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The Impact of the Parameters of Constructing a Model for a Microprocessor-Based Sensor's Multi-Segment Spatial Conversion Characteristics on the Accuracy of Measuring Physical Quantities

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Abstract: This work proposes a model for the multi-segment spatial conversion characteristics of microprocessor-based sensors for performing measurement of physical quantities. The model is a system of local linear and non-linear spatial elements called segments. Each segment can be defined by its function. Segments on the division border of their definition do not stitch together and can overlap. The author has assessed the impact of the parameters of constructing the model on the accuracy of calculating a physical quantity and defined recommendations on controlling errors in processing data in microprocessor-based sensors through modifying the model's spatial configuration.

Key words: Model · Microprocessor-based sensor · Conversion characteristics · Physical quantity · Accuracy of measurement

INTRODUCTION

Boosting the accuracy and credibility of determining the values of physical quantities, such as pressure, temperature, etc., is one of the most important objectives in streamlining mathematical and algorithmic methods of processing measurement results in microprocessor-based sensors. Resolving this objective in large part defines the degree of the reliability and security of the operation of complex technical objects and industrial manufactures.

Microprocessor-based sensors for physical quantities have been in wide use in monitoring and technical object diagnostics systems. For processing data coming from primary measuring converters, different models for conversion characteristics are used in microprocessor-based sensors[1-9].

In these[1, 2, 3, 4] models, we use the linearization of the sensor's conversion characteristics, which is effected, mainly, through piecewise linear approximation[1, 2, 4]. The method helps to substantially reduce non-linearity errors and attain quite a low temperature error (0.1%/100°C [2]).Using a polynomial-type conversion function for the primary measuring converter[5, 6] helps obtain higher accuracy indicators compared with piece wise linear approximation, but we need a considerable amount of sampled experimental points for constructing conversion characteristics(for instance, in work [5] there are over 10000 experimental points), which places limitations on using the model in practice. Also, for compensating non-linearity and the impact of external factors, mainly temperature, on calculation results, we use characteristics approximation using splines [7, 8] and neural networks [9].

Characteristic of most of the models above is the use of a single representation of conversion characteristics across the entire domain of changes in quantities measured and external impacting factors (the gauge characteristics definition domain). This approach has sure advantages, such as, for instance, the simplicity and speed of processing. However, if there is substantial non-linearity and dependence on external factors, it does not ensure allow and quantity-wise comparable error across all of the points of the definition domain. It also should be noted that there is a lack or absence of means of configuring and adapting calculation accuracy control models in the process of measuring physical quantities.

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The Multi-segment Spatial Conversion Characteristics of Microprocessor-Based Sensors: For control of errors in processing data in microprocessor-based sensors in measuring physical quantities, we propose using a model for spatial multi-segment conversion characteristics(SMCC) [10, 11, 12, 13]. The model is a system of linear and non-linear spatial elements called segments. The spatial segment system maximally accurately repeats the spatial form of the conversion function for the primary measuring converter inclusive of non-linearity, zero drift and the impact of external factors. Each segment can be defined by its function, while these functions can differ in type. For instance, some segments are described with linear and some by non-linear (polynomials) expressions. Segments on the border of division of their definition domains do not stitch together. We can also have a variant of the model where segment definition domains and, consequently, the segments themselves partially overlap. The spatial configuration of the segments' edges on the borders of their definition domains or overlap domains should ensure the attainment of set conversion characteristic approximation errors when choosing any of the segments during the process of performing measurements.

The model is aimed at attaining the sensor's set spatial characteristic approximation errors in all ranges of measuring physical quantities and change in impacting factors and is in line with requirements for the acceptable calculation complexity level. Using the model's characteristics, we can control approximation errors depending on tasks the sensor will be working on.

Our spatial model for the conversion characteristics of microprocessor-based sensors for converting physical quantities, for instance pressure sensors, can, inclusive of the impact of external factors, be generally represented as:

$$P = S(U_P, U_{f_1}, U_{f_2} ..., U_{f_N}, \Omega^{(v)}_{\alpha\beta^{(1)}\beta^{(2)}...\beta^{(N)}}, F^{(v)}_{\alpha\beta^{(1)}\beta^{(2)}...\beta^{(N)}}, \Psi^{(v)}_{\alpha\beta^{(1)}\beta^{(2)}...\beta^{(N)}}, \varepsilon_p) \quad (1)$$

