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THE USAGE OF THE APPROXIMATE METHODS TO DETERMINE THE UNCERTAINTY OF RELATIVE HUMIDITY MEASUREMENT USED TO INTEGRATED HUMIDITY SENSORS

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Abstract: Results of experiments concerning humidity measurements have been presented in the paper. Integrated humidity sensors were used for the experiments, which transformed the value measured into a corresponding capacity. The structure of a measuring system was described, and the requirements concerning particular elements of the measuring track were defined. Using the regression method, an analytical equation was modeled, combining the output capacity value of the sensor with the examined humidity changes. With the use of experimental results as well as the least square method, the values for the above equation's parameters were determined. The knowledge of coverage factor characteristics for the convolution of four selected probability distributions was used for the research.

Keywords: humidity sensor, expanded uncertainty, coverage factor, probability distribution, standard solution.

1. INTRODUCTION

Beside temperature and pressure, humidity forms a set of parameters, which have a very relevant influence on many physical phenomena and technological processes. Hence the need to determine humidity.

Humidity changes have an influence on operational reliability and restrictions of elements and devices. Therefore, humidity measurement is an exceptionally important issue. Several main principles of humidity measurement may be distinguished. They have different applications and give information on different quantities expressing humidity.

The most important principles are as follows:

- removal of humidity from the air and the measuring of the quantity of water acquired in this way;
- balancing of water vapour contained in the air with the second phase, and the measurement of this state's parameters;
- observation of temperature decrease, caused by water evaporation from a moistened substance into the outside air;
- changes in mechanical or electrical parameters of solid, influenced by relative humidity of the outside air.

To determine the uncertainty of measurement result during the estimation of experimental results is a very relevant problem.

The estimation of expanded uncertainty of a measurement result is always an approximate estimation. When deciding about the method of expanded uncertainty estimation, one should be aware of the effects of choosing a particular method from the viewpoint of its accuracy. The basis for estimating the accuracy of applied approximate methods of the estimation of expanded uncertainty is the assumption on the necessity the assessment methods, which could be regarded as exact one. An essentially appropriate concept was adopted, which is taken into consideration, that the method based on the command of the convolution of probability distributions of errors of components may be regarded as an exact method. Due to complexity and time-consuming character of computing the convolution of many distributions of components, the results of such computing are, in general, hardly ever published. Therefore, approximate methods are generally accepted and recommended.

2. HUMIDITY SENSOR

Now, a large number of humidity sensors are produced, which vary in working rule, resistance to outer conditions, measurement range, or errors. It was the relative FE09/2 type of humidity sensor that went under examination in the present experiments. The structure of measuring circuit was described and the transformation characteristics of these sensors were determined.

FE 09/2 sensors consist of a system of electrodes covered with a semiconductor protecting layer, located on ceramic base. Their working is based on the rule of output capacity C change in the function of relative humidity RH. The basic parameters of these sensors are the following [1]:

- measuring range between 0 and 100% of relative humidity,
- working temperature - between – 60 $^{\circ}C$ and 200 $^{\circ}C$,
- basic capacity - (135 ± 10) pF,
- response time - 10 s,
- linearity < ±1.5% of relative humidity.

3. EXPERIMENTAL RESEARCH

The transformation characteristics of this sensor were determined on the measuring system shown in Fig.1.

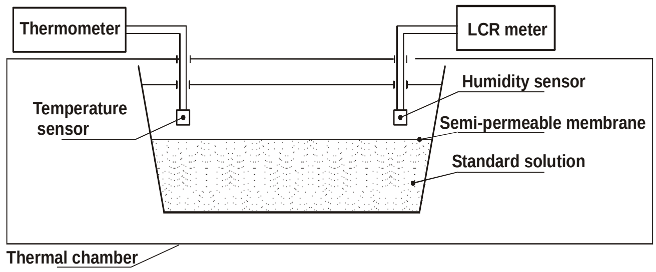

Fig. 1. Scheme of a measuring system designed to determine the transformation characteristics of humidity sensor

A calibrated sensor was put into a hermetically closed vessel in the environment of vapours of saturated standard solution. The vapours of this solution transpired into the field where the examined sensor was located through semi-permeable membrane. Depending on the kind of solution used for the experiment, appropriate value of relative humidity was acquired. Chlorides and bromide of different elements were used as standard solutions. For each solution relative humidity is defined in the function of temperature [2].

