УДК 681.5.017
DOI: 10.17277/vestnik.2024.01.pp.028-041

A FUZZY CONTROL MODEL OF AN INTELLIGENT INFORMATION-MEASURING AND CONTROL SYSTEM OF A DRUM DRYING UNIT

S. V. Artemova[1], M. A. Kamenskaya[2], P. I. Karasev[1]✉, N. S. Ershov[1], Vu Tri Chien[3], A. A. Domornikova[1]

*Department KB-1 "Data Protection", karasev@mirea.ru (1);
Department KB-6 "Instruments and Information-Measuring Systems" (3),
MIREA – Russian Technological University, Moscow, Russia;
Department of Power Engineering (2), TSTU, Tambov, Russia*

Keywords: Bayesian probability; fuzzy control model; linguistic variables; minimized functional; set of situations.

Abstract: This article discusses the models and methods underlying the functioning of the intelligent information-measuring and control system of a drum drying unit. They allow real-time minimization of losses in the quality of the dried material and the productivity of the drying process. A mathematical formulation of the problem of controlling the drying process with minimization of a given functionality and the structure of a drum drying installation as a control object are presented. Many possible control situations are described, linguistic variables are formulated, membership functions of terms of linguistic variables are determined, and a base of fuzzy control rules is formed. Examples of calculating the control action minimizing the loss functional, and the intelligent information-measuring and control system of the drum drying unit that implements it are shown.

Introduction

One of the important tasks of development of industrial facilities is considered to be the search for ways to improve the competitiveness of manufactured products. To solve the assigned goal, there are many industries, where a special place is occupied by the use of the latest information-measuring and control systems, including those containing elements of artificial intelligence [1].

Drying is a widespread process in various industries. Drying units are energy-intensive technological devices. Monitoring of indicators and making timely decisions on the management of the drying process has a significant impact not only on the quality of the dried material, but also on the energy performance of the entire production as a whole.

The specificity of automation of drying processes is determined by the peculiarities of dynamic properties of drying units as control objects: by state of the distribution of the parameters; by the multiplicity of the controlled and adjustable parameters, as well as the complexity of controlling the moisture content of the moving material and of the optimality criterion related to the quality of the product, the plant productivity and the economy of the drying process.

Drying units as control objects are usually nonlinear systems with distributed parameters. To control such objects it is necessary to solve systems of heat and mass transfer equations in real time, which is difficult in most cases. In this regard, these methods cannot be used in solving control optimization problems [1 – 4].

Therefore, we propose to use an information measuring and control system (**IMCS**) of the drum drying unit (**DDU**) when controlling the drying process in order to improve the competitiveness of the manufactured products.

Problem Statement

The presented peculiarity implies the possibility of regulating humidity by means of indirect methods, the presence of several factors of influence, as well as the complexity of functional criteria. The object of the study is a VetterTec GmbH unit, which belongs to the class of drying units with a shell and tube type drum, in which a drying after distillery stillage takes place.

In order to achieve the right level of product quality, it is important to solve the key problems of the correct choice of operation mode that will control the speed of rotation of the drum and the quality of the dried material. It is required to consider the key features of the unit and set a general task of its control and a number of tasks arising from it [5].

The general task should be understood as finding the optimal way of controlling the drying process using an IMCS. For this purpose, we must determine:

– the operator f affecting the degree of humidity of dried distillery stillage in a drum-type drying unit before and after the process performance $y = (y_1,..., y_p)^t$ and having a ratio with the value of the control action and vector function of perturbing influences $x = (x_1,..., x_n)^t$ in the flowing of various situations

$$f : T \times U \times X \times S \to Y , \tag{1}$$

where *T*, *U* is a generalized multitude of permissible values of the value of the control; *X* is a generalized multitude of perturbations' values; *S* is a generalized multitude of situations; *Y* is a generalized multitude of output data;

– the range of permissible values of output variables *y*, as well as the restrictions of the change of control actions *t*, *u*, i.e.

$$y_z \in Y_z^{\text{per}}, \;\; z = \overline{1, p} ; \tag{2}$$

$$t_i \in T_i^{\text{per}}, \;\; i = \overline{1, h}; \qquad u_j \in U_j^{\text{per}}, \;\; j = \overline{1, k} , \tag{3}$$

where $Y_z^{\text{per}}, T_i^{\text{per}}, U_j^{\text{per}}$ are the ranges of permissible values of y_z, t_i and u_j respectively;

– the determination of the optimality criterion, which is able to determine the degree of quality of the final product (Ql) and the level of productivity (Pr)

$$Q_{\min} = Q(\Delta \text{Ql}, \Delta \text{Pr}, u, t) \to \frac{\min}{u, t} , \tag{4}$$

where ΔQl, ΔPr are losses, which are determined by the drop of productivity or quality aspect of the dryable material.