where S is some ratio which helps define the value of pressure P based on the values of the electrical signals of pressure measurement channels and external factors using a conversion characteristics segment that corresponds to these signals; P is the value of measured pressure, $P \in \bar{P} = (P_{\min}, P_{\max})$; $\bar{P} = (P_{\min}, P_{\max})$ is the range of measured values of pressure, P_{min}, P^{max} are the minimum and maximum values of the pressure change range; U_p is the value of the electric signal recorded at the output of the measurement pressure channel in the intellectual sensor's analog part (hereinafter "sensor pressure channel"), $U_P \in \bar{U}_p = (U_{p\min}, U_{p\max})$; $\bar{U}_p = (U_{p\min}, U_{p\max})$ is the range of changes in the values of the electric signal of the pressure channel when there is change in pressure and external factors within the limits of ranges set, U_{pmin}, U_{pmax} are the minimum and maximum values of the signal; Uf_1, Uf_2,...,N_{fN} are the values of electric signals recorded at the output of the impacting factor channels f_1, f_2,...,f_N (hereinafter "impacting factor channels"), $U_{f_n} \in \bar{U}_{f_n} = (U_{f_n \min}, U_{f_n \max}), n = 1,..., N$; $\bar{U}_{f_n} = (U_{f_n \min}, U_{f_n \max})$ is the range of changes in the values of the electric signal often – impacting factor channel, U_{fnmin}, U_{fnmax} are the minimum and maximum values of the signal; $\alpha\beta^{(1)}\beta^{(2)}...\beta^{(n)}...\beta^{(N)}$ is the numeric code identifying some conversion characteristics segment, $\Omega^{(v)}_{\alpha\beta^{(1)}\beta^{(2)}...\beta^{(N)}} = \bar{U}_{P,\alpha} \cup \bar{U}_{f_1\beta^{(1)}} \cup \bar{U}_{f_2\beta^{(2)}} \cup ... \cup \bar{U}_{f_n\beta^{(n)}} \cup ... \cup \bar{U}_{f_N\beta^{(N)}}$ is the definition domain of the $\alpha\beta^{(1)}\beta^{(2)}...\beta^{(n)}...\beta^{(N)}$-th characteristics segment, $\bar{U}_{P\alpha}$ is the interval of changes in the pressure channel signal, which corresponds to the definition domain of the $\alpha\beta^{(1)}\beta^{(2)}...\beta^{(n)}...\beta^{(N)}$-the segment, $\bar{U}_{P\alpha} \in \bar{U}_p$, $\bar{U}_{P\alpha} = [U_{P,\alpha-1}, U_{P,\alpha}]$, α is the number of the interval, $\alpha = 1,...,L_p$; $U_{P,\alpha-1}$, $U_{P,\alpha}$ are the top and bottom limits of the interval $\bar{U}_{P\alpha}$; $\bar{U}_{f_n,\beta^{(n)}}$ is the interval of changes in the values of the f_n-the impacting channel signal, which corresponds to the definition domain of the $\alpha\beta^{(1)}\beta^{(2)}...\beta^{(n)}...\beta^{(N)}$-the segment, $\bar{U}_{f_n,\beta^{(n)}} \in \bar{U}_{f_n}$, $\bar{U}_{f_n,\beta^{(n)}} = [U_{f_n,\beta^{(n)}-1}, U_{f_n,\beta^{(n)}}]$, $\beta^{(n)}$ is the number of the interval $\beta^{(n)}$, = 1,..., L_n, $n=1,...,N$; U_{fn}, $\beta^{(n)}{}_{-1}$,U_{fn},$\beta^{(n)}$ are the top and bottom limits of the interval $\bar{U}_{f_n,\beta^{(n)}}$; $F^{(v)}_{\alpha\beta^{(1)}\beta^{(2)}...\beta^{(N)}}$ is the function approximating the $\alpha\beta^{(1)}\beta^{(2)}...\beta^{(n)}...\beta^{(N)}$-the conversion characteristics segment; $\Psi^{(v)}_{\alpha\beta^{(1)}\beta^{(2)}...\beta^{(N)}}$ is the array of the values of the coefficients of the approximation of the function $F^{(v)}_{\alpha\beta^{(1)}\beta^{(2)}...\beta^{(N)}}$ for the $\alpha\beta^{(1)}\beta^{(2)}...\beta^{(n)}...\beta^{(N)}$-the sensor conversion characteristics segment; $v$is the identifier of à version of the set of parameters of the conversion characteristics segment; ε_P is the maximum error in approximation of conversion characteristics in set ranges of a measured factor and changes in impacting factors.

For most physical quantity sensors, there is a dominating external factor which to the largest degree impacts measurement results. In this case, the model (1) is simplified [13]. The initial information for constructing the SMCC of microprocessor-based sensors is information on the behavior of the spatial conversion function of the sensor's primary measuring converter when it is subjected to the impact of a measured physical quantity and a most significant external impacting factor.

The assessment of the impact of the parameters of constructing an SMCC model on the accuracy of measuring physical quantities was conducted using data from testing microprocessor-based pressure sensors. The temperature of the environment was taken as an impacting factor.

