Graduation technique for vibration flow device for grain mass moisture control

Alexander Ivashina, *Andrey* Adoshev, *Sergey* Antonov, and *Valery* Zhdanov

Stavropol State Agrarian University, 12 Zootechnicheskiy Ln, Stavropol, 355017, Russian Federation

Abstract. The article shows that sampling of grain while controlling the moisture content is carried out in accordance with the current recommendations and standards. The mass of a sample should be sufficient to form 10-15 samples with uniformly distributed moisture values with an interval of no more than 3-4% in the measurement range of a vibration-flow moisture meter. Determination of grain moisture is carried out by the thermogravimetric method using a drying oven as a standard in the following sequence. Measurements with a moisture meter are taken at least three times. For the final measurement result, the average value α of the moisture meter readings from a series of successive measurements is taken. The range in a series of measurements should not exceed 0.05α; otherwise the measurements are repeated. The moisture measurement results and the corresponding readings of the device are entered in the appropriate table. When constructing graduation curves, a correlation-regression analysis of the measurement results is carried out, which is as follows. A correlation field is constructed - a graphical representation of the relationship between the moisture values of the material W_i and the readings of the moisture meter α_i. If the analysis is performed correctly, the theoretical regression line plotted on the correlation field should be located as close as possible to the experimental measurement points. The basic error of the vibration-flow moisture meter, obtained as a result of the calculation, should not exceed the permissible value. Otherwise, the graduation of the moisture meter is repeated.

1 Introduction

The importance of the task to develop a graduation technique for measuring the moisture content of grain is especially great for a number of reasons. Firstly, moisture is a less definite value than a number of other physicochemical parameters [1-4]. This is caused by various forms of the state and connection of moisture with the solid phase and its uneven distribution in the grain, as a result of which the so-called average samples (with the imperfection of the existing methods of their selection) insufficiently accurately characterize the moisture content of the entire mass of the material. Secondly, most modern moisture meters are graduated not on the basis of exact mathematical relationships, but empirically [5-7].

Finally, the large scope of application and mass scale of grain moisture measurements predetermine the economic significance of the graduation technique for measuring the grain moisture content and the high requirements for it.

2 Materials and methods

The moisture meter graduation should be carried out in laboratories for the analysis of the quality of feed and in specially equipped rooms, under the conditions specified in the relevant regulatory documents.

The grain mass must be homogeneous in composition. The presence of inorganic impurities is not allowed.

Measuring instruments used for graduation must have technical data sheets with a note on periodic verification.

Grain samples are taken in accordance with the recommendations and standards in force in grain production. The mass of the sample should be sufficient to form 10-15 samples with moisture values uniformly distributed with an interval of no more than 3-4% over the measurement range of the moisture meter.

To obtain samples of wheat grain with the required moisture difference, the sample is divided into the required number of initial samples, each of which is dried to the desired moisture content at room temperature or under natural conditions. In the process, the material is periodically mixed. The mass of each sample should be sufficient for measurement with a graduated moisture meter and a standard, taking into account the possibility of repeating measurements.

Determination of grain moisture is carried out by the thermogravimetric method using a drying oven as a standard in the following sequence.

* Corresponding author: av_ivashina49@mail.ru

The prepared sample is distributed in an even layer in the form of a square and divided diagonally into four triangles with a bar. From different places of each triangle, two samples with a mass of 20-25 g each are taken to the entire depth of the layer. They are poured into sealed containers and mixed. The rest of the material is used for measurements with a moisture meter. Sample preparation and sampling should be done as soon as possible.

Empty weighing bottles are dried at a temperature of 100-105°C for 30-40 minutes, cooled in a desiccator for at least 20 minutes and weighed.

Eight weighed portions of 10.0-10.1 g are selected into pre-prepared weighing bottles. The weighing bottles with a sample are weighed open together with a lid; the permissible weighing error is ± 0.005 g.

