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Mathematical Modeling of Energy-Efficient Active Ventilation Modes of Granary

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Abstract—**A mathematical model of the system fordetermining energy-efficient modes of active ventilation of grain is presented. Dependences are established for the detection of the influence of high-speed ventilation modes on the state of grain in granary, taking into account abiotic factors. The simulation process was performed using parametric identification and adaptive neuro-fuzzy technologies. An analysis of the efficiency of the system was carried out using the developed simulation model implemented in Matlab environment.**

Keywords—math modeling, parametric identification, adaptive control algorithms, neuro-fuzzy technologies, active ventilation, energy-efficient operating modes

I. Introduction

The energy crisis and the problem of resource conservation today require the modernization of automated electrical technologies, which would reduce the lossess of quality of bioresurses and reduce the energy intensity of technological processes associated with their storage and processing.

An effective search tool in this case is the mathematical modeling of a complex of processes occurring in the real system, followed by the experimental development of solutions and schemes [1,4]. The use of expert systems combined with the models of technological and ecosystems, leads to a new way of solving problems and making practical decisions in the production.

The analysis of published scientific papers indicates that existing methods and models for diagnosing the state of grain during storage do not provide adequate information for determining the required parameters [3,7,8,12]. In most cases, these models can be analyzed only by numerical methods. This imposes restrictions on their use in real time for search defects in grain mass.

After all, the processes occurring in the grain mound are characterized by nonlinear behavior. They are characterized by the emergence of abnormal situations, it is difficult to describe them mathematically. In turn, neural networks are capable of forming a very precise approximation for complex non-deterministic nonlinear functions. So, here it is necessary to use adaptive algorithms and neuro-fuzzy technologies with their implementation on the basis of the relevant expert systems. In the future, using simulation, you can track the dynamics of changes and determine the energy-efficient modes of active ventilation of the granary.

II. Task Statement

The determination of effective active ventilation modes should be based on a comprehensive analysis of all components of the electrotechnology complex: grain mound as a ventilation object, control systems as a means of controlling technological parameters and setting control modes.

The grain, like any living organism, breathes, while its mass is lost, temperature and humidity rises. This leads to the propagation of insect pests. Intensification of the development of the population of pests can be effectively avoided by intensive cold air flows.

In addition, the differentiation of air supply is possible by taking into account the type of grain. Different grain crops have different thermal conductivity and bending properties. For example, in oilseeds, the processes of self-heating are more intense. That is, more intense cooling is required. However, differentiation is possible here, because corn porosity is much larger than that of rape, and therefore the resistance of the grain mound as a ventilation object is lower, which reduces energy consumption.

Consequently, to establish energy-efficient modes of active ventilation of grain it is necessary to construct a mathematical model. Equation 1 represents the corresponding objective function F_{AV} – minimization of grain losses L_{gr}, energy consumption E_{AV} with appropriate restrictions on qualitative indicators of the product:

$$F_{AV} = L_{gr} \wedge E_{AV}, \begin{cases} E_{AV} = f(FC, H_{gr}, m_{gr}) \Rightarrow \min \\ L_{gr} = f(t_{gr}, MC_{gr}, k_{p\_inf}) \Rightarrow \min \end{cases} \quad (1)$$

Where, FC – fan capacity, H_{gr} – the resistance of the grain mound, m_{gr} – grain weight, t_{gr} – grain temperature, MC_{gr} – grain moisture content, k_{p_inf} – identification of the presence of insect pests.

To achieve the target function, the following tasks must be solved:

- To develop a mathematical model of grain status diagnostics for the identification of the process of self-heating.
- To form the algorithm of determination of energy-efficient modes of active ventilation. To carry out its approbation with the help of simulation model of the electrotechnical complex of active ventilation of the granary..

