Technical science and innovation

Volume 2020 | Issue 3 Article 23

9-30-2020

INCREASING CALIBRATION ACCURACY OF THE HUMIDITY CONTROL MEASURING DEVICE OF BULK MATERIALS

E. Uljaev
Tashkent State Technical University, raximshokirov2@gmail.com

Sh.N. Narzullaev
Tashkent State Technical University

S.M. Erkinov
Moscow State University of Technology «STANKIN»

Recommended Citation
Uljaev, E.; Narzullaev, Sh.N.; and Erkinov, S.M. (2020) "INCREASING CALIBRATION ACCURACY OF THE HUMIDITY CONTROL MEASURING DEVICE OF BULK MATERIALS," *Technical science and innovation*: Vol. 2020: Iss. 3, Article 23.
DOI: https://doi.org/10.51346/tstu-01.20.3-77-0087
Available at: https://btstu.researchcommons.org/journal/vol2020/iss3/23

UDC 621.714.39

INCREASING CALIBRATION ACCURACY OF THE HUMIDITY CONTROL MEASURING DEVICE OF BULK MATERIALS

E. Uljaev[1*], Sh.N. Narzullaev[1], S.M. Erkinov[2]

[1]*Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan*

[2]*Magistr of Moscow State University of Technology «STANKIN», Moscow, Russia.*

E-mail: narzullayevsh1993@mail.ru.

Abstract: *For increasing accuracy of a measuring device, before carrying out measurement, implementation of graduation, which consists of the establishment of correlation dependence between indications of the measuring device and humidity of specific material, is required. For the creation of calibration dependence of the developed measuring device as the measured 10 test samples of ammonium nitrate (nitrogen) with humidity from 0% to 2.5%, with different intervals are selected. For determination of the humidity content of ammonium nitrate, it is measured the dependence of the frequency on the humidity content of the sample. For each test, several values of frequencies of the measuring generator entered in the table with a calibration frequency* $f_k = 717{,}482\ KHz$ *are received. In this work, the short review of the known methods on the creation of calibration dependence is carried out, the impossibility of application of exact methods for an objective solution because of removal need of an excessively large number of experimental data at the calibration of the measuring transducer is set and for some other reasons. The analysis of the application of some classes of functions is made for the approximation of an output characteristic. However, the described methods above should be exposed to modification and simplification. In this regard, it is offered to use the least-squares method for improvement of calibration characteristic of a measuring device in the work, the function of calibration dependence in the form of a polynom of the seventh degree is made and matrixes of a system of equations of derivatives of first order are constructed. Further, the help of applying the software environment of Mathcad calculates the made systems of equations. For this, the coefficients of the system of equations are presented in the form of a matrix, and the free terms - in the form of a vector. Further, utilization of the Gaussian method, correction factors were found, on the basis of which a mathematical model of the calibration dependence was built that allows for the optimal accuracy of the calibration of the measuring device.*

Keywords: *Calibration, calibration of a measuring device, humidity of bulk materials(nitrogen), least-squares method, Gauss's method, function of calibrating dependence, augmented matrix of systems of equations, mathematical model, accuracy.*

Introduction

For increasing measurement accuracy of any measuring device, before carrying out measurement, it is required carrying out graduation which consists in the establishment of correlation dependence (in an analytical, graphic or tabular form) between indications of the measuring device and, for example, the humidity of specific material. This stage is the most responsible in the described technique as the accuracy of quantitative determination of humidity depends on care of the execution of operations on graduation. For the creation of calibration dependence, it is required to have a set of samples of specific material with different humidity. At the same time, the humidity range in which graduation of measuring equipment is made breaks into intervals which length depends on the selected range and on the quantity of the available samples.

When conducting measurement of the humidity of ammonium nitrate the most difficult stage is the preparation of reference tests (samples) based on which is selected reference calibration frequencies. For the preparation of reference tests and determination of calibration frequencies, we used an arbitration method (a drying method) and exact digital scales with the five-unit display.

In this research, it is selected 10 samples of ammonium nitrate (nitrogen) with humidity from 0% to 2.5%, with different intervals for the creation of calibration dependence of the developed measuring device as the measured sample. These samples(according to GOST 2-2013) were made at the Information Processing Systems and Managements department of the Tashkent state technical university named Islam Karimov. Measurement of calibration frequency and real values of output frequencies of the measuring generator carried out by "A frequency meter electronic calculating CHZ-54 type», the measuring device of «IVSX1», which is received the «CERTIFICATE COMPLIANCE», and "STATEMENT", the AGENCY of GOSSTANDART of UZBEKISTAN for carrying out measurement of the humidity of bulks [11, 15].