The weighing bottles with a sample of grain are placed in a drying oven, and the lids are installed under the appropriate weighing bottles. Dehydration of samples is carried out at a temperature of 115 ± 3°C for four hours. After the specified time the weighing bottles are removed from the oven, covered with lids and placed in a desiccator for 30-40 minutes for cooling.

The result of measuring the moisture content of the sample is the arithmetic mean of eight moisture values of the weighed samples, measured simultaneously. The range of moisture values (discrepancy between higher and lower values) should not exceed 0.8%. If this condition is not met, the sample is thoroughly mixed and the measurements are repeated.

It is allowed to use other duly certified methods for measuring the moisture content of the grain mass, the error of which does not exceed the limit of permissible values of the basic error of the moisture meter.

Measurements with a moisture meter are carried out at least three times. For the final measurement result, the average value α of the moisture meter readings from a series of successive measurements is taken. The range in a series of measurements should not exceed 0.05α; otherwise the measurements are repeated.

When constructing graduation curves, a correlation-regression analysis of the measurement results is carried out, which is as follows. A correlation field is constructed figure 1 (a graphical representation of the relationship between the moisture values of the material W_i and the readings of the moisture meter α_i).

The order of the regression coefficients is determined by the nature of the dependence. In the case of a linear dependence, the regression equation has the form (1):

$$W_L = \overline{W} + r_{W/\alpha}\frac{\sigma_W}{\sigma_\alpha}\left(\alpha - \overline{\alpha}\right), \quad (1)$$

where $\overline{W}$, $\bar{\alpha}$ is arithmetic mean values of measured values;

$r_{W/\alpha}$ is a correlation coefficient;

σ_W, σ_α are standard deviations of measured values.

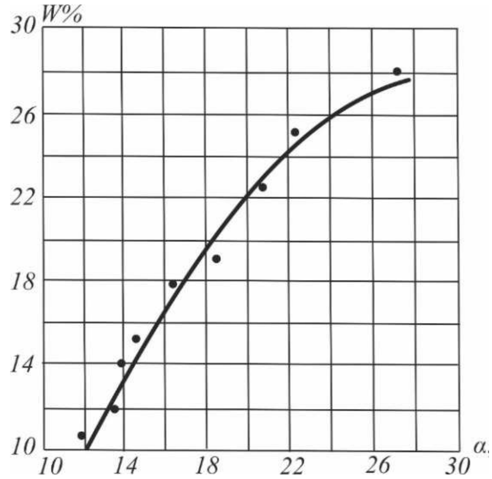

Fig. 1. The relationship between the moisture content of wheat grain Bezostaya-1 and the readings of the moisture meter

Values $\overline{W}$, $\bar{\alpha}$, σ_W, σ_α are calculated according to the scheme in Table 1.

In Table 1 symbols ΔW and $\Delta\alpha$ are deviations of measurement results from average values. The correlation coefficient included in the equation (1) is calculated by the formula:

$$r_{W/\alpha} = \frac{C_{W/\alpha}}{\sigma_W \sigma_\alpha}. \quad (2)$$

The basic error of a graduated moisture meter on a given material is (in % moisture):

$$\sigma_{bas.} = \sigma_W\sqrt{1 - r^2_{W/\alpha}}. \quad (3)$$

If the dependence is clearly non-linear:

$$W = W_L + \sigma_W \frac{b}{a}\left[\frac{\left(\alpha - \overline{\alpha}\right)^2}{\sigma_\alpha^{\;2}} - \frac{r_{3\alpha}}{\sigma_\alpha}\left(\alpha - \overline{\alpha}\right) - 1\right], \quad (4)$$

where σ_W, σ_α are root-mean-square deviations when determining moisture by sample methods with a graduated moisture meter, respectively.