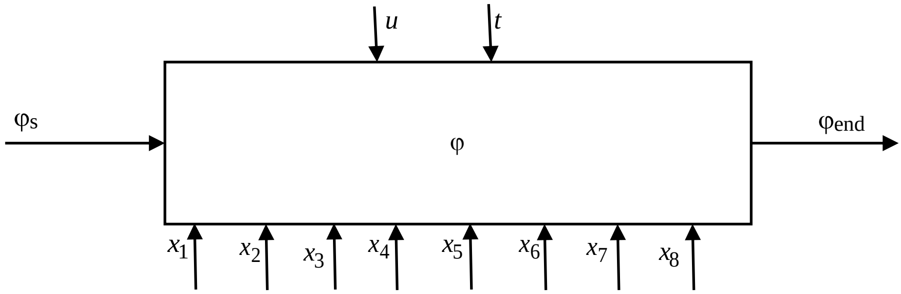

Fig. 1. Structure of the DDU as a control object

When performing calculations, it is important to identify such a value of the control action of u^* and t^*, when the restrictions specified in (2), (3) will be fulfilled, and criterion (4) is minimized [6].

The control is carried out by the engine rotations of the drum drying unit (Fig. 1).

Taking into account the direct dependence of losses on the direct control of processes, as well as the same interconnection between quality and ruling, the presented processes can be expressed through the criterion Q

$$Q = c_1(a_0 + a_1 u_0) + c_2(b_0 + b_1 u_0{}^2) + c_3(a_0 + a_1 t_0) + c_4(b_0 + b_1 t_0{}^2)\,, \tag{5}$$

where c_1, c_2, c_3, c_4 are weight coefficients; a_0, a_1 are parameters of the process productivity losses function; b_0, b_1 are parameters of the final product quality losses function.

In the considered case, the multitude of situations S can be referred to the available trajectories of moisture content change along the length of the industrial equipment, that is, we can express $S(\cdot) = (\varphi_s, \varphi_{end})$.

The specified problem is determined by the solution based of primary information that allows us to determine the quality of the material at the input, the primary values of the control and the perturbations. From the mathematical point of view, the specified problem must be addressed for a certain batch of material (m), in this case the problem is specified as follows [2, 7]:

– a model of moisture content at the output of the DDU is formed

$$\varphi\left(t^m\right) = f(A, u, x)\,, \tag{6}$$

where φ is the level of moisture content at the output; t^m is time interval, which determines the passage of material through the device; A is an aggregate of parameters of the neural network [2, 8], on the basis of which the moisture content is determined.

The perturbation vector x and control vector u are correlated with the following key components:

$$u = f(I); \tag{7}$$

$$x = (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8), \tag{8}$$

where I is the current strength;

– the introduction of constraints (2), (3) on the control action and the variable φ, where U_j^{per} is an area of possible characteristics of the control action; Y_z^{per} is an area of possible values of relative humidity; $Q_{\min}$ is a minimization of the functional (4). In general, the minimized functional is represented by formula (4).

To solve the control problems, we will use a complex analysis, which is based on the optimization of DDU operation. The key provisions should be considered taking into account the processes occurring in the DDU.

The solution of this problem is based on the use of real data obtained during the operation of the DDU in the production post-alcohol distillery stillage. The value of relative humidity of distillery stillage is determined by means of the developed method of its indirect measurement in the drum drying unit, providing the application of the created and trained neural network. At the inputs of the neural network, normalized values of signals are fed, received from the following primary measuring transducers: initial moisture content of distillery stillage; temperature of distillery stillage at the outlet; pressure, temperature, oxygen content of the coolant; power of exhaust fans, vented steam temperature, load of the electromotor, which have a significant impact on the drying process. From the output of the neural network, the value of relative humidity of the material is obtained [9, 10].

The vector of control variables at the output will be represented by the formula $y = [\varphi(t_m + m\Delta t), m(\varphi(t_m + (m)\Delta t))]$, at the same time possible trajectories should be applied depending on the situation arising after the realization of the control action, and values y_i from $\bar{y}_i$ are considered

$$S = \left\{ s_l(\cdot),\ l = \overline{1, L} \right\}, \tag{9}$$

where $\bar{y}_i$ is the optimized value of the material moisture level.

To simplify the process of working with the multitude of situations *S*, it is represented as a morphological table by introducing the following generalization for $s_l(\cdot) \in S$, which will be given by two components $s_l(\cdot) = (s_{l1}, s_{l2})$. For the latter components, there is an assumption which assumes the presences of only five values for s_{l1} and three for s_{l2}:

$$s_{li} = \begin{cases} s_{li}^{\text{LOW}}, & \text{if } y_i < 0.65; \\ s_{li}^{\text{AVG}}, & \text{if } y_i \in [0.65;\ 0.8]; \\ s_{li}^{\text{HIGH}}, & \text{if } y_i > 0.8,\ i = 2, \end{cases} \tag{10}$$

$$s_j = \begin{cases} s^{\text{CBPL}}, & \text{if } y < 2; \\ s^{\text{BPL}}, & \text{if } y \in [1.5;\ 3.5]; \\ s^{\text{P}}, & \text{if } y \in [2.5;\ 4.5]; \\ s^{\text{APL}}, & \text{if } y \in [4; 6]; \\ s^{\text{SAPL}}, & \text{if } y > 5. \end{cases} \tag{11}$$

The system under consideration will have several variants of solutions depending on the situation $s_j(\cdot) \in S$. Under the condition of realization of the control development $u(s_j(\cdot))$, in which the control device carries out the performance of the tasks related to the productivity and quality of the products received [11]. This means that $y \in Y^{\text{per}}$ will be within the limits of the transit time of the work pieces through the drying unit. In this case, the multitude of situations will fulfill the condition of includability under which the expression $\forall s_j(\cdot) \in S$ is true.