Research Methods and the Received Results

Several batches of samples were prepared and the dependence of the frequency on the moisture content of the sample was measured for investigation of the accuracy of the indications of the developed cylindrical capacitive measuring device with a coaxial core, as well as for determining the moisture content of ammonium nitrate. For each sample, the following values of the frequencies of the measuring generator were obtained (Table 1), at the calibration frequency $f_k = 717{,}482\ KHZ$.

Table 1.

Experimental data, which depends on the measuring transducer frequency of the moisture content of ammonium nitrate

i	Indication of measuring instrument (f_i), kHz	Humidity sample(W_i), %
1	657009,33	0
2	641256,12	0,1
3	633614,0	0,2
4	626568,68	0,3
5	619345,62	0,4
6	612325	0,5
7	575240,5	1
8	569468,45	1,5
9	564622,19	2
10	560796,33	2,5

Using the data in table 1, a point table of the dependence of the measuring generator frequency on the moisture content of the measured sample is built (Fig. 1).

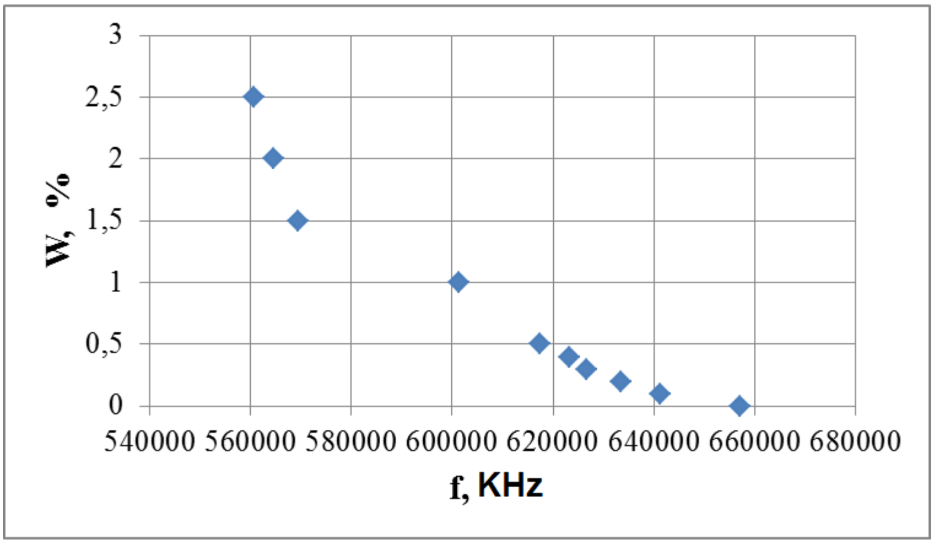

Fig. 1. Point graph of the basic data.

A number of values of humidity of ammonium nitrate to which corresponds a number of instrument readings (the established values) is received As a result of the conducted measurements and calculations. On the corresponding values of humidity of a sample and instrument indications, it is possible to construct calibration dependence "instrument indication – humidity of ammonium nitrate"

Various methods are known for building a calibration dependence (regression curve).

Now, we analyze the possibility of using linearization methods.

Exact methods of linearization are inapplicable for an objective solution owing to the need for removal of the excessively large number of experimental data at the calibration of the measuring transducer that is impracticable and economically not reasonable in some cases. In addition, it is required to store a large amount of experimental data in the microcontroller memory of the measuring transducer, which is several times higher than the available capabilities of the built-in memory devices.

For the application of the segment approximating functions, it is necessary to break an output characteristic of the measuring transducer into linear sections and to describe the equation of each section. It is obvious that this approach demands labor-consuming calculations and storage of a large volume of calibration information in memory of the measuring transducer. The situation is complicated by the fact that in this case, we are talking about a two-dimensional output characteristic and the segments must be parts of the surface. The computing power of microcontrollers that are used popularly in measuring transducers does not allow solving the problem.