The Impact of the Parameters of Constructing a Model for a Sensor's Multi-Segment Spatial Conversion Characteristics: The accuracy of measuring pressure using multi-segment spatial characteristics is impacted directly by the choice of the dimensions of spatial elements in the definition domain $P \times T$.

For assessing the impact of the dimensions of spatial elements on errors in calculating pressure values, let us use data from temperature tests on tensoresistor- type primary measuring converters.

The tests were conducted by the following scheme: the temperature changed from-40°C to +80°C with a step of 5°C; the pressure changed from 0 to 600 kPa with a step of 60 kPa; for each recorded temperature value, the pressure changed from the lower value to the upper limit and back. The number of pressure change cycles for a set temperature is 4.

For the sensor we constructed two versions of SMCC – based on linear (LSE) [10] and non-linear spatial elements (NSE) [11, 12, 13]. We examined the impact of the elements' sizes separately along the pressure and temperature axes. For assessing the impact of the sizes of LSE's and NSE's along the pressure axis on calculation accuracy we used a spatial multi-segment conversion characteristic constructed based on experimental points with a temperature step of 5°C for two variants of the pressure step, 300 kPa and 120 kPa. Points not used in calculating approximation coefficients were used for assessing errors in calculating pressure values, which makes it possible to assess the effectiveness of employing them in terms of calculation accuracy. The graphs for the maximum values of reduced errors in calculating pressure values using LSE's and NSE's with a pressure step of 120 kPa and 300 kPa, are provided in Figure 1.

The analysis of Figure 1 reveals that a 2.5 times reduction of the quantity of the local spatial element leads to a 1.7-1.8 times reduction of the error in calculating pressure values, as a result of which the maximum error in determining pressure using LSE's is 0.12% and LSE's – 0.1%.

We should keep in mind that with other sizes of spatial elements error reductions can be lower or higher than the values listed depending on the degree of non-linearity of areal spatial multi-segment conversion characteristic as part of formed local spatial elements.

For assessing the impact of the sizes of LSE's and NSE's along the temperature axis on calculation accuracy we used a spatial multi-segment conversion characteristic constructed based on experimental points with a pressure step of 60kPa for three variants of the temperature step, 20°C, 15°C and 10°C.

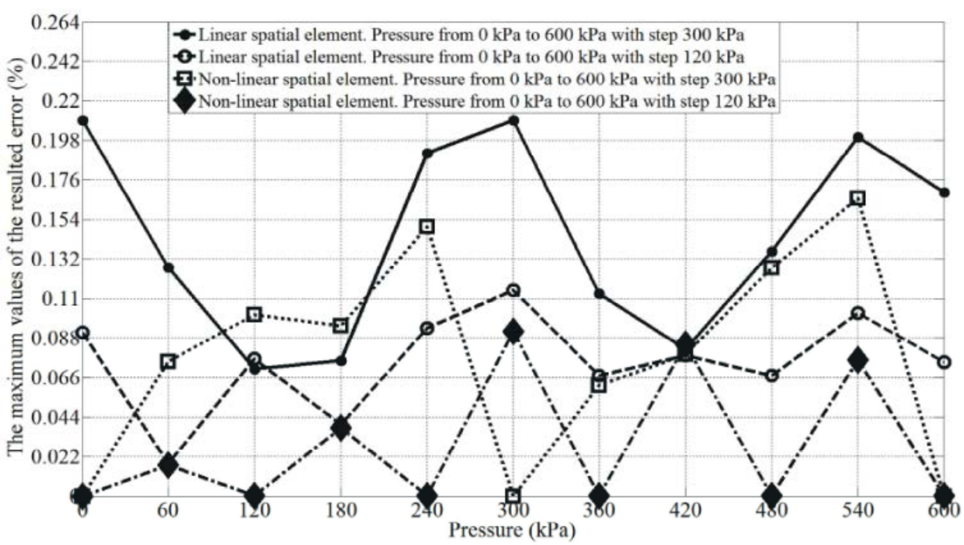

Fig. 1: The maximum values of reduced errors in calculating pressure values using LSE's and NSE's