III. MODEL OF DIAGNOSTICS PARAMETERS GRAIN MOUND

Currently, the main problems that prevent qualitative diagnosis of the state of the grain mass as an object of storage are, above all, inaccuracies in the information received from the sensors (due to noise), the limited number of diagnostic parameters (as a rule, only the humidity and temperature of the raw material are controlled) and an insufficient number of points control.

The grain is very sensitive to external influences and over time can not only change its parameters within acceptable limits, but also, as a result of the process of breathing and self-heating, can reach dangerous temperatures that can cause damage and self-ignition [7]. On the basis of the experiment to study the self-heating process, it is established that if in the initial time of time the temperature throughout the area research does not reach critical values, then after a certain period of time when the temperature In the of self-heating center already reaches the indicators that are hazardous to the quality of the grain, in the sensors sensitivity zone, the initial temperature can only slightly increase (Fig. 1).

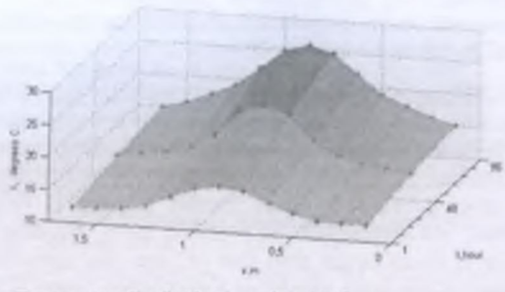

Fig. 1. Temperature distribution in grain mound.

So, the organization of the search for areas of spoilage and self-heating of grain is relevant, which should have a methodology for correctly recognizing and classifying the signs of defects of any multiplicity.

In order to ensure effective monitoring of the state of grain in the granary in the presence of insufficient quantity measurement information and a variety of factors affecting the results of measurements, it is advisable to use the Data Mining technology, which involves a decision support process based on the search for hidden patterns [9,15].

Effective forecasting is possible in the presence of a certain minimum of observations. However, since the grain is a living organism, it is almost impossible to predict all its possible temperature-humid responses to changes in the environment or storage conditions. In this case, it's possible to build a system containing a neural network for forecasting, while the model will be refined in the process of receiving fresh data [2,11,12].

It has been established that the number of physical sensors used in the grain store is not enough to adequately represent the thermal processes occurring in the granary. Therefore, the use of virtual sensors has been proposed to determine the temperature at the required points. Their operation is based on a neural network that uses data from sensory sensors and knowledge bases that store information from previous periods of time. The activity diagram for virtual sensors presented in Fig. 2

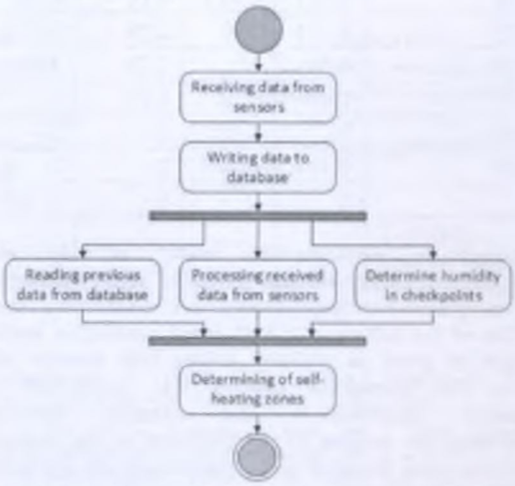

Fig. 2. The activity diagram for virtual sensors.

According to this technology it is possible to establish not only the current temperature values, but also the general tendency of changing the temperature gradient in the granary at a distance from the self-heating center and the rate of temperature rise.

However, the presentation of the biophysical state of the mass of raw materials without taking into account the presence of insect pests does not allow obtaining sufficient information about the processes occurring in the grain embankment. After all, their livelihoods lead to the emergence of hotbeds of self-heating, and, conversely, self-warming activates the multiplication of pests in a geometric progression. Thus, it is expedient to conduct a comprehensive analysis of temperature and humidity parameters that contribute to the emergence of hotbeds of self-heating and are favorable for pests [3,6,16].