Because of the facts above, the hardware features of modern measuring transducers allow us using only global approximating functions to linearize the output characteristic

In the work [4], an analysis of the application of some classes of functions for approximating the output characteristic was done. The analysis used the following types of functions

1. Algebraic polynomials which have the following view:

$$P(U) = a_0 + a_1 U + ... + a_n U^n,$$

where *n* – polynomial order; a_i – polynomial coefficients.

2. Fractional rational functions:

$$P(U) = \frac{a_0 + a_1 U + ... + a_m U^m}{1 + a_{m+1} U + ... + a_n U^n},$$

where *n* and *m* – some natural numbers.

3. Functions, which are the solution of ordinary differential equation

$$\frac{d^n P}{dU^n} = a_0 \frac{d^{n-1} P}{dU^{n-1}} + ... a_{n-1} p + a_n U.$$

The mean square deviation of a mathematical model, the absolute maximum value of deviations brought to the range value of the maximum value of a deviation was calculated for each class of functions. In addition, the applicability of the functions was assessed from the point of view of the convenience of further use of the function by the number of mathematical operations included in the function.

In the course of the analysis, it was revealed, "the choice of either algebraic polynomials of the 3rd order or fractional rational functions of the 1st order, since they are comparable in terms of the complexity of implementation and the accuracy of descriptions, is optimal for all the selected quality criteria of approximating functions"].

In the works [4, 5, 8, 9], the algorithm of calibration of reference measuring transducers of humidity based on the iterative approach of the polynomial function approximating output characteristics of the transformer according to a criterion of uniformity is considered. In addition, the main properties and stages of an algorithm, and its application are considered during calibration of measuring transducers of humidity

However, the algorithms and methods mentioned above should still be modified and simplified.

According to the statements of authors [10, 12, 13], the method of the smallest squares is still considered in the most effective and easy way for calibration of graphs of dependencies on various parameters. Therefore, we will use a method of the smallest squares for the creation of calibration dependence (a regress curve).

Thus, according to the least-squares method, we will describe the function of calibration dependence $W = k(f)$ in the form of a polynomial:

$$W = X_0 + X_1 f + X_2 f^2 + X_3 f^3 + X_4 f^4 + X_5 f^5 + X_6 f^6 + X_7 f^7. \quad (1)$$

Make a difference formula S_m between the valid measured value and calibration values

$$S_m = \sum_{i=1}^{10} [W(f_i) - W_i]^2 = \sum_{i=1}^{10} \left[(X_0 + X_1 f_i + X_2 f_i^2 + X_3 f_i^3 + X_4 f_i^4 + X_5 f_i^5 + X_6 f_i^6 + X_7 f_i^7) - W_i \right]^2. \quad (2)$$

Calculating derivatives and equating the right parts to zero, we will construct a matrix of an equations system of derivatives:

$$\begin{cases} \frac{\partial S_m}{\partial X_0} = 2 \sum_{i=1}^{10} \left[(X_0 + X_1 f_i + X_2 f_i^2 + ... + X_7 f_i^7) - W_i \right] = 0, \\ \frac{\partial S_m}{\partial X_1} = 2 \sum_{i=1}^{10} \left[(X_0 + X_1 f_i + X_2 f_i^2 + ... + X_7 f_i^7) - W_i \right] f_i = 0, \\ \frac{\partial S_m}{\partial X_2} = 2 \sum_{i=1}^{10} \left[(X_0 + X_1 f_i + X_2 f_i^2 + ... + X_7 f_i^7) - W_i \right] f_i^2 = 0, \\ \vdots \\ \frac{\partial S_m}{\partial X_7} = 2 \sum_{i=1}^{10} \left[(X_0 + X_1 f_i + X_2 f_i^2 + ... + X_7 f_i^7) - W_i \right] f_i^7 = 0. \end{cases} \quad (3)$$

