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Study of Grain Drying in the Automated Grain Drying Unit

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Abstract. Mine and column grain dryers are a fairly complex object of control in the production line. The process of grain drying is characterized by a large number of parameters, quantitatively and qualitatively characterizing the dryer operation. First of all, this includes the criteria of maximum performance and minimum deviations of the moisture content of the dried grain from the standard values. These criteria, as studies show, are interconnected with each other: an increase in the performance П of the dryer leads to an increase in the moisture content of the grain coming out of it, and, conversely, an attempt to reduce the moisture content of grain causes the need to reduce the performance П. (*Research purpose*) The research purpose is to develop the expression for the transfer functions of the of grain flow control depending on perturbations of the initial moisture content and the maximum grain temperature, as well as to conduct experimental studies. (*Materials and methods*) The authors have developed simplified mathematical models of moisture perturbation compensation of grain coming in for drying and its heating temperature in a drying chamber by changing the dryer performance on the basis of theoretical-and-experimental studies. (*Results and discussion*). The authors have obtained expressions to control the process performance when the current humidity and temperature change through the dryer performance parameters as a function of grain moisture flow and heat used to grain heating up to an acceptable temperature. Farm tests of developed transition management functions have been implemented for dryer SZT-16 controlled by PLC S7-1200 Siemens and operating in an automatic mode. Tests have been conducted on the "Babachev" farm, Karachev district of the Bryansk region in the process of drying food wheat grain. (*Conclusion*) It has been confirmed that the dryer performance is determined not only by the rated capacity but also by the deviation of the current moisture content of grain from the specified values and by the ratio of the amount of heat used for evaporating and heating. The dryer performance at constant initial humidity is determined by its rated performance, the maximum specified difference of grain temperatures, as well as the ratio of the amounts of heat used for evaporating and heating.

Keywords: grain, drying, automation, control algorithms.

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Automatic control of grain drying processes opens up wide prospects for increasing its efficiency, reducing labor costs and improving the product quality.

Shaft and column grain dryers are quite a complex control object in the production line. The process of grain drying is characterized by a large number of parameters that quantitatively and qualitatively affect the dryer performance. Among these parameters the are the moisture content of grain at the dryer inlet and outlet, the dryer performance, the temperature of grain heating and the drying agent supplied to and spent in the dryer [1-6].

From this set of particular criteria, those relating to the dryer include, first of all, the criteria for maximum productivity and minimum deviations in the moisture of the dried grain from the standard values. These criteria, as studies show, are related to each other: an increase in the dryer performance Π reduces the moisture content of grain coming out of it, and, conversely, an attempt to reduce the moisture content of grain causes the need for a reduction in the performance Π. Since grain and seed processing enterprises should meet the requirements of standards, the moisture content of the obtained grain and seeds should not exceed the standard value, so the criterion $min\ W$ becomes a restriction of the form $W \leq W_{con}$. In addition, the drying process of seed grain should meet the requirement of impermissibility of reducing the seed quality of finished products. This requirement, when applied to grain dryers, is to prevent grain overheating, i.e., the temperature θ of the grain should not exceed the permissible value $\theta_{доп}$ [7, 8].

Thus, the optimal control function is often expressed in the form:

$$max\ \Pi = f(\theta, W, t), \qquad (1)$$

where Π – performance, t/h; θ – temperature of grain, °C;

W – moisture content of grain, %; t – temperature of the drying agent, °C.

With restrictions:

$$W \le W_{кон} \text{ и } \theta \le \theta_{доп}. \quad (2)$$

To describe the drying process in shaft and column dryers, a number of mathematical models have been developed, both based on differential equations and found empirically, but in the latter case, a number of parameters must be determined experimentally for each particular object, which is rather difficult [9, 10].

The task is to develop, on the basis of theoretical and experimental studies, simplified mathematical models for compensating the humidity disturbances of grain entering the drying stage and the temperature of its heating in the drying chamber by changing its performance.

The purpose of the present research is to develop expressions of the transfer functions of controlling the amount of grain dried, depending on the disturbances of the initial moisture and the maximum grain temperature, and also to carry out an experimental test.