As for the calculation of $\tilde{u}_0(t)$, it should be realized through the formula

$$\tilde{u}_0(t) = \begin{cases} f(y(t); \bar{u}_0), & \tilde{u}_0 \in [u_0^{\text{LOW}}; u_0^{\text{HIGH}}]; \\ u_0^{\text{LOW}}, & \tilde{u}_0 < u_0^{\text{LOW}}; \\ u_0^{\text{HIGH}}, & \tilde{u}_0 > u_0^{\text{HIGH}}. \end{cases} \quad (12)$$

In our case S corresponds to fifteen $L = 15$ situations of different types. Each row of the tabular representation defines the gradation of the importance of the components for the final batch of products dried in different time periods.

Let's introduce the following designations of fuzzy variables: CBPL – the level of humidity and temperature of the material is considerably below the permissible level; BPL – humidity and temperature correlate with the level below the permissible level; P – the level of humidity and temperature is within the permissible ranges (the level is permissible); APL – humidity correlates with the level above the permissible level; SAPL – the level of humidity and temperature is significantly above the permissible limits.

Let's formulate the problem of drum speed control as follows. The moisture content of the material at the input of the drying unit, the permissible ranges of their variation and the Bayesian probability of achieving the required quality of the material at the output of the drying unit are known. It is required to determine the rotational speed of the DDU drum at which the required necessary quality of the used material at the outlet of the unit will be achieved with the maximum possible efficiency of the drying process.

A Fuzzy Control Model of the Rotation Speed of a Drum of the Drying Unit

One of the stages of creating a control algorithm is the description of input and output variables of the problem in the form of linguistic variables. The input variable represents by $\varphi(t_0 + \Delta t)$, which correlates with the moisture content of the material, and also by $P(\varphi(t_0 + \Delta t))$, which is a probabilistic value of achieving the required parameter of humidity content at the output. The output linguistic variable is the change of the rotation speed of the drum $\Delta\tilde{u}_0(t_0 + \Delta t)$.

The use of a fuzzy control model becomes the basis for faster achievement of the required level of quality characteristics, as well as for the achievement of a high level of resource saving at various adjustments and changes in the technological process [3, 12]. Let us consider the formalization of the task: the control of the rotation speed of the drum.

The control process is technologically defined on the basis of changes in the speed parameters of rotation of the mobile part of the unit using a fuzzy multitude which regards the value of the humidity content of the material φ.

As linguistic variables are used: “Material humidity content”, “Drum rotation speed”. The names of terms and the values of fuzzy variables are presented in the Tables 1 – 3. The table 1 specifies the appropriate range of the value of the term $T(\varphi)$. A signal of the speed rotation to control of the drum is generated, based on the values of the term $T(\nu_d)$.

Table 1

Estimation of the moisture content of the material used in the dryer

Number of the term	Name of the term, $T(\varphi,t)$	Fuzzy variable, %
1	CBPL	1/0 + 1/1 + 0/2
2	BPL	0/1,5 + 1/2.5 + 0/3.5
3	P	0/2,5 + 1/3.5 + 0/4.5
4	APL	0/4 + 1/5 + 0/6
5	SAPL	0/5 + 1/7 + 1/100

Table 2

Terms and values of the probability of achieving the required humidity at the outlet of the dryer

Number of the term	Name of the term, $T(P(\varphi))$	Fuzzy variable, %
1	LOW	1/0 + 1/0.575 + 0/0.675
2	AVG	0/0.575 + 1/0.675 + 1/0.725 + 0/0.825
3	HIGH	0/0.725 + 1/0.825 + 1/1

Table 3

Drum rotation speed ν_d

Number of the term	Name of the term, $T(\nu_d)$	Fuzzy variable, %
1	SDDR	1/–3 + 1/–2 + 0/–1.7
2	DDR	0/–2 + 1/–1.2 + 0/–0.4
3	N	0/–0.7 + 1/0 + 0/0.7
4	IDR	0/0.4 + 1/1.2 + 0/2
5	SIDR	0/1.2 + 1/2.1 + 1/3

N o t e : The following linguistic variables are used here SDDR – strongly decrease the drum rotation speed; DDR – decrease the drum rotation speed; N – leave the drum rotation speed unchanged; IDR – increase the drum rotation speed; SIDR – strongly increase the drum rotation speed.