According to [3, 4, 10, 12, 13], we obtain the following system of equations after conducting some transformations:

$$\begin{cases} 10X_0 + X_1\sum_{i=1}^{10} f_i + X_2\sum_{i=1}^{10} f_i^2 + ... + X_7\sum_{i=1}^{10} f_i^7 = \sum_{i=1}^{10} W_i \ , \\ X_0\sum_{i=1}^{10} f_i + X_1\sum_{i=1}^{10} f_i^2 + X_2\sum_{i=1}^{10} f_i^3 + ... + X_7\sum_{i=1}^{10} f_i^8 = \sum_{i=1}^{10} f_i W_i \ , \\ X_0\sum_{i=1}^{10} f_i^2 + X_1\sum_{i=1}^{10} f_i^3 + X_2\sum_{i=1}^{10} f_i^4 ... + X_7\sum_{i=1}^{10} f_i^9 = \sum_{i=1}^{10} f_i^2 W_i \ , \\ \vdots \\ X_0\sum_{i=1}^{10} f_i^7 + X_1\sum_{i=1}^{10} f_i^8 + X_2\sum_{i=1}^{10} f_i^9 + ... + X_7\sum_{i=1}^{10} f_i^{14} = \sum_{i=1}^{10} f_i^7 W_i \ . \end{cases} \quad (4)$$

We will write the results of the calculations in the tab. 2.

Table 2.

Experimental results of calculating the equations system (4)

i	W_i	f_i	f_i^2	f_i^3	...	f_i^{14}
1	0	657009,33	$4,32\cdot10^{11}$	$2,84\cdot10^{17}$	...	$2,79\cdot10^{81}$
2	0,1	641256,12	$4,11\cdot10^{11}$	$2,64\cdot10^{17}$	...	$1,99\cdot10^{81}$
3	0,2	633614	$4,01\cdot10^{11}$	$2,54\cdot10^{17}$	...	$1,68\cdot10^{81}$
4	0,3	626568,68	$3,93\cdot10^{11}$	$2,46\cdot10^{17}$	...	$1,44\cdot10^{81}$
5	0,4	623345,62	$3,89\cdot10^{11}$	$2,42\cdot10^{17}$	...	$1,33\cdot10^{81}$
6	0,5	617325,14	$3,81\cdot10^{11}$	$2,35\cdot10^{17}$	...	$1,17\cdot10^{81}$
7	1	601423,5	$3,62\cdot10^{11}$	$2,17\cdot10^{17}$	...	$8,10\cdot10^{80}$
8	1,5	569468,45	$3,24\cdot10^{11}$	$1,85\cdot10^{17}$	...	$3,77\cdot10^{80}$
9	2	564622,19	$3,19\cdot10^{11}$	$1,80\cdot10^{17}$	...	$3,35\cdot10^{80}$
10	2,5	560796,33	$3,14\cdot10^{11}$	$1,76\cdot10^{17}$	...	$3,04\cdot10^{80}$
∑	8,5	6095429,36	$3,73\cdot10^{12}$	$2,28\cdot10^{18}$	...	$1,22\cdot10^{82}$

Table 3.

Experimental results of calculating the equations system (4)

i	f_iW_i	$f_i^2W_i$	$f_i^3W_i$	...	$f_i^7W_i$	$W(f_i)$
1	0	0	0	...	0	-0,615
2	64125,612	$4,11\cdot10^{10}$	$2,64\cdot10^{16}$	...	$4,46\cdot10^{39}$	0,040
3	126722,8	$8,03\cdot10^{10}$	$5,09\cdot10^{16}$	...	$8,20\cdot10^{39}$	0,314
4	187970,604	$1,18\cdot10^{11}$	$7,38\cdot10^{16}$	...	$1,14\cdot10^{40}$	0,547
5	249338,248	$1,55\cdot10^{11}$	$9,69\cdot10^{16}$	...	$1,46\cdot10^{40}$	0,647
6	308662,57	$1,91\cdot10^{12}$	$1,18\cdot10^{17}$	...	$1,71\cdot10^{40}$	0,823
7	601423,5	$3,62\cdot10^{11}$	$2,18\cdot10^{17}$	...	$2,85\cdot10^{40}$	1,227
8	854202,675	$4,86\cdot10^{11}$	$2,77\cdot10^{17}$	...	$2,91\cdot10^{40}$	1,804
9	1129244,38	$6,38\cdot10^{11}$	$3,60\cdot10^{17}$	...	$3,66\cdot10^{40}$	1,868
10	1401990,825	$7,86\cdot10^{11}$	$4,41\cdot10^{17}$	...	$4,36\cdot10^{40}$	1,915
∑	4923681,214	$2,86\cdot10^{12}$	$1,66\cdot10^{18}$	...	$1,94\cdot10^{41}$	8,568

We will find coefficients by the help of the constructed system of equations (4) and the calculated data (tab. 2 and tab. 3): X_0, X_1, X_2, X_3, X_4, X_5, X_6, X_7.

