UDC 621.317.39 DOI: 10.24027/2306-7039.2.2021.236098

Synthesis of a linear static function for grain moisture meter with capacitive sensors

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Abstract

Moisture content is a grain quality factor, a parameter which changes during the processes of storage and processing and determines consumer properties of different food products. OIML organization in its international recommendation OIML R59 "Moisture Meters for Cereal Grain and Oilseeds" restricts maximal permissible value of moisture meters uncertainty to not more than 3% of relative full scale error. Main task of the research is in receiving linear static function for the grain moisture meter with four capacitive sensors. Method of Least Squares and general linear regression instruments had been used for that purpose. Analyzing the graphs of modified static function for different moist substances it was possible to say that it happened to be far more effective than initial static function and the static function received from a first-order polynomial after the LS method implementation. Root mean estimator was calculated for initial static function, the static function received with the LS method and static function, received after general linear regression implementation as an integral difference between nominal and calculated values of moisture content. Corresponding root mean estimator values were 1.3062%, 1.1616% and 0.4158%, that proves the effectiveness of a static function modified with the general linear regression instruments.

Keywords: moisture content measurement; capacitive moisture meter; reference channel; capacitive sensor; linear static function.

Received: 22.04.2021 Edited: 26.05.2021 Approved for publication: 02.06.2021

1. Introduction

Most of European countries had already changed their local standards for moisture meters in accordance with international recommendation OIML R59 "Moisture Meters for Cereal Grain and Oilseeds" which restricts maximal permissible value of moisture content uncertainty to not more than 3% of relative full scale error. From other hand, big list of different factors influence the value of modern moisture meters' full scale error in different bulk substances. Among them we have physical and chemical composition, temperature, granulometric composition, density etc. In addition, physical and chemical composition of grain products depends not only from grains' type, but origin and ways of cultivation, storage and processing – factors that can be hardly predicted.

Currently significant part among the means of substances' properties and composition control is occupied with capacitive measuring instruments which use capacitive sensors. "Successful" modifications of capacitive sensors appeared years ago [1]. But, as it was mentioned before, "type uncertainty" error can be of a strong influence on the result of moisture measurement and needs to be compensated. This compensation is traditionally performed in a secondary measuring transducer by using complementary reference capacitors, special analytic calculations, reference calibration curves etc. All it can be used for the limited number of materials and does not allow the moisture meter to be versatile for the wide range of bulk substances [2, 3].

Main task of the research is to receive robust linear static function for the capacitive moisture meter, described in [2].

2. Materials and methods

For capacitive sensors, where one of the capacitor plates should be placed in two or several positions, change of electric capacitance ΔC_0 (difference in electric capacitance before and after the distance between two plates had been changed) for empty sensor should be defined at first [1]. Then it is necessary to define change of electric capacitance ΔC_1 when capacitive sensor is filled with tested substance for the same positions of the capacitor plates. After that a relation $\Delta C_1/\Delta C_0$ should be calculated. In this method only the accuracy of capacitor plates positioning would influ-

Table 1

Calculated values of a static function (1)

W, %	ε_n	2.0	2.5	3.0	3.5
0	W_{calc}	0	0	0	0
10	W_{calc}	8.78	8.60	8.44	8.23
20	W_{calc}	19.56	20.78	18.71	18.31
30	W_{calc}	33.13	32.31	31.51	30.74

ence the uncertainty of measurements. This method can't be directly implemented for effective moisture measurement in grain, because we can easily move the plates of a capacitive sensor in gases and liquids, but it can be hardly performed in bulks and solids. Besides, there is a necessity to compensate the influence of grain types with different physical and chemical composition by creating a reference channel and direct comparison method application [2].

Measuring channel should be filled with a probe of bulk substance, being under moisture control (sensors C_1 and C_2), and reference channel should be filled with a same substance, but previously dehydrated (sensors C_3 and C_4). We have to measure values of electric capacitances C_1, C_2, C_3 and C_4, then to calculate differences $C_2 - C_1$ and $C_3 - C_4$. When it is done, we calculate relation of these differences $(C_3 - C_4)/(C_2 - C_1)$, and this would be an informative parameter, directly connected with moisture content.

