]. As a rule, significant errors of the measuring instrument are observed in the area of boundary values of influencing factors. Therefore, the main focus is on conditions with factors’ values limits. The experimental plan of a complete factor experiment, where each of the factors varies on two levels, should include $N = n + 1 + C_n^2$ experiments, where $n$ is the number of factors, $C_n^2$ is the number of combinations of elements from $n$ to 2. In this case, the required number of experiments would be 37. Each experiment should be repeated 4 times to increase the results reliability.

The factors are included in consideration of paired interactions were determined by the experts’ opinions. As a result, the approximating dependence considers the paired effects of factors: 1-8; 2-3; 4-5; 4-6; 5-6; 5-7.

When taking into account the influence of paired interactions of various factors on the parameter under study, the regression equation has the form of an equation:

$$y = \sum_{j=1}^{4} a_j x_j + \sum_{i,j} a_{ij} x_i x_j + c$$

(2)

It is necessary to conduct a screening experiment for uncomplication the mathematical model and facilitation its analysis. The method of random balance is used for screening experiment implementation. The random balance method’s idea is that there are not the whole FFE is implemented, but only its random selection. The planning matrix is compiled by randomly distributing factor levels across columns or randomly mixing fractional replicas of the FFE, taking into account the correlation between its columns.

When constructing the experiment plan, the entire list of factors ($x_1,\ldots, x_8$) was divided into 2 groups, which contain 4 factors each. Factors were selected in groups so that in one group there were those factors that are known in advance that they have synergy. The planning matrix was created based on a full or fractional factor experiment for each group. Both group planning matrices had the same number of rows so that they could be docked. The number of $N$ rows of each group matrix satisfied condition $2^4$. Group planning matrices are shown in table 2.

| Part number | Level of experimentation factor |
|-------------|---------------------------------|
|             | $x_1$  | $x_2$  | $x_3$  | $x_8$  |
| 1           | –      | –      | –      | –      |
| 2           | +      | –      | –      | –      |
| 3           | –      | +      | –      | –      |
| 4           | –      | –      | +      | +      |
| 5           | –      | –      | +      | –      |
| 6           | +      | –      | +      | –      |
| 7           | –      | +      | +      | –      |
| 8           | +      | +      | +      | –      |
| 9           | –      | –      | –      | +      |
| 10          | +      | –      | +      | –      |
| 11          | –      | +      | –      | +      |
| 12          | +      | +      | –      | +      |
| 13          | –      | –      | +      | –      |
| 14          | +      | –      | +      | +      |
| 15          | –      | +      | +      | +      |
| 16          | +      | +      | +      | +      |

The second group which is planned similar to the first included factors $x_4$, $x_5$, $x_6$, $x_7$. Based on this auxiliary plan, we made a combined plan for both groups, forming rows of group auxiliary plans randomly based on a table of random numbers. The combined planning matrix also includes rows with previously set paired factor impacts.
When selecting measuring instruments (registration) of influencing factors [4], their measurement range and the maximum permissible error should be taken into account as well as the sensitivity to changes in the measured value and speed.

The subject of further research will be the implementation of the plan for a complete factorial experiment and obtaining the desired dependence equation (2).

4. Conclusions
The factors of influence of external sources on the metrological characteristics of a digital pressure meter are determined and the influencing factors' values limits are set based on expert and experimental analysis methods.

The experimental plan for a full factorial experiment to evaluate the influence function is presented. The regression equation is compiled using the random balance method.

References
[1] GOST 8.395-80 State system for ensuring the uniformity of measurements. Reference conditions of measurements while calibrating. General requirements (Moscow: Standardinform) 2008.
[2] RMG 121-2013 State system for ensuring the uniformity of measurements. The order of testing procedure for measuring instruments for type approval (Moscow: Standardinform) 2015.
[3] GOST 8.508-84 State system for ensuring the uniformity of measurements. Metrological characteristics of measurement means and precision characteristics of automation means. General methods of estimate and control (Moscow: IPC Publishing House of Standards) 2002.
[4] GOST R 8.673-2009. State System for Ensuring the Uniformity of Measurements. Intelligent Sensors and Intelligent Measuring Systems. Basic Terms and Definitions (Moscow: Standartinform) 2010.
[5] Rajadurai M, Saseendran S and Prasad B.V.S.S.S. 2010 15th International Flow Measurement Conference 2010, FLOMEKO pp. 667-678.
[6] Gejji R, Walters I, Beard S, Lemcherfi A, Sardeshmukh S, Heister S and Slabaugh C 2018 AIAA Aerospace Sciences Meeting 0158.
[7] Yu Z, Jing Z, Hong-yan Z and Dong-xing P 2011 International Conference on Mechatronic Science, Electric Engineering and Computer (MEC) Mechatronic Science, Electric Engineering and Computer (MEC) 1403-06.
[8] Baranov V A, Myasnikova M G, Pecherskaya E A, Pushkareva A V and Cypin B V 2020 JOP Conference Series: Metrological Support of Innovative Technologies 1515 052024.
[9] Shevchenko V, Skatkov A, Bryukhovetskiy A, Chengar O and Kokodey T. 2020 JOP Conference Series 1515 022039.
[10] Mukolyants A A, Buranov M D, Sotnikova I V and Makhmudov H F 2020 JOP Conference Series: Metrological Support of Innovative Technologies 1515 022053.
[11] Possolo A and Pintar A 2017 Metrologia 54 5 617-32.
[12] Possolo A, Merkatas C and Bodnar O Metrologia 56 4 045009.
[13] Montoro Bustos A, Purushotham K, Possolo A, Murphy K and Winchester M 2018 Analytical Chemistry 90 24 14376-86.
[14] Possolo A 2020 Analytical and bioanalytical chemistry 412 17 3955-56.
[15] Possolo A 2020 13th International Workshop on Intelligent Statistical Quality Control 2019, IWISQC - Proceedings.
[16] Li Y, Yang Y, Wang J and Sun J 2015 Metrologia 52 1 111-20.
[17] Wübbeler G, Bodnar O, Mickan B and Elster C 2015 Metrologia 52 2 400-06.
[18] Shirono K and Cox M 2019 Metrologia 56 4 045001.
[19] Operations manual. Digital pressure-measuring device IDC-2.
[20] Koshlyakova I G, Sosin A V 2016 Development of modern science: theoretical and applied aspects. Perm. 22-25.