In this case, the system of equations (3) concerning X_0, X_1, X_2, X_3, X_4, X_5, X_6, X_7 takes the following form:

$$\begin{cases} 10X_0 + 6{,}10\cdot10^6 X_1 + 3{,}73\cdot10^{12} X_2 + \ldots + 3{,}31\cdot10^{41} X_7 = 8{,}5, \\ 6{,}10\cdot10^6 X_0 + 3{,}73\cdot10^{12} X_1 + 2{,}28\cdot10^{18} X_2 + \ldots + 2{,}05\cdot10^{47} X_7 = 4{,}92\cdot10^6, \\ 3{,}73\cdot10^{12} X_0 + 2{,}28\cdot10^{18} X_1 + 1{,}40\cdot10^{24} X_2 \ldots + 1{,}28\cdot10^{53} X_7 = 2{,}86\cdot10^{12}, \\ \vdots \\ 3{,}31\cdot10^{41} X_0 + 2{,}05\cdot10^{47} X_1 + 1{,}28\cdot10^{53} X_2 + \ldots + 1{,}22\cdot10^{82} X_7 = 1{,}94\cdot10^{41}. \end{cases} \quad (5)$$

Then we write these equations systems in the form of a matrix

$$A\cdot X = B \quad (6)$$

Multiply both parts of the equation (6), on the left side by an inverse matrix of A^{-1}. As at $A^{-1}\cdot A\cdot X = A^{-1}\cdot B$. $A^{-1}\cdot A = E$ are equal to a unit matrix, equality is formed as follows:

$$X = A^{-1}\cdot B. \quad (7)$$

Applying the software environment of Mathcad, we will calculate the stated systems of equations that are given above. For this purpose, we will represent coefficients of a system of equations in the form of a matrix, and absolute terms in the form of a vector (fig. 2) in the software environment of Mathcad.

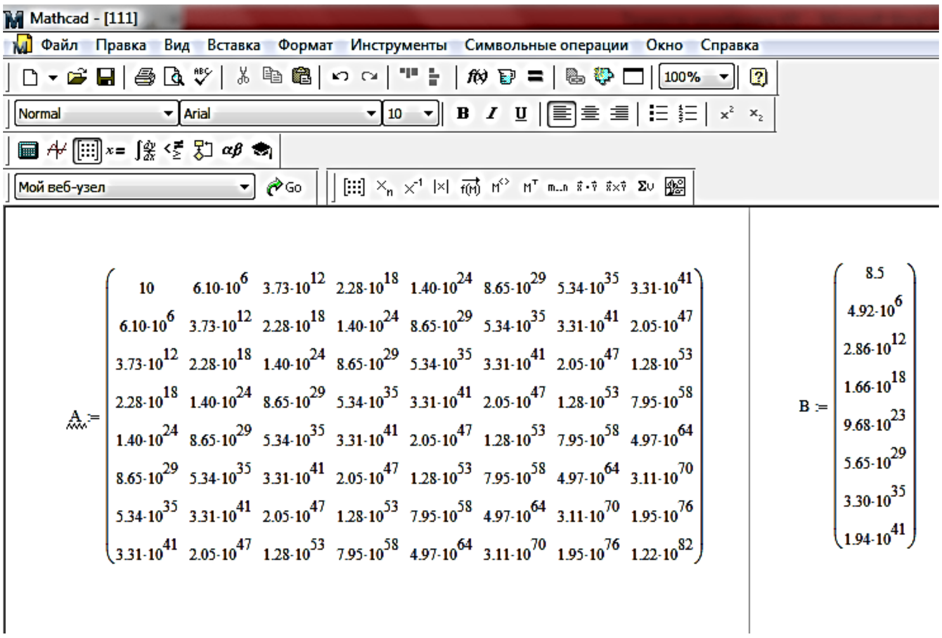

Fig. 2. Input a system of equations into the Mathcad software environment

Column X that was found according to (7) will be a solution of unknown matrixes (fig. 3).