In order to achieve the control objective, a knowledge base consisting of the following fuzzy rules is formed considering the set of *S*, and the names of the terms of linguistic variables:

1. If $T(\varphi,t)$ = CBPL and $T(P(\varphi))$ = LOW, then $T(\nu_d)$ = SIDR;
2. If $T(\varphi,t)$ = BPL and $T(P(\varphi))$ = LOW, then $T(\nu_d)$ = SIDR;
3. If $T(\varphi,t)$ = P and $T(P(\varphi))$ = LOW, then $T(\nu_d)$ = IDR;
4. If $T(\varphi,t)$ = APL and $T(P(\varphi))$ = LOW, then $T(\nu_d)$ = IDR;
5. If $T(\varphi,t)$ = SAPL and $T(P(\varphi))$ = LOW, then $T(\nu_d)$ = DDR;
6. If $T(\varphi,t)$ = CBPL and $T(P(\varphi))$ = AVG, then $T(\nu_d)$ = SIDR;
7. If $T(\varphi,t)$ = BPL and $T(P(\varphi))$ = AVG, then $T(\nu_d)$ = SIDR;

8. If $T(\varphi, t)$ = P and $T(P(\varphi))$ = AVG, then $T(\nu_d)$ = N;
9. If $T(\varphi, t)$ = APL and $T(P(\varphi))$ = AVG, then $T(\nu_d)$ = IDR;
10. If $T(\varphi, t)$ = SAPL and $T(P(\varphi))$ = AVG, then $T(\nu_d)$ = DDR;
11. If $T(\varphi, t)$ = CBPL and $T(P(\varphi))$ = HIGH, then $T(\nu_d)$ = SIDR;
12. If $T(\varphi, t)$ = BPL and $T(P(\varphi))$ = HIGH, then $T(\nu_d)$ = SIDR;
13. If $T(\varphi, t)$ = P and $T(P(\varphi))$ = HIGH, then $T(\nu_d)$ = IDR;
14. If $T(\varphi, t)$ = APL and $T(P(\varphi))$ = HIGH, then $T(\nu_d)$ = IDR;
15. If $T(\varphi, t)$ = SAPL and $T(P(\varphi))$ = HIGH, then $T(\nu_d)$ = DDR.

Let us consider the steps of the proposed method for controlling the drying process in the DDU:

1. The initial moisture content of the m^{th} batch of material $\varphi_{in}(t_0^m)$ is measured.

2. The values of components of the vector of perturbing *x* values of control actions *u* in the process of drying the m^{th} batch of material in the DDU corresponding to the moment of time $t_0^m + \Delta t$ are measured. The calculation of the moisture content of the material in the DDU $\varphi\left(t_0^m + \Delta t\right)$ is being made using a model based on a neural network.

3. A verification of the calculated moisture content of the material $\varphi\left(t_0^m + \Delta t\right)$ is being performed to find whether it is entering within the permissible range, and the drying process is being corrected if necessary.

4. The probabilistic values of $P\left(\varphi_k\left(t_0^m + \Delta t\right)\right)$ are determined when the process takes place in the m^{th} batch directly at the DDU outlet using the obtained values of material moisture content, taking into account $\varphi\left(t_0^m + \Delta t\right)$, calculated by the Bayesian method.

5. A recalculation of the control action is carried out in a given range of $\tilde{u}_0 \in U_0^{\text{per}}$ with the involvement of fuzzy logic model. In this case, the Mamdani algorithm is used, which involves determining the value of the rotation speed. The numeric value can be obtained using the methods of:

1) centre of gravity;
2) calculation of median;
3) centre of maximum.

6. The optimal control action is selected taking into account the functional

$$Q = c_1(a_0 + a_1 u_0) + c_2(b_0 + b_1 u_0{}^2) + c_3(a_0 + a_1 t_0) + c_4(b_0 + b_1 t_0{}^2)\,. \qquad (13)$$

The method presented above becomes the basis for controlling the production process in the DDU, which provides quality control of the final product, as well as the efficiency of the technological process depending on changes in the operation [4].

Let us consider the application of calculations using the centre of gravity method. Fuzzy regions for input values are shown in Figs. 2 – 4.

Graphs of the membership functions of terms of linguistic variables have been constructed.

Figure 5 shows the result obtained using the *center of gravity method*. If the moisture content is 3.53 and the probability of achieving the required quality is 0.468, then the speed = 1.2.

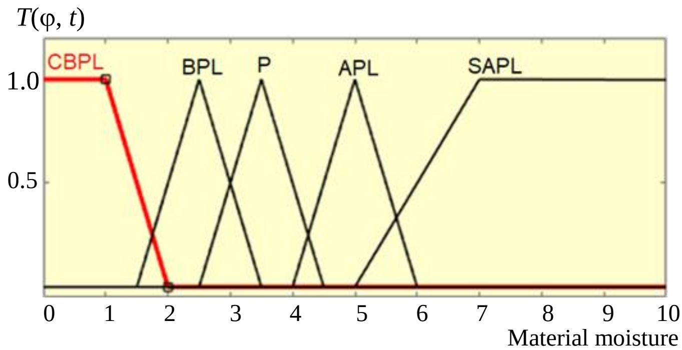

Fig. 2. Fuzzy regions of material moisture values

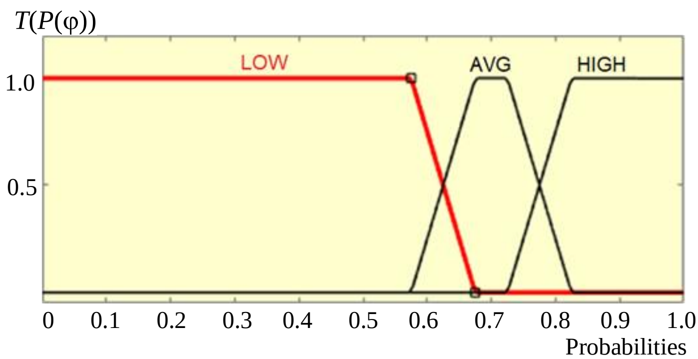

Fig. 3. Fuzzy regions of Bayesian probability to reach the required humidity at the output