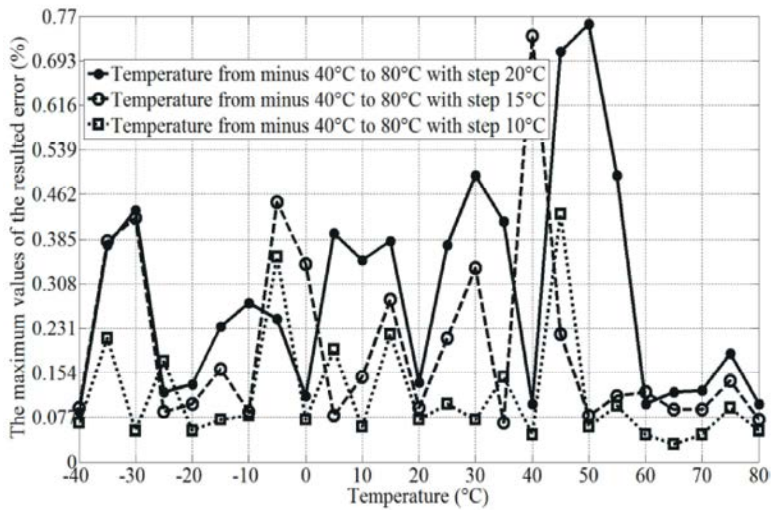

Fig. 2: The maximum values of reduced errors in calculating pressure values using LSE's

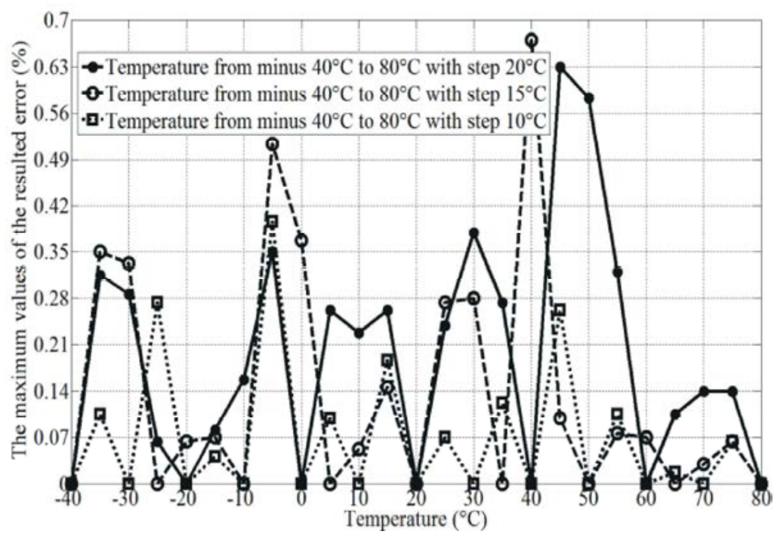

Fig. 3: The maximum values of reduced errors in calculating pressure values using NSE's

The maximum values of reduced errors in calculating pressure values using LSE's and NSE's are listed in Figures 2 and 3 respectively.

The analysis of results obtained shows that reducing the size of the local spatial element along the temperature axis has a greater impact in boosting the accuracy of pressure values calculations than analogous changes in the size of the spatial element along the pressure axis. Thus, with a decrease in the size of local spatialelements along the temperatureaxis from 20°C down to 10°C, we get a 1.7–1.8 times reduction in pressure values calculation errors; a decrease from 10°C down to 5°C even with large sizes of local spatial elements along the pressure axis leads to a 4 times reduction of errors.

CONCLUSION

The article formulates a summarized notion of the multi-segment spatial conversion characteristic for a microprocessor-based physical quantity sensor, which takes account of the impact of many external and internal factors on measurement accuracy.

We conducted an analysis of the impact of the constructive characteristics of implementing the SMCC model on calculation accuracy in microprocessor-based sensors in performing measurements. Two versions of SMCC models for pressure sensors were examined inclusive of the impact of one external factor. The versions were constructed based on linear and non-linear spatial elements. We performed a comparison of the models in terms of the impact on the accuracy of measuring the constructive dimensions of elements and defined ways of control, particularly ways of boosting measurement accuracy.

Inferences: The proposed model for multi-segment spatial conversion characteristics ensures high accuracy of approximating a sensor's real conversion characteristics [10, 11, 13]. Reduced relative pressure value measurement errors without taking account of the sensor's primary converter errors with the use of non-linear spatial elements as fundamental can be 0.03%-0.16% across the entire range of measuring physical variables and a set range of temperatures [13].

Approximation errors obtained in using SMCC with NSE's are much smaller compared with SMCC approximation errors based on LSE's.

The model is oriented towards control of the accuracy of measuring physical variables with compensation for the impact of external factors and short comings in real conversion characteristics. Such control can be administered through selecting the type and optimizing the dimensions of and schemes for arranging the segments until desired calculation accuracy is attained. Along with this, we get a minimized volume of experimental data needed for constructing a sensor's conversion characteristics and reduced costs related to calibration of microprocessor-based sensors.

The highest reduction in errors is attained in reducing segment dimensions in the SMCC definition domainaxis in the direction of which a sensor's real conversion characteristics, represented in the form of a surface, has the steepest curve.

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