Consequently, the solving the problem of grain diagnostics is carried out according to the scheme, which is presented in Fig. 3. [12].

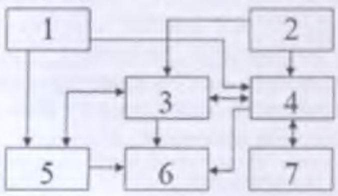

Fig. 3. Functional diagram of the diagnostic process: 1 – Operative data of the sensors of the state of raw materials; 2 – Operational meteorological data; 3 – Expert system; 4 – Knowledge base; 5 – Block of operative control; 6 – Block simulation and loss estimation; 7– Block of Risk Analysis.

Operational information from temperature sensors regarding grain temperature in different storage areas as well as data on grain humidity in control measurements are entered into the knowledge base and analyzed in the operational control unit. The results of the calculated values and parameters, the data on the temperature and humidity of the surrounding air, the infection of the grain are entered into the database in order to further use them to predict the process of self-heating.

IV. Model of Definition of Speed Modes Active Ventilation

Since the characteristics of the object in the process of functioning can vary considerably, therefore, the electro-technological system must provide differentiated modes of operation. In such cases, traditional methods often become either unacceptable or give poor results. In this regard, it is advisable to use adaptive systems that do not require complete a priori knowledge of the object of management and the conditions for its functioning. The effect of adapting to the conditions of operation in adaptive systems is provided by the accumulation and processing of information about the behavior of the object in the process of functioning [13].

The use of adaptive regulators allows:

- to optimize the modes of operation of the electrotechnical complex in conditions of incomplete information;
- to ensure the efficiency of the control system in the conditions of changing the dynamic properties of the object in wide range;
- to reduce the technological requirements for nodes and elements of the control object;
- shorten the terms of development and debugging of the system.

The fuzzy-control technology has become the most commonly used to formulate adaptive control algorithms.

In the simulation of dynamic processes, the provision of guaranteed accuracy can be realized through the use of an optimization approach for parametric identification of model parameters [14].

The structural analysis of the processes occurring in the grain embankment during active ventilation is carried out taking into account the set of characteristics necessary for effective grain cooling. So, the following options (2) are defined:

- condition S^1: MC_{gr} – grain moisture, t_{gr} – grain temperature;
- control S^2: v_{air} – speed of air supplied;
- disturbance S^3: $MC_{gr}{}^{in}$ – initial moisture content of grain, $t_{gr}{}^{in}$ – initial temperature of grain, P_{gr} – grain porosity, λ_{gr} – termal conductivity of grain, RH – humidity of air, t_{air} – air temperature;
- observation S^4 : $MC_{gr}{}^{P}$ – grain humidity in laboratory measurements, $t_{gr}{}^{P}$ – the temperature of the grain at the measuring points, k_{p_inf} – the presence of pests in samples of grain;

The functional relationship of the parametric model will have the form:

$$f(S^1 : MC_{gr}, t_{gr}) = f\begin{pmatrix} S^2 : v_n; \\ S^3 : MC_{gr}{}^{in}, t_{gr}{}^{in}, P_{gr}, \lambda_{gr}, RH, t_{air} \\ S^4 : MC_{gr}{}^{P}, t_{gr}{}^{P}, k_{p\_inf} \end{pmatrix} \quad (2)$$

In order to obtain a stable temperature of cooled grain, it is necessary to develop an algorithm for the operation of a control system that would control the process of the air parameters at the input and output of the grain layer and adjust the speed modes of the fan [8,10].

The algorithm allows to differentiate air supply in three basic modes. The first is a mode for the disposal of pests, where air is fed with maximum pressure, at maximum speed. The second one is for avoidance self-warming, where air supply is possible with less intensity. The third one is for preventive work, which allows you to save energy by about 50%.