Materials and methods. The dryer capacity by the mass of evaporated moisture can be presented as:

$$\Pi = \frac{G\left(U_1 - U_2\right)}{\tau\eta}, \text{ kg moist./h}, \quad (3)$$

where Π – rated performance of the dryer, t/h; G – grain mass in the dryer, kg; U_1, U_2 – moisture content of the initial and conditioned grain, kg moist./kg dry mat.; τ – duration of drying, h; η – the fraction of heat used to evaporate moisture.

Changing the dryer performance with deviations in the initial moisture content of the grain can be presented as:

$$\Pi_m = \frac{G\left(U_0 - U_1\right)}{\tau\eta}, \text{ kg moist./h},$$

where U_0 – the current moisture content of grain, kg moist./kg dry mat.; finally, the current performance looks like:

$$\Pi_m = \Pi \frac{\left(U_0 - U_1\right)\eta}{\left(U_1 - U_2\right)\eta_1}, \text{ t / h}, \quad (4)$$

where η_1 – the fraction of heat used to evaporate moisture in the case of humidity deviations.

The amount of heat used to evaporate moisture equals:

$$\eta = \frac{\Delta U\, r}{\Delta U\, r + \Delta\theta\, c},$$

where ΔU – the difference in moisture content, kg moist./kg dry mat.; $\Delta\theta$ – temperature difference at grain drying, °C; c – heat capacity of grain, kJ/kg. evap. moist.; specific heat of moisture evaporation, kJ/kg.

At a significant excess of the current humidity U_0 above the standard moisture (more than 1-1.5%), the dryer is transferred from the stream to the circulation mode, so grain rate ceases, and the expected circulation time can be determined by the expression:

$$\tau_ц = \tau\frac{U_0 - U_2}{U_1 - U_2}, \text{ h}, \quad (5)$$

where τ – drying time, h.

The value of τ is calculated from the known U_1, U_2 and the temperature mode of drying in order to estimate the time for transferring the operation of the dryer from the circulation to flow mode [11].

The main parameters characterizing the thermal mode of a grain dryer are the temperature of the coolant supplied to the drying chamber and the temperature of grain heating. On the one hand, the drying process must be carried out in such a way as not to exceed the permissible temperature of grain heating, but on the other hand, drying is most effective at the heating temperature limits. The desire to intensify the drying process led to the development of various systems of automatic regulation (stabilization) of the grain heating temperature, in which the control of the fuel supply and drying exposure (by varying the performance) were used as control actions. These systems allow maintaining the specified moisture content of grain, but do not prevent its drying or excess moisture of the output grain.

Let us consider a particular problem of changing the grain temperature with a constant initial moisture content. The dryer capacity for the heat used for drying can be presented as follows:

$$\Pi = \frac{G\,c\left(\theta_к - \theta_н\right)\eta_1}{\tau}, \text{ kJ/h}, \quad (6)$$

where $\theta_к$, $\theta_н$ – the final and initial temperature of grain, °C.

With temperature perturbations, the heat output varies according to the expression:

$$\Pi_0 = \frac{G\,c\left(\theta'_к - \theta_к\right)\eta_2}{\tau}, \text{ kJ/h}, \quad (7)$$

where $\theta'_к$ – the current grain temperature, °C.

The current capacity of the dryer is:

$$\Pi_0 = \Pi\frac{\left(\theta'_к - \theta_к\right)\eta_2}{\left(\theta_к - \theta_н\right)\eta_1}, \text{ t/h}. \quad (8)$$

When calculating $\theta'_к$ it is necessary to take into account the location of the temperature sensors and the inertia of grain heating.

Assuming that the temperature increases linearly along the shaft length and its maximum value is reached at the mine outlet, it is advisable to control the grain temperature in the upper regions of the column, for example, to place a thermal sensor at the entrance of the last drying section and determine $\theta_{к0}$ and $\theta'_{к0}$, decreasing their values by:

$$\Delta\theta = \frac{\theta_{\text{к}} - \theta_{\text{н}}\,(n-1)}{n};$$

$$\theta_{\text{к}0} = \theta_{\text{к}} - \Delta\theta \text{ и } \theta'_{\text{к}0} = \theta'_{\text{к}} - \Delta\theta, \qquad (9)$$

where n – the number of drying sections.

The economic checking-up of the developed transmission control functions was carried out during testing of the NWT-16 grain dryer, controlled by the S7-1200 Siemens logic controller and operating in an automatic mode. The tests were carried out in the «Baibashev» peasant farm, Karachev district of the Bryansk region, in the process of drying food wheat grain.