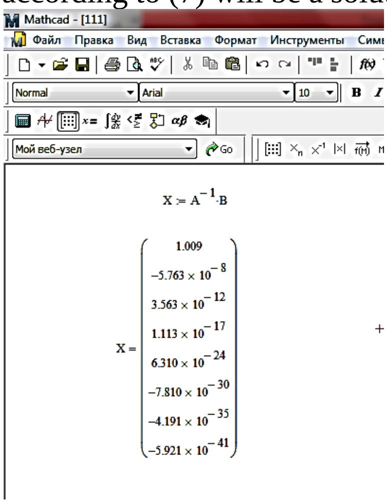

Fig. 3. The solution of an equations system in the software environment of Mathcad

According to [3, 4, 10, 12, 13], solving the equations system (3) by the help of the Gauss method, we find the coefficients, such as $X_0 = 1{,}009$, $X_1 = -5{,}763 \cdot 10^{-8}$, $X_2 = 3{,}563 \cdot 10^{-12}$, $X_3 = 1{,}113 \cdot 10^{-17}$, $X_4 = 6{,}310 \cdot 10^{-24}$, $X_5 = -7{,}810 \cdot 10^{-30}$, $X_6 = -4{,}191 \cdot 10^{-35}$, $X_7 = -5{,}921 \cdot 10^{-41}$.

The equation of calibration dependence will have the following appearance if we substitute the found coefficients in (1):

$$W = 1{,}009 - 5{,}763 \cdot 10^{-8} f + 3{,}563 \cdot 10^{-12} f^2 + 1{,}113 \cdot 10^{-17} f^3 + 6{,}310 \cdot 10^{-24} f^4 - \\ - 7{,}810 \cdot 10^{-30} f^5 - 4{,}191 \cdot 10^{-35} f^6 - 5{,}921 \cdot 10^{-41} f^7. \quad (8)$$

Expression (8) is a mathematical model of calibration dependence of ammonium nitrate humidity on frequency.

From the calculated values of coefficients X_0, X_1, X_2, X_3, X_4, X_5, X_6, X_7, it is visible that coefficients of values beginning from X_3 and above have insignificant values and therefore they can be neglected. Paying attention to the facts given above, the mathematical model of calibration dependence of a measuring device can be written in the following view:

$$W = 1{,}009 - 5{,}763 \cdot 10^{-8} f + 3{,}563 \cdot 10^{-12} f^2. \quad (9)$$

The diagram of dependence of ammonium nitrate humidity on the frequency of the measuring transducer that is constructed respecting the worked-out calibration equation (8) is provided in fig. 4.

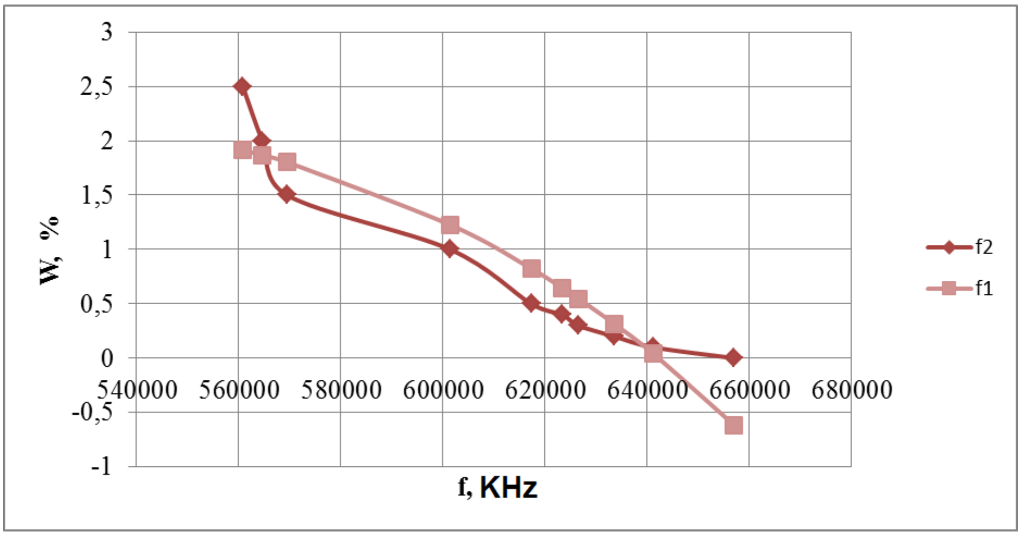

Fig. 4. Graph of the calibration equation with the correction coefficient (*f1*) and without it (*f2*).

From diagrams, it is visible that the dependence of humidity on frequency, (fig. 4, *f1*) constructed taking into account calibration coefficients is much better than the diagram provided on fig. 4, *f2*.

