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MODEL OF FACTOR INFLUENCE ON THE OPERATION OF THE INFORMATION AND MEASURING SYSTEM

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Abstract. The solution of the scientific and practical problem of determining the effect of factor influence on the result of the work of the information measuring system for the technological process of manufacturing processed cheese is considered through the use of a factor influence model that takes into account the simultaneous effect of five factors and their cross-interactions on the control indicator. The task of the study is to implement for use a simplified cross-classification model that makes it possible to estimate the amount of expected information about the levels of the control parameter when taking into account the levels of both influencing factors and their mutual interactions. An electrical schematic diagram of the control system has been developed and its practical implementation has been carried out, thanks to which statistical data on the main parameters of the technological process have been obtained. Conclusions have been drawn about the possibility of further use of the proposed cross-classification model for various information measuring systems regardless of their purpose.

Keywords: information and measurement system, quality control, factor influence, mathematical model, variance analysis, measurement uncertainty, error.

INTRODUCTION

A large number of problems that arise during control and technical diagnostics of information and measuring systems could be avoided if obtaining primary information about the state of the control object were not associated with the a priori uncertainty of its output values. This is most critical when the output value cannot be reduced to a normalized level, since the complexity of the information and measuring system (IMS) and its dynamic properties lead to the randomness of the relationship between the measured output values and the levels of the controlled parameters. Thus, the problem of increasing the reliability of control and diagnostics arises in conditions when the uncertainty of measurements is added to the much greater uncertainty of the output values. IMS used in production for metrological control of technological processes are objects with stochastic parameters. For such systems, it is impossible to create deterministic models of controlled values, and the use of only existing structural and algorithmic methods to increase the reliability of control does not always make sense. In [1] it is stated that processed cheese is a popular dairy product, which is produced by thermomechanical processing of one or more cheeses and cheeses, in the presence of melting salts or structuring agents, with the addition of products derived from milk and food products, and biologically active additives, flavorings or without them. In Ukraine, the quality of processed cheese is regulated by the State Standard of Ukraine [2]. Analysis of works [3–7] showed the interest of the world scientific community in the problems of maintaining high quality and competitiveness of processed cheese produced in their countries, and also proved the need for constant search for sources of improving the taste and usefulness of this product. One of such ways is the method proposed in [5] for improving the quality of processed cheese using ultrasound. This study investigated the effect of different ultrasonic energy densities on the functional properties of processed cheese with different levels of emulsifying salt (0 %, 0.5 %, 1 %, 2 % or 3 % disodium phosphate). However, all of these studies agree on the need to ensure automated control of process parameters taking into account the effect of factor influences.

A number of works [8–11] are devoted to the development of IMS for production and research tasks, in which the emphasis is on the significant miniaturization of all components of measuring and computing equipment, especially electronic components. In such systems, the entire measuring and processing part can occupy an area of several square millimeters, and the measuring equipment can be completely placed in one or two structures with connectors for connecting sensors. Due to miniaturization, the effect of factor influences on the quality of IMS functioning becomes especially significant and its consideration is a necessary component of ensuring the metrological reliability of IMS regardless of their purpose.

ANALYSIS OF THE LAST ACHIEVEMENTS AND PUBLICATIONS

The work [12] is devoted to the creation of theoretical foundations of probabilistic mathematical modeling and synthesis of information procedures for control and diagnostics under conditions of parametric uncertainty.

In [13], the task of assessing the effect of random factor influence was solved by using analysis of variance as a method of organizing sample data according to possible sources of dispersion. The approach chosen in [13] allowed us to decompose the total dispersion into components that are due to the influence of factor levels. The task of assessing the informativeness of colorimetric control indicators in [14] was solved by using discriminant analysis models.

However, the problem of developing such a generalized method for quality control of the functioning of the IMS, which would be able to be used for systems regardless of their purpose, remained unsolved. In the work [15], such a control method was proposed. One of the main stages of the method for quality control of the functioning of the IMS proposed in [15] is the analysis of the effect of factor influence on the result of measuring the control indicator. In the sense of the quality of the IMS operation, compliance with the established metrological characteristics of the IMS is, and through this, the maintenance of the established norms for the parameters of the product to ensure the release of which the IMS was developed. The method proposed in [15] combines the advantages of statistical analysis methods, test control methods, fuzzy set theory and the theory of calculation of measurement uncertainty, therefore it is used in the presented work to analyze the effect of factor influence on the operation of the IMS for controlling the parameters of the technological process of manufacturing processed cheese. The method allows for ranking control indicators by decreasing the amount of information, i.e. determining the level of their influence on the control parameter.

