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ALGORITHM FOR OPTIMIZATION OF THE MEMBERSHIP FUNCTION OF THE FUZZY CONTROL MODEL ON THE BASIS OF THE PROBABILISTIC APPROACH

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Annotation. *The problem of optimization of the fuzzy control model of the drying unit in the cotton ginning industry operating under conditions of a priori uncertainty is considered.*

As an example, the process of temperature control in a drying unit is considered. As methods of optimization, it is proposed to use probabilistic methods. As an optimization parameter, the fuzzy model membership functions are used. A comparative analysis of the results obtained on the basis of simulation modeling before and after optimization is carried out.

Key words: *fuzzy model, optimization algorithm, probability theory, accuracy estimation, membership function, drying unit, temperature.*

At the present time for fuzzy control of various technological objects, fuzzy regulators are widely used [1].

The development of a fuzzy model for controlling a dynamic object will be considered using the example of controlling the temperature regime of a drying unit in the cotton ginning industry [2]. We set the parameters of the fuzzy temperature control model by denoting the term-sets of the input variables as follows:

T - current temperature in the drying unit:

$T :< T_1, T_2, T_3, T_4, T_5 >$

$Z -$ aggregate loads: $Z :< Z_1, Z_2, Z_3 >$

$P -$ heat consumption $P :< P_1, P_2, P_4, P_5 >$.

Term sets for output variables:

$G -$ fuel consumption:

$G :< G_1, G_2, G_3, G_4, G_5 >$;

$V -$ air consumption:

$V :< V_1, V_2, V_3, V_4, V_5 >$.

As an algorithm of fuzzy logic inference, the algorithm of Mamdani [3] on the basis of which the base of production rules is formed, the number of which is determined as follows.

$$K = T \times Z \times P = 75$$

To estimate the accuracy of the fuzzy temperature control model in the drying unit, the standard deviation (MSD) for fuel consumption is selected:

$$\text{MSD} = \sqrt{\frac{1}{N}\sum_{i=1}^{5}(y_{\text{given}} - y_{current})^2} \rightarrow \min \quad (1)$$

$$\text{MSD}_{current} \le \text{MSD}_{\text{given}} \le 5\%, \quad (2)$$

where N - *number of simulations;* $\text{MSD}_{тек}$ - *current error value;* $\text{MSD}_{\text{givent}}$ - the set error value; y_{given} - the specified value of the variable; $y_{current}$ - the obtained values of the variable.

It should be noted that the set values of the variable "fuel consumption" are determined based on the technological procedure, and the values of the variable "air flow" are determined on the basis of the ratio [4]:

$$\frac{G_{\text{givent}}}{V_{\text{givent}}} = \frac{1}{10}$$

Based on these prerequisites, an experimental study of a fuzzy temperature control model in a drying unit for 200 examples is carried out. In this case, the input values are formed randomly.

The values obtained as a result of the experiment are presented in Table 1.

An analysis of the obtained values of the parameters of the estimation of the fuzzy model of control of the object showed that in the average value of the MSD for one cycle, the simulation satisfies the condition (1) and does not exceed 2.12%. And in some examples, the MSD value exceeds the norm, and for the second parameter the value obtained does not correspond to the set value. In this regard, to improve the accuracy of the developed model, it is proposed to optimize it.

Consider the problem of an optimization algorithm based on probabilistic methods for a fuzzy control model of a drying unit. The developed optimization algorithm is considered on the example of fuzzy temperature control model in the drying unit.

As an optimization parameter, membership functions (FP) are selected that cover the entire set of variable values. To develop a fuzzy model and set-up triangular AFs are selected, this is due to the convenience of using them, the prevalence and ease of implementation. The triangular phase transition can be specified with the help of three numbers corresponding to the abscissa axis and determining the position of its boundaries and the vertex A, B, and C.

Table 1. Results of the fuzzy management model.

Fuzzy model parameters				
Input signals			Output signals	
$T^0 C$	Z, кг	P, кг	G $м^3/r$	V $м^3/r$
$[134C^0 \div 273C^0]$	$[45 \div 499]$	$[91;159]$	$[14;17]$	$[158\,;160]$
Accuracy estimation parameters				
MSD			*G / V*	
General common	min	max	General common	
0,021	$2{,}3 \cdot 10^{-14}$	0,36	0,0986	

Adjusting the parameters of the fuzzy control model of the drying unit based on the probabilistic approach assumes the use of the same estimation methods as for random variables, since fuzzy events are the same events, but occur in uncertain conditions. Based on the modeling results, histograms of the frequencies of the empirical distribution functions of each phase transition are constructed [5].

Based on the statistical data, the hypothesis that the empirical distribution functions constructed is consistent with the theoretical one based on the values of the Pearson criterion and the graphs of the empirical distribution functions of the phase transition can be verified that they have the form of a normal distribution [6].

