Automated control scheming of flat-type granaries to ensure grain safety

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Abstract. The article considers the implementation of the strategic grain production planning to provide the population with high-quality and safe food in the Russian markets, as well as to improve the standard of living. Various conditions of grain storage have been investigated. The analysis of flat-type granaries has been carried out and their shortcomings have been revealed. At the established higher wheat moisture the problems that contribute to the loss of weight and quality have been identified. Methods of moisture measurement for grain crops have been studied. During the study, the grain moisture index was measured using thermogravimetric, conductometric, dielectric and microwave moisture measurement. The influence of the wheat «Favorit» and «Donskaya Elegia» moisture mass fraction on self-heating and grain contamination has been studied. These grain varieties were stored in a flat-type granary. A promising direction for the automated control scheming is the use of waveguide grain moisture sensors for technological operations which require a flat floor surface. The sensor design features and the conditions for their placement have been presented. The study have proved the need to create an automated humidity control scheme to ensure basic indicators of wheat quality. The paper proposes a scheme of water-wave sensors installation.

1. Introduction

Pursuant to Federal Law № 172 «On Strategic Planning in the Russian Federation», a long-term strategy for the grain production development for 2016-2025 was developed in 2016 [1]. The grain production involves many sub-sectors of agriculture, food and processing industry, transport and trade, which provide production, transportation, storage, processing and sale of cereals and further processed products in the domestic and foreign markets [2].

Grain production is an important part of the Russian agricultural economy development. The level of this agricultural sector development largely determines the country’s food security and improves the standard of living meeting food needs. According to the National Food Security Doctrine [3, 5] the minimum value of specific weight of home-grown grain (not less than 95%) is established. In recent years this index has never fallen below the specified level [2].

Therefore, the maintenance of grain quality at a high level for a long time until it is sent for processing or for seed purposes is a very important task.

For reliable grain storage it is important to create optimal conditions that will save the grain from the external influences, in particular, from high humidity, temperature changes, pathogenic...
microorganisms for a long time. The main means of ensuring the implementation of this aspect is a
granary. Currently there are more than 500 grainaries and grain silos in the Russian Federation [4].
The flat-type granaries are especially important because they are able to accommodate large volumes
of grain, they are not so expensive as grain silos, their construction takes a little time, and they often
pay off in the first year of operation. However, such granaries usually do not assume the availability of
tools that contribute to the automation of loading and unloading, and most importantly, there is a
difficulty in creating facilities for full protection from the natural factors effects (high or low
temperature and high humidity, pests), which can lead to a decrease in the values of quality
characteristics and the presentation declining [6].

Grain is a living organism. A dry grain (with a moisture content not exceeding 11%) can be stored
for years with virtually no loss in weight and quality characteristics. With an increase in moisture in
wheat (a critical value is 15%), vital processes are intensified, as a result of which the following
problems may arise, leading to loss of mass and quality:
- intensification of respiration, which is the root cause of grain self-heating;
- the possibility of germination, and as a result, the activation of hydrolytic enzymes that break
down proteins, fats and carbohydrates;
- the growth of the microorganisms’ life activity that increase the likelihood of toxic substances,
  and insects intensification that dramatically increase the value of impurities.

Thus, grain storage is the most significant process in the grain production technology, during which
it is necessary to provide continuous control of the grain moisture and the temperature in granaries.
Due to the fact that grain storage is a lengthy process, special conditions are established for it to
control grain characteristics [7].

Today grain tedding by portable winnowers is used in flat-type granaries to prevent grain moisture
increase. It is important to note that the costs of using portable winnowers are most significant at the
stage of grain storage.

The grain tedding, as a rule, is carried out in accordance with the work schedule. Thus, the
moisture and temperature of the grain in the granary are not taken into account, which can lead either
to the use of the wasters “in vain” (if the grain parameters are in the optimal range), or to the
appearance of marriage during storage (with long intervals between teddings). That is, the absence of a
system for controlling the parameters of grain humidity and temperature in flat-type granaries
contributes to the increase in costs at this stage.

2. Materials and methods
The object of the study is the wheat produced in the Central Black Soil Region. They are spring soft
«Favorit» and spring durum «Donskaya Elegia».

All moisture measuring methods are divided into two groups: direct, which determine the moisture
content in the grain directly, and indirect, which measure a parameter that depends on moisture.
During the study, the grain moisture index was measured using the most common measurement
methods [8]: thermogravimetric, conductometric, dielectricmetric, and microwave moisture measurement.

The thermogravimetric method is based on the measurement of moisture by drying. Its advantages
are high accuracy and reliability of measurement. It does not require information about the grain
characteristics, but it takes a lot of time (up to 60 minutes) and the use of a human resource is a
prerequisite for its implementation. Therefore, it is considered a laboratory method and is not suitable
for automatic control.

The conductometric moisture measuring principle is based on determining the conductivity of the
grain mass. Its main disadvantage is a large variety of indicators depending on the grain type and the
place of growth. The conductivity of the grain mass depends on the parameters of the sensitive
element; in this measurement, the sample readings are considered to be the general indexes of the
whole grain mass. The appearance of high moisture zones in the total mass is not taken into account.