If we take values of electric capacitances (not filled with a substance), equal to 15 pF for C_1, C_4 and 50 pF for C_2, C_3, it would be possible to receive normalized equation (1) of a moisture meter static function [2].

$$W_N = 28.599\left[\left(\frac{C_3 - C_4}{C_2 - C_1}\right) - 1\right]. \quad (1)$$

To check workability of a static function (1) with different types of bulk materials, four values of dielectric permittivity for dehydrated substances ($\varepsilon_n = 2.0$; $\varepsilon_n = 2.5$; $\varepsilon_n = 3.0$; $\varepsilon_n = 3.5$) and four values of moisture content ($W = 0\%$; $W = 10\%$; $W = 20\%$; $W = 30\%$) were taken [3]. After appropriate values of dielectric permittivity for moist substances, calculated with a help of universal Wiener equation, and values of capacitances C_1, C_2, C_3, C_4 were received, calculated values of moisture content had been estimated and given in Table 1 [4–7].

As we can see, all static functions, received with a help of equation (1), are nonlinear, and calculated values of moisture content are significantly different from nominal in all points, except $W = 0\%$. So, at first, initial static function (1) should be linearized.

3. Theory/calculation

To receive linear dependence between moisture content W and relation $(C_3 - C_4)/(C_2 - C_1)$ method of Least Squares had been used:

$$a + b \cdot W = \frac{C_3 - C_4}{C_2 - C_1}, \quad (2)$$

where a and b – unknown coefficients of a first-order polynomial (2). After solving the system of four conditional equations with a help of LS method we have the values of a and b coefficients: $a = 0.9622$; $b = 0.0371$.

Calculated values of moisture content W', received from a first-order polynomial (2):

$$0.9622 + 0.0371 \cdot W' = \frac{C_3 - C_4}{C_2 - C_1}, \quad W' = \frac{\frac{C_3 - C_4}{C_2 - C_1} - 0.9622}{0.0371}, \quad (3)$$

are given in Table 2.

We can see that LS method is not effective, as it was expected to receive better linearity of the moisture meters' static function. But it was possible to calculate deviations ΔW of calculated moisture content values from Table 2 and nominal points of moisture content and approximate these deviations by applying instruments of general linear regression [8, 9]. Deviations between nominal points of moisture content and moisture values, taken for $\varepsilon_n = 3.0$, are given in Table 2.

To approximate values of deviation ΔW from Table 2, a sum of four functions (1, W, W^2 and W^3)

Table 2

Values of moisture content W', received from equation (3)

W, %	W'				$\Delta W = W' - W_{nominal}$
	$\varepsilon_n = 2.0$	$\varepsilon_n = 2.5$	$\varepsilon_n = 3.0$	$\varepsilon_n = 3.5$	
0	1.019	1.019	1.019	1.019	1.019
10	9.294	9.132	8.970	8.809	-1.030
20	19.456	19.051	18.647	18.270	-1.353
30	32.232	31.477	30.722	29.995	0.722

Table 3

Calculated values of a static function (5)

W, %	W'			
	$\varepsilon_n = 2.0$	$\varepsilon_n = 2.5$	$\varepsilon_n = 3.0$	$\varepsilon_n = 3.5$
0	0.268	0.268	0.268	0.268
10	10.230	10.045	9.859	9.674
20	20.850	20.470	20.085	19.723
30	30.658	30.211	29.476	29.280

was taken with appropriate coefficients, defined with a help of Mathcad software (function linfit (*x*, *y*, *Y*)).

$$\Delta W' = 1.019 - 0.269 \cdot W + 0.00527 \cdot W^2 + +0.000112 \cdot W^3. \quad (4)$$

Taking formula (4) into account, we can build modified static function for a moisture meter:

$$W_m = -1.019 + 1.269 \cdot \frac{\left(\frac{C_3 - C_4}{C_2 - C_1} - a\right)}{b} - 0.00527 \times \times \left(\frac{\left(\frac{C_3 - C_4}{C_2 - C_1} - a\right)}{b}\right)^2 - 0.000112 \cdot \left(\frac{\left(\frac{C_3 - C_4}{C_2 - C_1} - a\right)}{b}\right)^3. \quad (5)$$

New values of moisture content, calculated using formula (5), are given in Table 3.

If we compare Table 2 and Table 3, it would be possible to say that modified static function (5) is far more effective then initial static function (1) and static function, received from a first-order polynomial (3).