The algorithm for determining the speed modes follows:

1) Processing of information from temperature sensors, grain and air humidity values, and grain infection index with a certain discreteness in time;

2) Determination of the necessary conditions for active ventilation: the relative humidity of air and the equilibrium moisture content of the grain.

3) Selection of ventilation mode $R \in \{1,2,3\}$ according to the values of the detectors of contamination and self-heating.

4) Calculating the required fan speed:

$$v = f(\Delta t_{gr}, t_{air}, RH, Q, R) \quad (3)$$

The required capacity (airflow output) (Q) depends on the weight of the grain, the choice of the ventilation mode and the basic thermophysical characteristics of the grain of a certain culture (thermal conductivity – λ, thermal diffusivity – a, heat output – α):

$$Q = f(m_{gr}, R, \lambda, \alpha, a) \quad (4)$$

5) Determination of the duration of ventilation and correction of the required pressure, taking into account the resistance of the mound of grain..

The resistance of the grain layer varies for different crops (for example, it is much larger for rape than for corn), and also differs at different heights of the embankment. Therefore, in order to ensure adequate reproduction of processes and determination of the required pressure in the system, a module for determining the resistance of the grain layer synthesized on the basis of the fuzzy Sugeno system has been added to the system.

In order to evaluate the influence of external factors, to identify system parameters at different load modes in general and to analyze the functioning of an expert system, it is advisable to use simulation modeling [5].

So, in accordance with the algorithm, a simulation model was developed to determine the speed modes of active ventilation, which allows reproducing the dynamics of changes in the main parameters. The development of the model, which is shown in Fig. 4, was carried out using the Tools Simulink of environment Matlab .

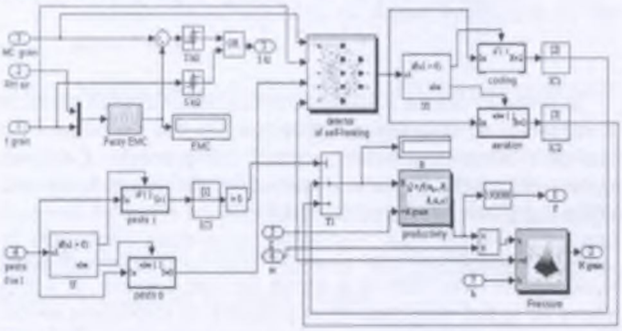

Fig. 4. Model of definition of speed modes depending on the active ventilation of the granary

With the help of individual modules, an initial check on the permissibility of ventilation (determination of equilibrium moisture content of the grain) is initially carried out. After that, the ventilation mode is selected according to the values of the detectors of the presence of pests and self-heating.

On the basis of definite parameters, the required fan airflow is calculated, taking into account the loss of pressure due to the resistance of the grain layer. Since the final value of the required capacity depends on the interconnection of several processes, a cascade method of forming the system is used: to determine the equilibrium air humidity, a fuzzy system of Sugeno type is used; for identification of self-heating – a module containing a neural network for determining zones of temperature increase; To select the required fan airflow – Fuzzy system like Mamdami. A controller is used to combine fuzzy systems, neural networks and perform additional calculations. Verification of the adequacy of the model operation showed that this model allows to calculate the parameters of the system with a permissible error.

V. Conclusion

With the help of mathematical modeling, the influence of the presence of self-heating areas, the index of pests and meteorological conditions on the state of the grain mound has been analyzed.

The simulation model of the system is developed on the basis of the use of adaptive neuro-fuzzy technologies. The simulation model of the system analyzes the temperature and humidity of grain and air, establishes the necessary speed ventilation modes taking into account the type of grain and produces control actions to maintain technological parameters at a given level.

Approbation on the basis of the developed simulation model of the algorithm for differentiation of speed modes of active ventilation of the granary confirmed the possibility of reducing specific energy consumption by 17–35%.

In the future it is planned to expand research by taking into account the contamination of grain and ensuring the adaptability of the system for determining modes to different types of fans.

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