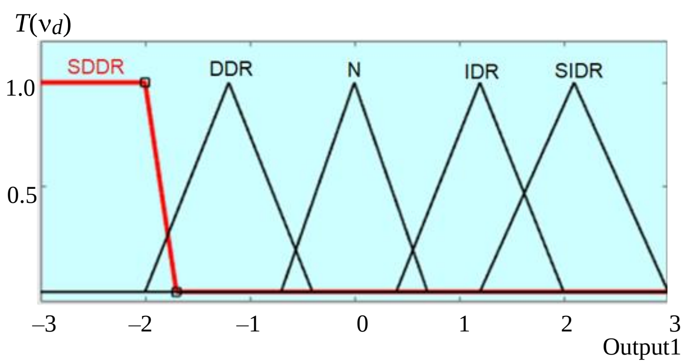

Fig. 4. Fuzzy regions of drum rotation speed values

Thus by changing the rotational speed of the drum of the drying unit by 1.2 m/s, a minimization of the quality loss of the manufactured products and the productivity of the drying process by 8 % is achieved.

The operation of the DDU is characterized by three modes - heating, stabilization, drying. Moreover, the first two modes are considered as dynamic, and the third as static. The structural diagram of the IMCS is shown in Fig. 6.

The production processes control system (**PPCS**), which includes the IMCS, consists of two main subsystems: information-measuring system (**IMS**) and information-control system (**ICS**), each one of which fulfills the function of measurement and control, respectively.

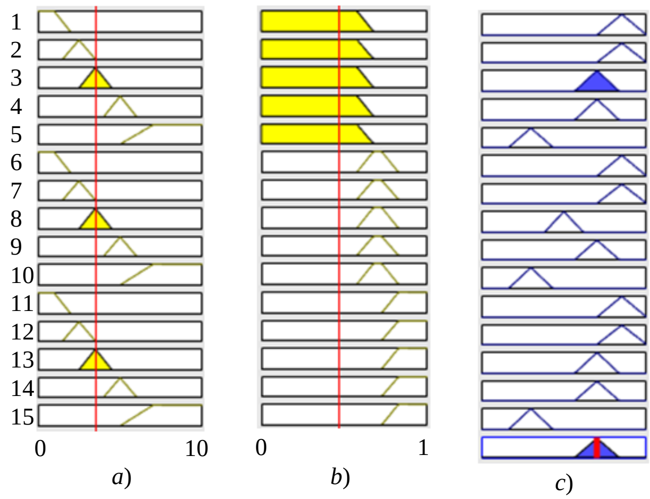

Fig. 5. Result obtained using the Centre of gravity method
a – material moisture = 3.53; *b* – probabilities = 0.468; *c* – output1 = 1.2