To prove it analytically, it seemed to be rational to calculate one of goodness-of-fit parameters, root mean estimator for example (6).

$$S = \sqrt{\frac{\sum \left(W_{ino\min al} - W_{icalc}\right)^2}{n}}. \quad (6)$$

Corresponding root mean estimator values were 1.3062% for initial static function from [2], 1.1616% for static function, received with a help of LS method, and 0.4158% for new static function, what proves the effectiveness of a static function, modified with a help of general linear regression instruments.

4. Conclusion

To receive linear static function for the capacitive moisture meter method of Least Squares had been used. After system of four linear conditional equations solvation it was possible to conclude, that LS method is not effective for our case as it was expected to receive better linearity of the moisture meters' static function. Next step of linearization was in calculating deviations between nominal points of moisture content and values, received after LS method application, and their approximation using general linear regression instruments.

Analyzing the graphs of modified static functions for different moist substances it was possible to say that they happened to be far more effective then initial static function, suggested in [2] and static function, received from a first-order polynomial after LS method implementation. Root mean estimator was calculated for initial static function from [2], static function, received with a help of LS method and static function, received after general linear regression implementation as an integral difference between nominal and calculated values of moisture content. Corresponding root mean estimator values were 1.3062%, 1.1616% and 0.4158% what proves the effectiveness of a static function, modified with a help of general linear regression instruments.

Синтез лінійної статичної характеристики перетворення для вологоміра зерна з ємнісними сенсорами

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Анотація

Вміст вологи в зерні є показником якості, параметром, який змінюється в процесі зберігання та переробки і визначає споживчі якості різних продуктів харчування. Міжнародна організація OIML в нормативі OIML R59 "Вологоміри хлібних зернових та олійних культур" обмежує максимально допустиме значення невизначеності вологомірів на рівні, що не перевищує 3% відносної зведеної похибки. Мета дослідження – синтез лінійної статичної характеристики перетворення для вологоміра зерна з чотирма ємнісними сенсорами.

Для отримання лінійної статичної характеристики перетворення було використано метод найменших квадратів. Результат розв'язання системи з чотирьох умовних рівнянь дав можливість зробити висновок, що метод найменших квадратів виявився неефективним, бо отримана статична характеристика перетворення повинна мати кращу лінійність. Наступним кроком для лінеаризації було обчислення відхилень між номінальними значеннями вмісту вологи і значеннями, отриманими внаслідок використання методу найменших квадратів, з подальшою їх апроксимацією за допомогою інструментів лінійної регресії загального виду.

Аналізуючи графіки отриманої статичної характеристики перетворення для різних вологих речовин, можна зробити висновок, що вона виявилась більш ефективною у порівнянні з початковою статичною характеристикою перетворення і статичною характеристикою, отриманою внаслідок використання методу найменших квадратів. Для порівняння було обчислено середньоквадратичну оцінку. Відповідні значення цієї оцінки дорівнюють: 1.3062%, 1.1616% та 0.4158%, що доводить ефективність статичної характеристики, отриманої внаслідок використання лінійної регресії загального виду.

Ключові слова: вимірювання вмісту вологи; ємнісний вологомір; опорний канал; ємнісний сенсор; лінійна статична характеристика перетворення.

Синтез линейной статической характеристики преобразования для влагомера зерна с емкостными сенсорами

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Аннотация

Цель исследования – синтез линейной статической характеристики для влагомера зерна с четырьмя емкостными датчиками.

Для получения линейной статической характеристики преобразования был применен метод наименьших квадратов. Он оказался неэффективным, так как полученная статическая характеристика преобразования имеет высокую нелинейность. Исправить ситуацию позволило применение инструментов линейной регрессии общего вида. Новая статическая характеристика преобразования оказалась более эффективной, чем исходная статическая характеристика и статическая характеристика, полученная в результате применения метода наименьших квадратов. Для сравнения была вычислена среднеквадратическая оценка, соответствующие значения которой равны: 1.3062%, 1.1616% и 0.4158%. Это подтверждает эффективность полученной статической характеристики преобразования для емкостного влагомера.

Ключевые слова: измерение влагосодержания; емкостный влагомер; опорный канал; емкостный датчик; линейная статическая характеристика преобразования.

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