Coefficients a and b are calculated by the formulas:

$$\left.\begin{aligned} a &= r_{4\alpha} - r^2_{3\alpha} - 1 \\ b &= r_{2\alpha/W} - r_{3\alpha} r_{W/\alpha} \end{aligned}\right\}. \quad (5)$$

The moments $r_{4\alpha}, r_{3\alpha}$, $\frac{r_{2\alpha}}{W}$ of the random variables ΔW_i and $\Delta\alpha_i$ are calculated by expressions:

Table 1. Scheme for calculating auxiliary values of the regression equation

W_i	α_i	ΔW_i	$\Delta\alpha_i$	ΔW_i^2	$\Delta\alpha_i^{\ 2}$	$\Delta W_i \Delta\alpha_i$	$\Delta\alpha_i^{\ 3}$	$\Delta\alpha_i^{\ 4}$	$\Delta\alpha_i^{\ 2}\Delta W_i$
W_1	α_1	$\Delta W_1 = W_1 - \overline{W}$	$\Delta\alpha_1 = \alpha_1 - \overline{\alpha}$	ΔW_1^2	$\Delta\alpha_1^{\ 2}$	$\Delta W_1 \Delta\alpha_1$	$\Delta\alpha_1^{\ 3}$	$\Delta\alpha_1^{\ 4}$	$\Delta\alpha_1^{\ 2}\Delta W_1$
…									
W_n	α_n	$\Delta W_n = W_n - \overline{W}$	$\Delta\alpha_n = \alpha_n - \overline{\alpha}$	ΔW_n^2	$\Delta\alpha_n^{\ 2}$	$\Delta W_n \Delta\alpha_n$	$\Delta\alpha_n^{\ 3}$	$\Delta\alpha_n^{\ 4}$	$\Delta\alpha_n^{\ 2}\Delta W_n$
$\sum_{i=1}^{n} W_i$	$\sum_{i=1}^{n} \alpha_i$	$\sum_{i=1}^{n} \alpha_i$	$\sum_{i=1}^{n} \Delta\alpha_i$	$\sum_{i=1}^{n} \Delta W_i^2$	$\sum_{i=1}^{n} \Delta\alpha_i^2$	$\sum_{i=1}^{n} \Delta W_i \Delta\alpha_i$	$\sum_{i=1}^{n} \Delta\alpha_i^3$	$\sum_{i=1}^{n} \Delta\alpha_i^4$	$\sum_{i=1}^{n} \Delta\alpha_i^2 \Delta W_i$
$\overline{W} = \frac{\sum_{i=1}^{n} W_i}{n}$	$\overline{\alpha} = \frac{\sum_{i=1}^{n} \alpha_i}{n}$	$\overline{\Delta W} = \frac{\sum_{i=1}^{n} \Delta W_i}{n}$	$\Delta\overline{\alpha} = \frac{\sum_{i=1}^{n} \Delta\alpha_i}{n}$	$C_W = \frac{\sum_{i=1}^{n} \Delta W_i^2}{n}$ $\sigma_W = \sqrt{C_W}$	$C_\alpha = \frac{\sum_{i=1}^{n} \Delta\alpha_i^2}{n}$ $\sigma_\alpha = \sqrt{C_\alpha}$	$C_{W/\alpha} = \frac{\sum_{i=1}^{n} \Delta W_i \Delta\alpha_i}{n}$	$C_{3\alpha} = \frac{\sum_{i=1}^{n} \Delta\alpha_i^{\ 3}}{n}$	$C_{4\alpha} = \frac{\sum_{i=1}^{n} \Delta\alpha_i^{\ 4}}{n}$	$C_{2\alpha/W} = \frac{\sum_{i=1}^{n} \Delta\alpha_i^{\ 2}\Delta W_i}{n}$

$$\left.\begin{aligned} r_{3\alpha} &= \left(c_{3\alpha} - 3c_\alpha \Delta\overline{\alpha}\right) / \sigma_\alpha^3 \\ r_{4\alpha} &= \left(c_{4\alpha} - 4c_{3\alpha}\Delta\overline{W}\right) / \sigma_\alpha^4; \\ r_{2\alpha/W} &= \left(c_{2\alpha/W} - 2c_{W/\alpha}\Delta\overline{\alpha} - c_\alpha \Delta\overline{W}\right) / \left(\sigma_\alpha^2 \sigma_W\right) \end{aligned}\right\}. \quad (6)$$