The controller was programmed for a specific 13 crops, including rapeseed, soybean, and corn. According to empirical relationships, the moisture content of grain at the inlet and outlet was measured by the Mikroradar-113 moisture meter. The grain temperature was measured by resistance thermometers. The grain dryer is controlled by changing the rotational speed of the rotor-type unloading device, for which a frequency converter is installed on its drive.

The technological scheme of the dryer is shown in *Fig. 1.*

The device operates as follows. The wet grain is fed through the first stream of the grain elevator through a valve that is set to flow or circulated into the moisture meter of wet grain (at the dryer inlet), then to the dryer, dried and cooled grain is discharged by the rotors, the drive of which is set to the specified flow rate and through a discharge the device is fed to the moisture meter at the outlet by the second stream of the grain elevator and is withdrawn from the dryer. The drying agent is prepared in a furnace and fed through a diffuser into the dryer.

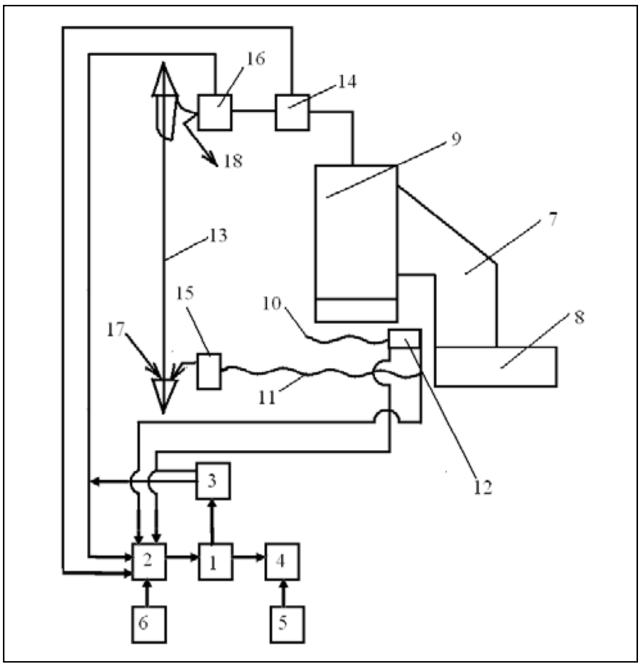

Fig. 1. Technological scheme of the dryer: 1 – contains micro-processor; 2 – meter; 3 – correction unit; 4 – sensor; 5 – grain crop selection unit; 6 – pause correction unit; 7 – dryer diffuser; 8 – furnace; 9 – dryer; 10 – discharge rotors; 11 – discharge device; 12 – rotor drive; 13 – grain elevator; 14 – moisture meter at the dryer inlet to the; 15 – moisture meter at the dryer outlet; 16 – transfer valve from the circulation to flow mode. Also shown in the diagram are directions of move-ment of wet grain 17 and dried grain 18

Sensor *4* is set for the crop name, the initial and final moisture of grain, the device is actuated in the humidity measurement mode of the set crop from moisture meter *15*, correction unit *3* is provided to compensate for external factors, in block *6*, the grain rate is automatically set according to the expression $V_i = K\cdot(W_i - W_{min})$, where V_i – a current value of the analog signal, V; K is the conversion coefficient of the moisture humidity index to the analog signal; W_i – current moisture value of the measured crop, %; W_{min} – the minimum value of humidity,%, there is a change in the rate of grain depending on its humidity at the dryer outlet.

When the moisture content of grain is relatively higher than the standard one, the grain rate decreases due to the rotational speed of the rotors, and then, if the moisture content of the grain does not reach the standard one, a pause is made.

At the end of the pause of at least *3* analog signals from moisture meter *15*, which is necessary to compensate for the current unevenness of grain in terms of humidity, grain unloading stops and the device enters the circulation mode. When the standard moisture ia achieved, the circulation stops, and the grain unloading resumes.

Two experiments were carried out with automatic correction of the rotor speed without grain circulation during the pause (*Fig. 2*) and with periodic circulation (*Fig. 3*).