The work of the optimization algorithm based on the probabilistic approach consists of the following stages:

- Carrying out a series of simulations. A series of simulations is carried out, the values of all input and output variables are recorded and their frequency falls within the prescribed intervals of each phase transition;

- Calculation of the mathematical expectation for all FPs:

$$\bar{x} = \sum_{i=1}^{N} x_i P_{lx}$$

where x_i current FP value; -the mean value of the FP , is the probability;

- Definition of MSD for all OP. On the basis of the obtained data and the mathematical expectation, the MSE is calculated for each phase transition:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}\ ;$$

- Construction of an interval according to the rule of three sigma. Since it is assumed that the graphs of the empirical distribution functions derived from the phase transition have a normal distribution, a rule of three sigma is used to adjust the boundaries of the phase transition. With a given accuracy, we can say that almost all the value of the fuzzy variable falls into the range:

$$[\,\bar{x}-3\sigma,\ \bar{x}+3\sigma\,]\ ;$$

- Configure the boundaries of the FP. After the determination of the new FP boundaries, the FP range is adjusted. Only the boundaries of the PF change, the vertices remain the same;
- Next, the second part of the FP setting is performed - the correction of the position of the AF vertex. It is necessary to evaluate the position of the apex of the phase transition and, if necessary, to correct it;
- Steps 1 and 2 are repeated;
- Definition of estimation of MSD. After finding the mathematical expectation, the evaluation of the MSD of each phase transition is calculated:

$$S=\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\bar{x})^2}\ ;$$

- Construction of a confidence interval for the vertices of a phase transition. For the obtained values of the mathematical expectation and the estimation of the standard deviation, a confidence interval is constructed that determines the position of the vertex of the phase transition:

$$u_z=(\bar{x}-t_{\text{table}}\frac{S}{\sqrt{N}};\quad \bar{x}+t_{\text{table}}\frac{S}{\sqrt{N}})$$

where u_z - confidence interval; $t_{табл}$- function of a Student;

- The breakdown of the confidence interval of the phase transition. The previously defined confidence interval of the vertex for the phase transition is divided into a number of sections, l_z in this case it is assumed that, $z=5$ and all areas l_z are equal;
- Determination of the position of the apex of the phase transition. After carrying out of experimental researches the site l_z with the maximum number of hits in it of the values of the variables. If the vertex of the PF coincides with the maximum number of hits, no changes occur;
- The conclusion of new FP. After making the adjustment of the boundaries and correcting the position of the vertex of the PF, the optimal values of the FP are obtained, and then the output of new FP;
- Evaluation of the results. The results of the operation of the fuzzy control model of the drying unit without taking into account the optimization block are compared with the values obtained after applying the optimization algorithm;
- To determine the effectiveness of the developed algorithm for optimizing the fuzzy model of drying unit management, based on the probabilistic methods, the initial values of the experimental studies were used (Table 1).

The optimization algorithm is performed until the values of the accuracy indicators reach the specified level (1) and (2).

The results of the algorithm for optimizing the values of the accuracy parameters are presented in Table. 2.

Table 2. The results of the optimization algorithm.

№	MSD общее	MSD min	MSD max	G/V общее
До	0,021	$2{,}3*10^{14}$	0,36	0,0986
1	0,0089	$6{,}55*10^{15}$	0,25	0,104
2	0,0059	$6{,}55*10^{15}$	0,156	0,1015
3	0,0029	$6{,}55*10^{15}$	0,098	0,1011
4	0,0009	0	0,0622	0,101
5	0,0005	0	0,03523	0,10002

Based on the results of Table 2, we can trace the dynamics of the algorithm for optimizing the fuzzy control model of the drying unit. After completing 5 iterations, the MSD on average decreased from 0.021 to 0.0005. The maximum values of the MSD satisfy the condition (1) and do not exceed 5%. and .

The second fuel-air accuracy parameter on the average reached the required value (2) and is practically 0.1.

The conclusion. In work the problem of optimization of fuzzy model of drying unit control was investigated. A fuzzy model for controlling the drying unit was developed and an analysis of its operation was carried out without taking into account the optimization block. Then, optimization of the fuzzy control model of the drying unit, adjustment of the boundaries of the FP, estimation and correction of the position of the vertices of the FP were performed.

The developed optimization algorithm based on the probabilistic approach is a universal way of adjusting the parameters of fuzzy models for controlling the drying unit. Using the connection between FP and the distribution function makes it possible to apply the methods of probability theory, thereby reducing the error resulting from the subjective specification of the parameters of the fuzzy model of the drying unit, which leads to an improvement in the accuracy of the results and the achievement of optimal performance management quality.

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