Calculations of the auxiliary values included in equations (4) and (6) are performed according to the scheme (Table 1). The basic error of the moisture meter (in % moisture) is calculated by the formula:

$$\sigma_{bas.} = \pm\sqrt{\frac{1}{n-3}\sum_{i=1}^{n}\left(W_i - W_{\alpha i}\right)^2}, \quad (7)$$

where n – dimension number;

W_i – experimental values of GM moisture content;

$W_{\alpha i}$ – theoretical values of GM moisture content, calculated by the formula (4).

If the conducted analysis is correct, the theoretical regression line plotted on the correlation field should be located as close as possible to the experimental measurement points.

Table 2. Scheme for calculating auxiliary values of the regression equation

W_i	α_i	ΔW_i	$\Delta\alpha_i$	ΔW_i^2	$\Delta\alpha_i^{\ 2}$	$\Delta W_i \Delta\alpha_i$	$\Delta\alpha_i^{\ 3}$	$\Delta\alpha_i^{\ 4}$	$\Delta\alpha_i^{\ 2}\Delta W_i$
W_1	α_1	$\Delta W_1 = W_1 - \overline{W}$	$\Delta\alpha_1 = \alpha_1 - \overline{\alpha}$	ΔW_1^2	$\Delta\alpha_1^{\ 2}$	$\Delta W_1 \Delta\alpha_1$	$\Delta\alpha_1^{\ 3}$	$\Delta\alpha_1^{\ 4}$	$\Delta\alpha_1^{\ 2}\Delta W_1$
W_n	α_n	$\Delta W_n = W_n - \overline{W}$	$\Delta\alpha_n = \alpha_n - \overline{\alpha}$	ΔW_n^2	$\Delta\alpha_n^{\ 2}$	$\Delta W_n \Delta\alpha_n$	$\Delta\alpha_n^{\ 3}$	$\Delta\alpha_n^{\ 4}$	$\Delta\alpha_n^{\ 2}\Delta W_n$
$\sum_{i=1}^{n} W_i$	$\sum_{i=1}^{n} \alpha_i$	$\sum_{i=1}^{n} \alpha_i$	$\sum_{i=1}^{n} \Delta\alpha_i$	$\sum_{i=1}^{n} \Delta W_i^2$	$\sum_{i=1}^{n} \Delta\alpha_i^2$	$\sum_{i=1}^{n} \Delta W_i \Delta\alpha_i$	$\sum_{i=1}^{n} \Delta\alpha_i^3$	$\sum_{i=1}^{n} \Delta\alpha_i^4$	$\sum_{i=1}^{n} \Delta\alpha_i^2 \Delta W_i$
$\overline{W} = \frac{\sum_{i=1}^{n} W_i}{n}$	$\overline{\alpha} = \frac{\sum_{i=1}^{n} \alpha_i}{n}$	$\overline{\Delta W} = \frac{\sum_{i=1}^{n} \Delta W_i}{n}$	$\Delta\overline{\alpha} = \frac{\sum_{i=1}^{n} \Delta\alpha_i}{n}$	$C_W = \frac{\sum_{i=1}^{n} \Delta W_i^2}{n}$ $\sigma_W = \sqrt{C_W}$	$C_\alpha = \frac{\sum_{i=1}^{n} \Delta\alpha_i^2}{n}$ $\sigma_\alpha = \sqrt{C_\alpha}$	$C_{W/\alpha} = \frac{\sum_{i=1}^{n} \Delta W_i \Delta\alpha_i}{n}$	$C_{3\alpha} = \frac{\sum_{i=1}^{n} \Delta\alpha_i^{\ 3}}{n}$	$C_{4\alpha} = \frac{\sum_{i=1}^{n} \Delta\alpha_i^{\ 4}}{n}$	$C_{2\alpha/W} = \frac{\sum_{i=1}^{n} \Delta\alpha_i^{\ 2}\Delta W_i}{n}$

The basic error of the vibration flow moisture meter [8-10] obtained as a result of the calculation should not exceed the permissible value. Otherwise, the graduation of the moisture meter is repeated.