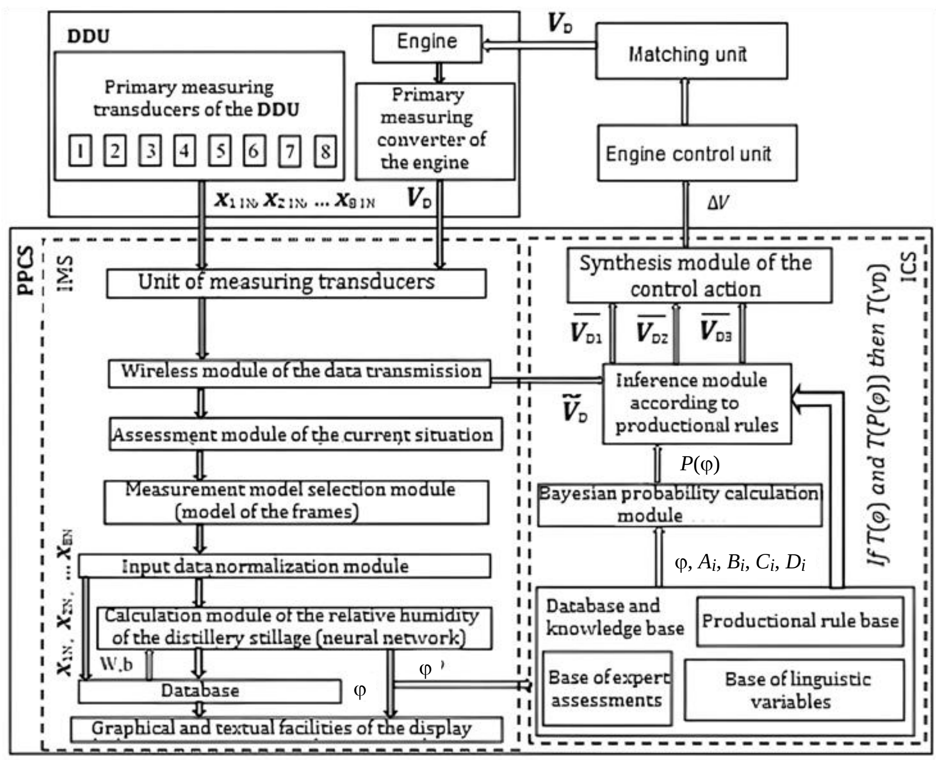

Fig. 6. Structure diagram of the system

Description of the IMCS

The system includes several modules and an aggregate of primary measuring transducers of technological parameters of the drying process. The main modules of the IMCS include: the module of normalized input variables, the module of measurement model selection, the module of calculation of relative humidity of distillery stillage [3], the module of the syntheses of the control actions, the inference module according to production rules, and the module of Bayesian probability calculation. Also, the IMCS contains databases and knowledge, graphical and textual means of information display.

The collected data are fed into the module of normalized input variables, which converts them into normalized values to ensure their compatibility with the inputs of the trained neural network.

Next, the data are processed in the measurement model selection module, which determines the optimal moisture measurement model depending on material parameters and other factors. Then they are transferred to the moisture calculation module, which performs a non-contact indirect measurement of material moisture in real time using normalized signals received from multiple sensors.

The obtained estimate of material moisture content is used to control the drying process with the help of an ICS, which works on the basis of production rules and Bayesian probability theory. The synthesis module of the control actions is designed to minimize the expense functional. It calculates optimized control inputs that change the speed of rotation of the drum in order to achieve the required moisture content of the material at the exit without losing the performance of the drying process.

All data obtained during the operation of the IMS and ICS are stored in a database for further analysis and use. The database includes information on technological parameters of the drying process, results of material moisture measurement, and forecasts of achieving the required moisture content, expert estimates and production rules.

For the convenience of analyzing and using the data, IMS and ICS provide graphical and textual means of displaying information. They can be used by operators to monitor and control the drying process and to analyze and optimize the production.

The IMCS blocks are also a frame-based knowledge base (**KB**). The KB contains knowledge about the technological process in the form of frames. Using them, the execution of algorithms is being carried out.

The knowledge base is the most important component of the control system, as it contains the technical information required for the execution of analysis and synthesis system in order to optimize the control according to specified criteria. The knowledge is represented here in the form of two types: declarative and procedural knowledge. The procedural knowledge include rules, procedures, operations, algorithms that define actions to implement the mechanism of inference when solving control problems for situations arising as a result of the functioning of the system. The declarative knowledge is a description of objects, elements, phenomena, connections, relations between elements and phenomena.

The form of knowledge representation significantly affects the IMCS characteristics. The knowledge representation in the control system is performed with frame component, semantic networks, as well as using logical models of knowledge, neural networks, Bayesian probability and fuzzy models.

Generally, the system operates without the involvement of a decision maker and provides real time indirect measurement of material moisture content and drying process management in order to minimize product quality losses and to increase productivity.

Conclusion

In order to minimize the losses of the product quality and productivity of their manufacturing process, a multitude of possible situations has been defined, linguistic variables have been introduced, Bayesian probabilities have been calculated, linguistic variables terms values have been determined, and a knowledge base including linguistic rules, frame models, and neural networks has been formed.

The technical realization of the IMCS contains two subsystems: the IMS and the ICS. At the heart of the IMS functioning are the models describing the drying process in the mode of the real time having the form of neural networks trained by the method of error back propagation, and the frame model taking into account the failures of primary measuring transducers, which allows estimating the moisture content of the material in the drying process.

Models and methods used in the construction of the created system allow it to function without the participation of a decision maker, which makes it intelligent. The use of the IMCS of the drum drying unit makes it possible to control the process of drying of post-alcoholic distillery stillage in real time with a minimum loss of such important indicators as the quality of manufactured products and productivity of the process of its production.

References

1. Lykov M.V. *Sushka v khimicheskoy promyshlennosti* [Drying in the chemical industry], Moscow: Khimiya, 1970, 432 p. (In Russ.)

2. Artemova S.V, Vu Chi Chiyen, Kamenskaya M.A. *Sposob otsenki vlazhnosti materiala v protsesse sushki v barabannoy sushil'noy ustanovke* [A method for assessing the moisture content of a material during drying in a drum drying installation], Russian Federation, 2022, Pat. № 2766517 (In Russ.)

3. Artemova S.V., Ladynin A.I., Shmeleva A.G., Vu Tri Chien, Kamenskaia M.A., Ryabchik T.A. Technological Processes Operational Assessment Frame Model in Automated Control Systems, *Proc. of IV International Conference on Control in Technical Systems*, St. Petersburg, 21-23 September 2021. St. Petersburg, 2021, pp. 27-29. doi: 10.1109/CTS53513.2021.9562783

4. Radharani M., Gopinath N., Sandeep P., Jagadeesh M. Object Detection with SSD and MobileNet, *International Journal for Recent Developments in Sciences and Technologies*, 2023, vol. 7, no. 2, pp. 40-51. available at: https://ijrdst.org/public/uploads/paper/362391681399621.pdf (accessed 15 January 2024).