The measurement of sensor capacity *C*, dependent on humidity value *RH*, was performed with 4263B LCR digital meter. The temperature inside the vessel was measured with DTM 1010 digital thermometer. As sensor co-operating with the thermometer, a nickel-chromium thermo-element was used. A special thread connection between humidity and temperature sensors inside the vessel and the thermometer and the LCR meter prevents the exchange of temperature and humidity with the outside environment.

Statement of measuring results of capacity *C* in the function of relative humidity changes *RH*, for three sensors, performed in the system shown in Fig.1, was presented in Table 1 [3].

Table 1. Statement of measuring results concerning the determination of transformation characteristics of humidity sensors

standard solution	relative humidity	sensor 1 capacity	sensor 2 capacity	sensor 3 capacity
	%	pF	PF	pF
Lithium Chloride	12	137.0	138.0	138.0
Magnesium Chloride	33	142.0	143.0	142.0
Sodium Bromide	59	151.0	152.0	151.0
Sodium Chloride	75	155.0	156.0	155.0
Potassium Chloride	85	159.0	160.0	160.0

All the measurements were conducted at a temperature of $T = 25\ ^{\circ}C$.

There are many possibilities of presenting the experimental data of Table 1 by means of an equation illustrating relations of the values of measurement-based variables. When selecting the shape of empirical equation that presents the experimental data, one should keep in mind two postulates. First – the equation should in the best possible way present the dependence among variables values that result from the measurement. Second – it should contain the least possible number of constants. Analysing the measurement results in Table 1, one can assume that it is possible to use linear regression to describe the dependence of the influence of relative humidity changes *RH* on changes in output capacity *C*.

Based on the results of the experiment shown in Table 1, the estimators of the correlation coefficient of the examined indicators were determined. Hence, a linear regression equation was accepted to describe the dependence between the variables *RH* and *C*:

$$C = \alpha + \beta \cdot RH \qquad (1)$$

Estimators *a* and *b* of parameters α and β were determined from trial. Number values of these parameters were determined using the least squares method. Parameters values *a* and *b* were determined using the computer program, hence the empirical regression equation was assumed:

$$C = 132{,}84 + 0{,}30 \cdot RH \qquad (2)$$

Fig. 2 presents the experimental characteristic $\dot{C}$ =f (*RH*) for sensor 1, in the form of measuring points, and transformation characteristic of the same sensor in the form of regression line with the use of equation (2).

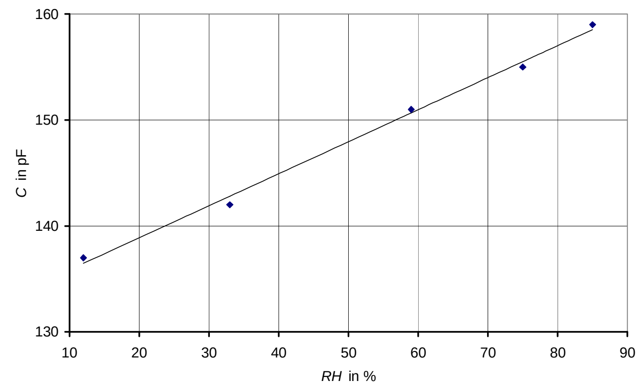

Fig. 2. Transformation characteristics $\dot{C}$ = f (*RH*) in the form of measuring points together with the determined regression line for sensor 1

4. UNCERTAINTY BUDGET

The expanded uncertainty of this integrated humidity sensor was evaluated according to an international document [4].

There are four uncertainty sources, according to the measuring system presented in Fig. 1:

- measurement of capacity value C of calibrated sensor, performed with LCR digital meter - u_1,
- temperature reading inside the vessel, measured with digital thermometer - u_2,
- nonlinearity of transformation equation of humidity sensor - u_3,
- uncertainty of evaluation of relative humidity standard solutions - u_4.