The dielectricmetric method of grain moisture measuring involves the determination of the medium
dielectricmetric permeability, which is significantly dependent on moisture. Devices of this type have a
high measurement speed and low error (up to 1%), but due to the design features of the sensitive
element they are mainly used in silos, which complicates their use in flat-type granaries.

The basic principle of a microwave moisture meter measurement is the absorption of
electromagnetic field energy by the measured sample; according to this process, the moisture value is
determined by the value of the power attenuation in the receiving device. The relationship between
moisture and the amount of power attenuation is close to linear. Moisture meters of this type have a
small measurement error (from 0.1 to 0.3%), their readings do not depend on the grain type.

The wheat grain quality was assessed by the mound temperature. Mercury thermometers were used to
measure the wheat temperature. They were immersed with a rod into the grain mound at different depths:
with a mound height of up to 3 m at a depth of 0.5-1.5-2.5 m, and with a mound height exceeding 3 m,
after 2.5 m through each meter. To control the readings results, the entire surface of the grain mound was
divided into sections (squares) 100 m² each. Within each section the thermal rods were placed in the
studied surface at five points, and 4 of 5 points should be 2-3 m. from the edges. At each point, repeated
temperature measurements were carried out at three depth levels.

Another grain quality indicator during storage is the product contamination determined by
QMFAFM (quantity of mesophyll aerobic and optional-anaerobic microorganisms). The determination
method is in seeding the test sample in a nutrient medium, incubating the crops, counting all grown
visible colonies.

3. Study of the product moisture changes during storage in a flat-type granary
Grain moisture is the main technological parameter characterizing the occurrence of self-heating,
germination, growth of the microorganisms’ vital activity. Grain with high moisture content is subject
to the occurrence of biological processes that increase its temperature. Thus, control of grain moisture
will prevent the process of grain self-heating and temperature increasing.

During the study, the maximum grain temperature in the mound was monitored for 2 months at
different initial wheat moisture. At the same time, the ambient temperature was maintained at the level
of (10.0 ± 1.5) ° C. In all cases, an increase in temperature was observed inside the mound due to
respiration processes. In dry «Favorit» and «Donskaya Elegia» grain (10% moisture) the temperature
reached critical only after 1.5 months, while in wet grain (20% moisture) the self-heating process was
quite intense, and for about 3.5 weeks the temperature reached the point of irreversibility, in which the
grain quality deteriorates irrevocably.

Figure 1. Temperature Changes in the wheat grain mound during storage at different initial grain
moisture levels (1 – 10 %; 2 – 15 %; 3 – 20 %): a – «Favorit» wheat; b – «Donskaya Elegia» wheat
The analysis of the wheat contamination studies during storage (figure 2) showed that the QMAFAnM change in dry grain is insignificant, and the growth is most likely due to factors unrelated to the initial moisture content. At the same time, if the moisture content in the grain exceeds the allowable 14.5%, there was a sharp increase in QMAFAnM over the permissible limits.

Figure 2. QMAFAnM changes in wheat grain during storage at different initial grain moisture (1 – 5%; 2 – 10%; 3 – 15%; 4 – 20%; 5 – 25%); a – “Favorit” wheat; b “Donskaya Elegia” wheat

Thus, timely automatic moisture control is an important factor for flat-type granaries.

4. Automated moisture control scheming of a flat-type granary

Microwave measuring methods were used for automated moisture control scheming. They are divided [9] into:

- free space methods - the test sample is located between two antennas;
- resonator methods - the test sample is located in the resonator;
- waveguide methods - the test sample is located in a segment of the waveguide line;
- probe methods - the probe is placed in the test sample.

The use of waveguide grain moisture sensors is the most promising for technological operations that require a flat floor surface. The feature of the sensor design is that a plate made of stainless steel with high abrasion resistance (made of 40X13 alloy) is fixed on its front surface. The specified plate serves as a sensor that forms the electromagnetic field of the probe in the test sample. The sensor is in contact with a controlled environment and has the highest sensitivity.

These sensors should be placed in the concrete base of the granary floor (Figure 3), which is due to the displacement of areas with high moisture in the lower layers, since the equilibrium moisture is established in areas contacting with air.

The feature of the proposed moisture control system is the use of moisture meters online. Real moisture data in the form of analog signals from grain moisture sensors in the storage area makes it possible to organize an automated control system aimed at saving fuel and ensuring the drying quality.

In the proposed moisture control system (Figure 4), the sensors are located in grain storage areas, while increasing their quantity improves the control system quality. The signals from moisture sensors are fed through an analog input module to an industrial controller by which the current value of a specific sensor is analyzed in order to determine increased grain moisture.
Figure 3. Placement of a moisture sensor in the concrete base of the granary floor.

Figure 4. Block diagram of a grain moisture control system.

If the moisture threshold is exceeded, the industrial controller switches the signal light power supply circuit located above the moisture sensor. At the same time, the industrial controller sends a message to the operators through a network or GSM module that in the near future it is required to carry out technological operations related to grain tedding.

5. Conclusion
Due to the use of remote warning, this moisture control system is suitable for remote flat-type granaries, maintained by a relatively small technical personnel group of several granaries located at a considerable distance from each other.

Moreover, using the proposed monitoring system, the operational determination of the high moisture zone will reduce the storage defects and the cost of equipment used to maintain optimal grain moisture.

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