5. Pavlidis T. *Algoritmy mashinnoy grafiki i obrabotki izobrazheniy* [Algorithms for computer graphics and image processing], Moscow: Radio i svyaz', 1986, 804 p. (In Russ.)

6. Kumar A., Zhang J., Lyu H. Object Detection in Real Time Based on improved Single Shot Multi-Box Detector Algorithm, *Journal on Wireless Communications and Networking*, 2020, no. 204. doi: 10.1186/s13638-020-01826-x

7. [Image segmentation]: TensorFlow Core. available at: https://www.tensorflow.org/tutorials/images/segmentation (accessed 15 January 2024).

8. Borgi A., Akdag H. Knowledge Based Supervised Fuzzy-Classification: An Application to Image Processing, *Annals of Mathematics and Artificial Intelligence*, 2001, no. 32 (1-4), pp. 67-86. doi: 10.1023/A:1016753214357

9. Vasil'yev K.K., Krashennikov V.R. *Statisticheskiy analiz mnogomernykh izobrazheniy* [Statistical analysis of multidimensional images], Ul'yanovsk: Ulyanovsk State Technical University, 2007, 170 p. (In Russ.)

10. Ince T. Unsupervised Classification of Polarimetric SAR Image with Dynamic Clustering: An Image Processing Approach, *Advances in Engineering Software*, 2010, vol. 41, no. 4, pp. 636-646. doi: 10.1016/j.advengsoft. 2009.12.004

11. Vinogradov S.Yu. [Component model of fuzzy clustering based on the c-means algorithm], *Matematicheskiye metody v tekhnike i tekhnologiyakh – MMTT*

[Mathematical methods in engineering and technology – MMTT], 2014, no. 6(65), pp. 111-113. (In Russ., abstract in Eng.)

12. Borovik V.S., Shidlovskiy S.V. *Innovatika-2017: sbornik materialov XIII Mezhdunar. shkoly-konf. studentov, aspirantov i molodykh uchenykh* [Innovatika-2017: collection of materials of the XIII International. schools-conf. students, graduate students and young scientists], Tomsk, 20-22 April 2017, Tomsk, 2017, pp. 392-395. (In Russ., abstract in Eng.)

Нечеткая модель управления интеллектуальной информационно-управляющей системы барабанной сушильной установки

С. В. Артемова[1], М. А. Каменская[2], П. И. Карасев[1]✉, Н. С. Ершов[1], Ву Чи Чиен[3], А. А. Доморникова[1]

Кафедры: КБ-1 «Защита информации», karasev@mirea.ru (1); КБ-6 «Приборы и информационно-измерительные системы» (3), ФГБОУ ВО «МИРЭА – Российский технологический университет», Москва, Россия; кафедра «Электроэнергетика» (2), ФГБОУ ВО «ТГТУ», Тамбов, Россия

Ключевые слова: Байесовская вероятность; лингвистические переменные; минимизируемый функционал; множество ситуаций; нечеткая модель управления.

Аннотация: Рассмотрены модели и методы, лежащие в основе функционирования интеллектуальной информационно-управляющей системы (ИИУС) барабанной сушильной установкой (БСУ). Они позволяют в реальном режиме времени минимизировать потери качества высушиваемого материала и производительность процесса его сушки. Приведены математическая постановка задачи управления процессом сушки с минимизацией заданного функционала и структура барабанной сушильной установки как объекта управления. Дано описание множеств возможных ситуаций управления, сформулированы лингвистические переменные, определены функции принадлежностей термов лингвистических переменных, сформирована база нечетких правил управления. Показаны пример расчета управляющего воздействия, минимизирующего функционал потерь и ИИУС БСУ его реализующей.

Список литературы

1. Лыков, М. В. Сушка в химической промышленности / М.В. Лыков. – М. : Химия, 1970. – 432 с.

2. Пат. № 2766517 C1 РФ, МПК F26B 25/22. Способ оценки влажности материала в процессе сушки в барабанной сушильной установке / Артемова С. В, Ву Чи Чиен, Каменская М. А. ; заявитель ФГБОУ ВО «МИРЭА – Российский технологический университет». – № 2021112482 ; заявл. 29.04.2021; опубл.. 15.03.2022, Бюл. № 8. – 12 с.

3. Technological Processes Operational Assessment Frame Model in Automated Control Systems / S. V. Artemova, A. I. Ladynin, A. G. Shmeleva, Vu Tri Chien, M. A. Kamenskaia, T. A. Ryabchik // Proc. of IV International Conference on Control

in Technical Systems, St. Petersburg, 21 – 23 September 2021. St. Petersburg, 2021. – P. 27 – 29. doi: 10.1109/CTS53513.2021.9562783

4. Object Detection with SSD and MobileNet / M. Radharani, N. Gopinath, P. Sandeep, M. Jagadeesh // International Journal for Recent Developments in Sciences and Technologies. – 2023. – Vol. 7, No. 2. – P. 40 – 51. – URL: https://ijrdst.org/public/uploads/paper/362391681399621.pdf (дата обращения: 15.01.2024).