3 Results and discussion

Here is the analysis of data obtained as a result of the graduation of grain moisture meter using the example of Bezostaya-1 wheat grain of 2020. The graduation table based on the constructed correlation field has been drawn up (Figure 1). The correlation dependence between the values of grain moisture and moisture meter readings is nonlinear, measurements are carried out at an ambient temperature of $t = 20°$.

Auxiliary quantities included in the second-order regression equations have been found (Table 3).

Table 3. Calculation results of auxiliary values for basic error of the moisture meter

W_i	α_i	Wa_i	W_i - Wa_i	$(W_i - Wa_i)^2$
28.3	27.6	27.95	0.35	0.12
27.1	24.4	25.85	1.25	1.56
25.0	22.3	23.97	1.03	1.06
22.2	20.6	22.16	0.04	0.0016
19.1	18.3	19.29	-0.19	0.04
17.0	16.5	16.72	0.28	0.08
15.2	15.1	14.51	0.69	0.48
13.5	14.2	13.0	0.5	0.0
12.0	13.6	11.95	0.05	0.0

The correlation coefficient has been calculated by the formula:

$$r_{W/\alpha} = C_{W/\alpha} / \sigma_W \, \sigma_\alpha = \frac{28.96}{6.11 \cdot 4.83} = 0.981 .$$

The moments of random variables have been calculated by the formulas:

$$r_{3\alpha} = \frac{\left(C_{3\alpha} - 3C_\alpha \Delta\overline{\alpha}\right)}{\sigma_\alpha^3} = 0.499 ;$$

$$r_{4\alpha} = \frac{\left(C_{4\alpha} - 4C_{3\alpha} \Delta\overline{W}\right)}{\sigma_\alpha^4} = \frac{1066.12 - 4 \cdot 56.26 \cdot 0}{4.83^4} = 1.959;$$

$$r_{2\alpha/W} = \frac{\left(C_{2\alpha/W} - 2C_{W/\alpha} \cdot \Delta\overline{\alpha} - C_\alpha \Delta W\right)}{\sigma_\alpha^2 \cdot \sigma_W} = \frac{52.36 - 2 \cdot 28.96 \cdot 0 - 23.36 \cdot 0}{4.83^2 \cdot 6.11} = 0.367.$$

The coefficient of the nonlinear part of the regression equation has been determined by the formulas (2):

$a = 1.959 - 0.499 = 1.959 - 0.249 = 0.710$;

$b = 0.367 - 0.499 \cdot 0.981 = -0.123$.

The regression equation (4) of the second order has been calculated:

$$W = 18.96 + 0.981 \cdot 1.265(a - 18.5) + 6.11\frac{-0.123}{0.171} \times \left[\frac{(\alpha - 18.5)^2}{23.33} - \frac{0.499}{4.83}(\alpha - 18.5) - 1\right];$$

$$W = -0.045\alpha^2 + 2.997\alpha - 20.484. \qquad (8)$$

The basic error of the moisture meter has been calculated and, for convenience, these results have been brought into Table 3.