The speed of rotors is determined basing on the condition that Π = 32 t/h at P=100%. The main indicators of the dryer are given in *Tab. 1.*

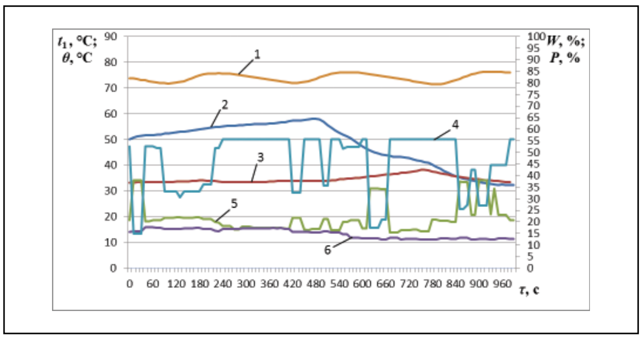

Fig. 2. Dependence of temperature (t, θ), rotor speed (P) and grain moisture W from time τ for dryer SZT-16 with controller 1 – drying agent temperature; 2 – grain temperature after drying; 3 – before drying; 4 – rotation speed of the unloading rotor; 5 – initial grain moisture; 6 – final grain moisture

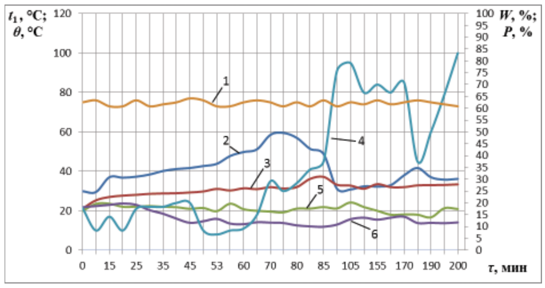

Fig 3. Dependence of temperature (t, θ), rotor speed (P) and grain moisture W from time τ for the automated dryer SZT-16: 1 – drying agent temperature; 2 – grain temperature after drying; 3 – before drying; 4 – rotation speed of the unloading rotor; 5 – initial grain moisture; 6 – final grain moisture

or the maximum grain temperature , correspond to the experimental data (with an error of not more than 15-20%).

Simplified analytical expressions have been developed for automatic control of the dryer's performance with respect to the initial and maximum moisture content of grain, which do not require specifying additional parameters. Comparison is made of a signal coming from moisture meters at the inlet and outlet of the dryer with the values of the initial and final moisture content of grain and the amount of heat used to evaporate moisture that are set in the control program. It is possible to stabilize the temperature mode of drying by varying the dryer performance, depending on the change in the grain heating temperature at W = const.

Periodic grain circulation is used when the current humidity value is higher than the standard one and it contributes to increased performance.

Table

The main performance indicators of the dryer SZT-16 (wheat processing)

Performance indicators	Indicators values	
	Flow-line mode, background 1	With periodic circulation, background 2
Performance, tons/h	14,2	14,7
Grain moisture, %		
– before drying	19,7	21,4
– after drying	13,4	13,8
Temperature, °C:		
– coolant	74	74,6
– grain at the dryer inlet	25	20
– grain in the maximum heating zone	48	48
– cooled grain	34	32
– external air	25	19
Fuel consumption (natural gas), m^3/h	78	80,5
Coolant consumption, m^3/h	35000	35000
Relative heat consumption, kJ/kg evap. moist.	2560	2472
Temperature of flue gases, °C	207	-
Heat productivity, MW	0,6	0,622

Results and discussion. In the first experiment, grain was dried with correction of its flow rate according to the expression $V_i = K (W_i – W_{min})$ set in the dryer control program. When the humidity deviated from the standard value, the circulation of grain was not used [9]. In the second experiment, when the final humidity deviated from the standard value, the circulation was used, which led to a higher performance of the dryer.

The experimental data obtained were compared with those calculated from expressions (4) and (8), developed for a simplified control system for the dryer by humidity and grain temperature. It has been established that the calculation results of the performance, depending on the change in the initial moisture content

Conclusions. The dryer performance is determined by its rated performance, the deviation of the current moisture content of grain from the specified values and from the ratio of the amount of heat used for evaporation and heating.

If the initial moisture content is constant, the dryer performance is determined by its rated performance, maximum set difference of grain temperatures, and the amount of heat used for evaporation and heating.

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