5. Павлидис, Т. Алгоритмы машинной графики и обработки изображений / Т. Павлидис. – М. : Радио и связь, 1986. – 804 с.

6. Kumar, A. Object Detection in Real Time Based on improved Single Shot Multi-Box Detector Algorithm /A. Kumar, J. Zhang, H. Lyu // Journal on Wireless Communications and Networking. – 2020. No. 204. doi: 10.1186/s13638-020-01826-x

7. Сегментация изображения: TensorFlow Core. – Текст: электронный. – URL: https://www.tensorflow.org/tutorials/images/segmentation (дата обращения: 15.01.2024).

8. Borgi, A. Knowledge Based Supervised Fuzzy-Classification: An Application to Image Processing / A. Borgi, H. Akdag // Annals of Mathematics and Artificial Intelligence. – 2001. – No. 32 (1-4). – P. 67 – 86. doi: 10.1023/A:1016753214357

9. Васильев, К. К. Статистический анализ многомерных изображений / К. К. Васильев, В. Р. Крашенников. – Ульяновск : УлГТУ, 2007. – 170 с.

10. Ince, T. Unsupervised Classification of Polarimetric SAR Image with Dynamic Clustering: An Image Processing Approach / T. Ince // Advances in Engineering Software. – 2010. – Vol. 41, No. 4. – P. 636 – 646. doi: 10.1016/j.advengsoft.2009.12.004

11. Виноградов, С. Ю. Компонентная модель нечеткой кластеризации на основе алгоритма c-средних / С. Ю. Виноградов // Математические методы в технике и технологиях – ММТТ. – 2014. – № 6(65). – С. 111 – 113.

12. Боровик, В. С. Распознавание образов на цифровых изображениях с помощью гистограмм направленных градиентов / В. С. Боровик, С. В. Шидловский // Инноватика-2017 : сб. материалов XIII Междунар. школы-конф. студентов, аспирантов и молодых ученых, Томск, 20 – 22 апреля 2017 г. – Томск, 2017. – С. 392 – 395.

Fuzzy-Control-Modell des intelligenten Informations-Mess- und Steuersystems der Trommel-Trocknungsanlage

Zusammenfassung: In diesem Artikel sind Modelle und Methoden betrachtet, die der Funktionsweise des intelligenten Informationsmess- und Steuerungssystems (IISS) der Trommeltrocknungsanlage (TTA) zugrunde liegen. Sie ermöglichen die Echtzeitminimierung von Verlusten bei der Qualität des getrockneten Materials und der Produktivität des Trocknungsprozesses. Es sind die mathematische Formulierung des Problems der Steuerung des Trocknungsprozesses unter Minimierung der gegebenen Funktionalität und der Aufbau einer Trommeltrocknungsanlage als Steuerungsobjekt vorgestellt. Es sind viele mögliche Kontrollsituationen beschrieben, linguistische Variablen formuliert, Zugehörigkeitsfunktionen von Termen linguistischer Variablen bestimmt und die Basis von Fuzzy-Kontrollregeln gebildet. Es sind Beispiele für die Berechnung der Steuerwirkung zur Minimierung der Verlustfunktion sowie das intelligente Informationsmess- und Steuersystem der Trommeltrocknungseinheit gezeigt, das diese Funktion umsetzt.

Modèle de la commande flou d'un système intelligent d'information et de contrôle d'une installation de séchage à tambour

Résumé: Sont examinés les modèles et les méthodes qui sous-tendent le fonctionnement du système intelligent d'information et de contrôle (SIIC) d'une unité de séchage à tambour (UST). Ils permettent, en temps réel, de minimiser les pertes de qualité de la matière séchée et de productivité du processus de séchage. Sont présentées la formulation mathématique du problème de la commande du processus de séchage avec minimisation d'une fonctionnalité donnée et la structure d'une installation de séchage à tambour en tant qu'objet de contrôle. Sont décrites de nombreuses situations de la commande possible; sont formulées des variables linguistiques; sont déterminées des fonctions d'appartenance aux termes des variables linguistiques; est formée une base de règles de contrôle floues. Sont présentés un exemple de calcul d'une action de commande qui minimise la perte fonctionnelle et un système automatisé pour le système de commande qui la met en œuvre.

Авторы: ***Артемова Светлана Валерьевна*** – доктор технических наук, заведующий кафедрой КБ-1 «Защита информации», ФГБОУ ВО «МИРЭА – Российский технологический университет», Москва, Россия; ***Каменская Мария Анатольевна*** – кандидат технических наук, доцент кафедры «Электроэнергетика», ФГБОУ ВО «ТГТУ», Тамбов, Россия; ***Карасев Павел Игоревич*** – кандидат технических наук, доцент кафедры КБ-1 «Защита информации»; ***Ершов Никита Сергеевич*** – преподаватель кафедры КБ-1 «Защита информации»; ***Ву Чи Чиен*** – аспирант кафедры КБ-6 «Приборы и информационно-измерительные системы», институт кибербезопасности и цифровых технологий; ***Доморникова Анна Александровна*** – студент, ФГБОУ ВО «МИРЭА – Российский технологический университет», Москва, Россия.