$W_{\alpha 1} = -0.045 \cdot 27.6^2 + 2.997 \cdot 27.6 - 20.484 = 27.95;$

$W_{\alpha 2} = -0.045 \cdot 24.4^2 + 2.997 \cdot 24.4 - 20.484 = 25.85;$

$W_{\alpha 3} = -0.045 \cdot 22.3^2 + 2.997 \cdot 22.3 - 20.484 = 23.97;$

$W_{\alpha 4} = -0.045 \cdot 20.6^2 + 2.997 \cdot 20.6 - 20.484 = 22.16;$

$W_{\alpha 5} = -0.045 \cdot 18.3^2 + 2.997 \cdot 18.3 - 20.484 = 19.29;$

$W_{\alpha 6} = -0.045 \cdot 16.5^2 + 2.997 \cdot 16.5 - 20.484 = 16.72;$

$W_{\alpha 7} = -0.045 \cdot 15.1^2 + 2.997 \cdot 15.1 - 20.484 = 14.51;$

$W_{\alpha 8} = -0.045 \cdot 14.2^2 + 2.997 \cdot 14.2 - 20.484 = 13.0;$

$W_{\alpha 9} = -0.045 \cdot 13.6^2 + 2.997 \cdot 13.6 - 20.484 = 11.95;$

Substituting the moisture meter readings into the regression equation with an interval of 0.2 scale division in the range of 12-27.8 the values of grain moisture have been calculated. The data has been entered into the graduation in Table 4.

The basic error of the moisture meter has been calculated by the formula (7) in % of moisture:

$$\sigma_{bas.} = \pm\sqrt{\frac{1}{10-3}3.40} = \pm 0.49\%.$$

Substituting into equation (4) the current values of the moisture meter readings in the range from α_I to α_n with an interval of 0.2 division for the grain mass, the moisture values have been calculated and entered in Table 4.

4 Conclusions

1. The graduation technique of the vibration flow grain moisture control device is closely related, in particular, with the following directions of grain moisture measurement: a) regulation of the moisture content of various grain materials used in the national economy; b) standardization of methods for analytical laboratory control of their moisture content; c) standardization of physical methods for measuring moisture and technical means based on these methods; d) standardization of verification charts, measurement standards, sample methods, installations and substances; e) creation of a unified terminology, a system of units of measurement and standard reference data in the field of grain moisture measurements.

2. The presented graduation technique made it possible to solve two problems: a) determination of the graduation dependence that meets the requirement of the most accurate correspondence to statistical data; b) assessment of the basic error of graduated device.

3. The basic error of the moisture meter was no more than ± 0.5%, which is an acceptable result for practice.

Table 4. Graduation table of moisture meter of wheat grain Bezostaya-1

Moisture meter readings, div.	Moisture, %	Moisture meter readings, div.	Moisture, %	Moisture meter readings, div.	Moisture, %	Moisture meter readings, div.	Moisture, %	Moisture meter readings, div.	Moisture, %
12.0	9.0	15.2	14.7	18.4	19.4	21.6	23.3	24.8	26.2
12.2	9.4	15.4	15.0	18.6	19.7	21.8	23.5	25.0	26.3
12.4	9.8	15.6	15.3	18.8	20.0	22.0	23.7	25.2	26.5
12.6	10.1	15.8	15.6	19.0	20.2	22.2	23.9	25.4	26.6
12.8	10.5	16.0	15.9	19.2	20.5	22.4	24.1	25.6	26.7
13.0	10.9	16.2	16.3	19.4	20.7	22.6	24.3	25.8	26.9
13.2	11.2	16.4	16.6	19.6	21.0	22.8	24.5	26.0	27.0
13.4	11.6	16.6	16.9	19.8	21.2	23.0	24.6	26.2	27.1
13.6	12.0	16.8	17.2	20.0	21.5	23.2	24.8	26.4	27.3
13.8	12.3	17.0	17.5	20.2	21.7	23.4	25.0	26.6	27.4
14.0	12.7	17.2	17.8	20.4	21.9	23.6	25.2	26.8	27.5
14.2	13.0	17.4	18.0	20.6	22.2	23.8	25.4	27.0	27.6
14.4	13.3	17.6	18.3	20.8	22.4	24.0	25.5	27.2	27.7
14.6	13.7	17.8	18.6	21.0	22.6	24.2	25.7	27.4	27.8
14.8	14.0	18.0	18.9	21.2	22.8	24.4	25.9	27.6	28.0
15.0	14.3	18.2	19.2	21.4	23.0	18.2	26.0	27.8	28.1

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