Conclusion

In that way, the application of the least-squares method for conducting graduation of the diagram of the dependence of ammonium nitrate humidity on the frequency of the measuring transducer gave the chance to increase the calibration accuracy of a measuring device.

References

1. L.Z.Rumshinsky. Mathematical processing of the experimental results. M., Science, 1971(in Russian).
2. Verzhbitsky V.M. Numerical methods. Linear algebra and nonlinear equations. / V.M. Verzhbitsky - M .: Onyx 21st century, 2005(in Russian).
3. Kobzar A.I. Applied Mathematical Statistics. - M.: Fizmatlit, 2006. - 816 (in Russian).

4. Nikolaeva E.A. Algorithm of calculation of uncertainty when conducting a calibration of measuring instruments / E.A. Nikolaeva, Nikolaev A.V. // Vestnik KuzGTU. -2017. No. 5. -C. 162-167.
5. Zakharov I.P., Reference manual «Calibration 17025» - St. Petersburgh: Politehnica-Cervi. 2016.-68 p.
6. GOST R 54500.3-2011 / ISO / IEC Guide 98-3: 2008 “Measurement uncertainty. Part 3. Guidance on the expression of measurement uncertainty”(in Russian).
7. GOST ISO / IEC 17025-2009 General requirements for the competence of testing and calibration laboratories(in Russian).
8. Dobrovolski V.I. Investigation of metrological characteristics of silver-silver chloride electrodes of GET 54-2011, the state primary standard for the ph activity of hydrogen ions in aqueous solutions / V.I. Dobrovolskii, S.V. Prokunin, I.V. Morozov, A.A. Glazdov // «Measurement techniques» Springer, T 59 № 9. P. 1013— 1016.
9. Vinge, A.F. National primary standard for the units of relative humidity of gases, molar (volume) fraction of moisture, and dew/frost point temperature, GET 151-2014 / A.F. Vinge, M.A. Vinge, V.N. Egorov, O.A. Podmurnaya // «Measurement techniques» Springer, T 59 № 9. P. 1-8.
10. Zorkal'tsev, V.I. The method of least squares / V.I. Zorkaltsev. - Novosibirsk: VO "Science", 1995. - 220 p(in Russian).
11. E.Uljaev, U.M.Ubaydullaev, Sh.N.Narzullaev, E.F.Xudoyberdiev, F.G.Haydarov. (2020). Classification of Detectors of Capacitive Humidity Transducers of Bulk Materials. International Journal of Advanced Science and Technology, 29(11s), 1949 - 1953. Retrieved from http://sersc.org/journals/index.php/IJAST/article/view/21858
12. Tulbaev F.A., Uljaev E., Pardaev G.E., Makhmarazhabov M.B. Application of the Least Squares Method to Improving the Calibration Accuracy of a Measuring Device // Chemical Technology. Control and management. - Tashkent, 2013. No. 2. -FROM. 29-33(in Russian).
13. Uljaev E., Ubaydullaev U.M., Narzullaev Sh.N. (2020). Capacity transformer of coaxial and cylindrical form of humidity meter. Chemical Technology, Control and Management, №4(94), 2020. –pp. 23-30. journal homepage: https://uzjournals.edu.uz/ijctcm/
14. Uljaev E., Narzullaev Sh.N. Xaydarov F.G. K voprosu razrabotki intellektualnogo kombinirovannogo ustroystva kontrolya vlajnosti sipuchix materialov // Materiali mejdunarodnoy nauchnoy konferensii «Innovatsionnie resheniya injenerno-texnologicheskix problem sovremennogo proizvodstva». 2 TOM. 14-16 noyabrya 2019 g. Buxara-2019 [On the issue of developing an intelligent combined device for controlling the moisture content of bulk materials // Materials of the international scientific conference «Innovative solutions of engineering and technological problems of modern production». 2 vol. November 14-16, 2019 Bukhara-2019]. –S.204-206.
15. Aslanyan. A.E. National primary standard for hardness according to the martens scales and indentation scales, GET 211-2014 / A.E. Aslanyan, E.G. Aslanyan, S.M. Gavrilkin, A.S. Doinikov, I.N. Temnitskii, A.N. Shchipunov // «Measurement techniques» Springer. T 59 № 6. P. 555-559.
16. www.maΣprofʃru.ru
17. www.reshmat.ru