All uncertainty values were determined. Based on the results of the experiment, a combined standard uncertainty u_C, when variables are independent, was determined according to dependence:

$$u_C = \sqrt{\sum_{i=1}^{4} u_i^2} \tag{3}$$

In this situation all uncertainties are uncertainties of type B, because for each standard solution the capacity of humidity sensor was measured once.

Therefore, four standard uncertainties of type B are analyzed, which reflects a standard deviation of rectangular distribution.

The expanded uncertainty U is determined as:

$$U = k_{JJJJ}(\alpha) \cdot u_C \tag{4}$$

where coverage factor $k_{JJJJ}(\alpha)$ acquires values of standardized variable of distributions being convolution of four rectangular distributions.

The calculations were executed for one selected probability value α = 0.95. The Matlab program was used for the calculations.

On the presumption that the knowledge of convolution of component distributions permits to estimate the expanded uncertainty with strict accuracy, it is assumed that error, of which absolute value is described by relationship given below will be measured as discrepancy between the approximate and exact method:

$$\delta = \frac{|U - U_e|}{U_e} \tag{5}$$

Where U is the expanded uncertainty evaluated by means of approximate method and U_e is the expanded uncertainty estimated "exactly", on the basis of knowledge of distribution, which in the measuring event is the convolution of four rectangular distributions. The coverage factor $k_{JJJJ}(\alpha)$ could be regarded as exact value. In most of considered measuring events, the error described by the dependence (5) will be error estimated as unknown the coverage factor value $k(\alpha)$, which takes form:

$$\delta = \frac{|k(\alpha) - k_{JJJJ}(\alpha)|}{k_{JJJJ}(\alpha)} \tag{6}$$

The result of experiments for one, selected approximate method of estimating the expanded uncertainty – method of imposed values, has been presented in the paper. The international document [4] recommends among other things, to use arbitrarily imposed values of coverage factors which are equal appropriately to $k(\alpha) = 2$ for $\alpha = 0.95$.

According to this assessment, factor $k(\alpha)$ is attributed to the values of the factor, which are close to the values of standardized variable of normal distribution. In the analyzed situation of indirect measurements, the absolute values of errors resulting from estimation of coverage factors by means of the method of imposed values are defined as:

$$\delta = \frac{|2 - k_{JJJJ}(\alpha)|}{k_{JJJJ}(\alpha)} \tag{7}$$

Fig.3 presents absolute error values δ of factor estimations $k(0.95)$.

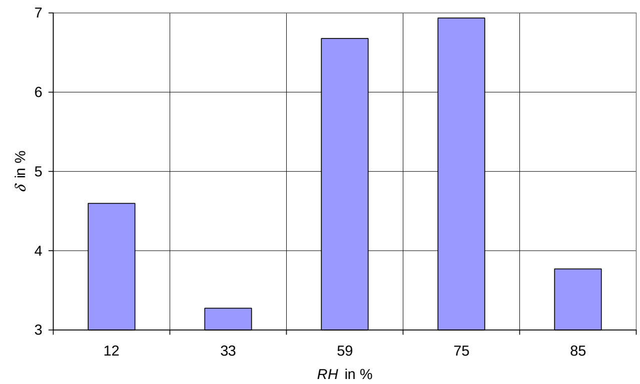

Fig. 3. Absolute error values δ of coverage factor estimation in the function of relative humidity *RH*

5. CONCLUSION

The static transformation characteristics of humidity sensors FE09/2 were determined on a designed and performed measuring system presented in Fig. 1.

The measurement results obtained, set up in Table 1 and presented for an exemplary sensor in Fig. 2, testify to a good linearity of the sensors examined.

The evaluation of the expanded uncertainty U of the integrated humidity sensors tested by means of a selected saturated standard solution was presented in this paper.

The maximum value of an absolute error δ presented in Fig.2, for the analyzed probability α does not exceed 7%.

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