FORMULATION OF THE ARTICLE PURPOSE

The aim of the article is to implement the developed model of factor influence on the result of determining the control indicator for the IMS of the technological process of manufacturing processed cheese. This model takes into account the effects of the simultaneous interaction of five factors, such as: temperature during melting of the cheese mass, pH level of the cheese mass, steam pressure level during melting of the cheese mass, temperature during sterilization of the cheese mass, noise of the analog part of the steam pressure measurement channel. Based on the presented model, to estimate the amount of expected information about the levels of the control parameter (quality of processed cheese) for the information control indicator, taking into account the levels of both influencing factors and their mutual interactions. To rank the control indicators by the level of their influence on the control result. To establish the factor that has the greatest influence on the quality of processed cheese.

STATEMENT OF THE MAIN MATERIAL

Maintaining high quality and taste properties of processed cheese directly depends on the control of the main parameters of the technological process at the stages of production. This becomes possible due to the implementation of the IMS, which receives information from the technological process. Based on the comparison of the current values of the parameters with the pre-set values, the IMS generates (if necessary) control influences for the actuators in order to actively influence the technological process. A simplified structural diagram of the IMS (without actuators), used to control the production of processed cheese, is presented in Fig. 1.

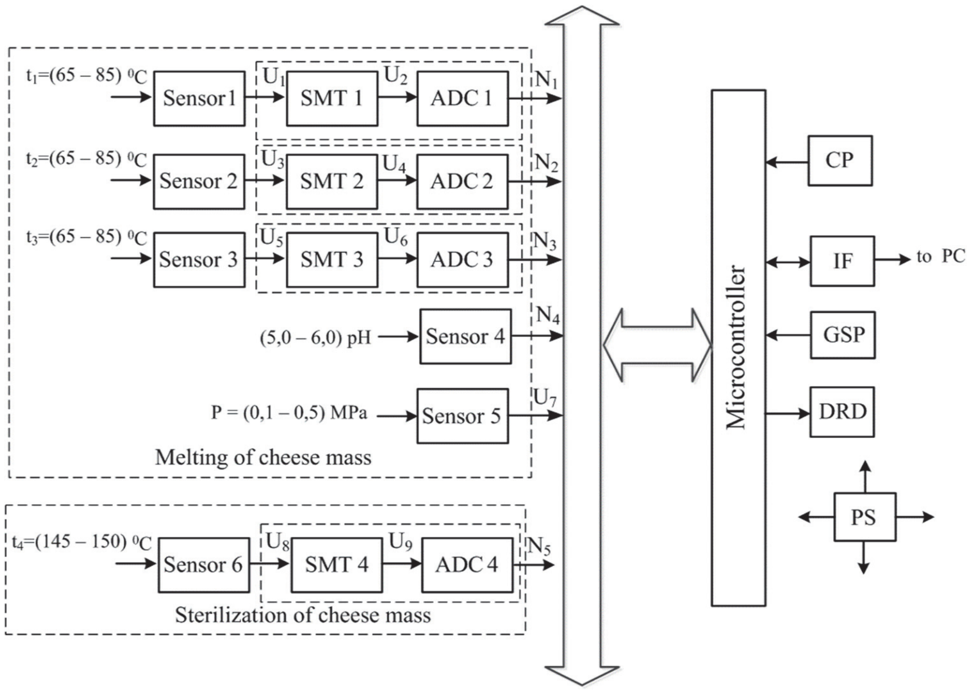

Fig. 1. Simplified structural diagram of the IMS for controlling the process of making processed cheese

The IMS includes the following elements: Sensor 1, Sensor 2, Sensor 3 – primary measuring transducers designed to control the temperature of the cheese mass in the vat (three sensors are required to be able to obtain an integral value of the temperature of the cheese mass over the entire volume); Sensor 4 – designed to control the pH level of the melted cheese mass; Sensor 5 – to measure the pressure of the steam that melts the cheese mass; Sensor 6 – to measure the temperature during sterilization; SMT 1 – SMT 4 – secondary measuring transducers, which use digital voltage converters with built-in precision amplifiers and analog-to-digital converters (ADC); microcontroller – processes measurement information and generates control commands; GSP – additional to the built-in microcontroller generator of synchronizing pulses; CP – control panel; IF – interface, provides data exchange with a personal electronic computer (PC); DRD is a digital reading device that provides information on the status of control parameters; PS is a power supply.

Based on the structural diagram, an electrical schematic diagram of the IMS was developed, which is presented in Fig. 2.

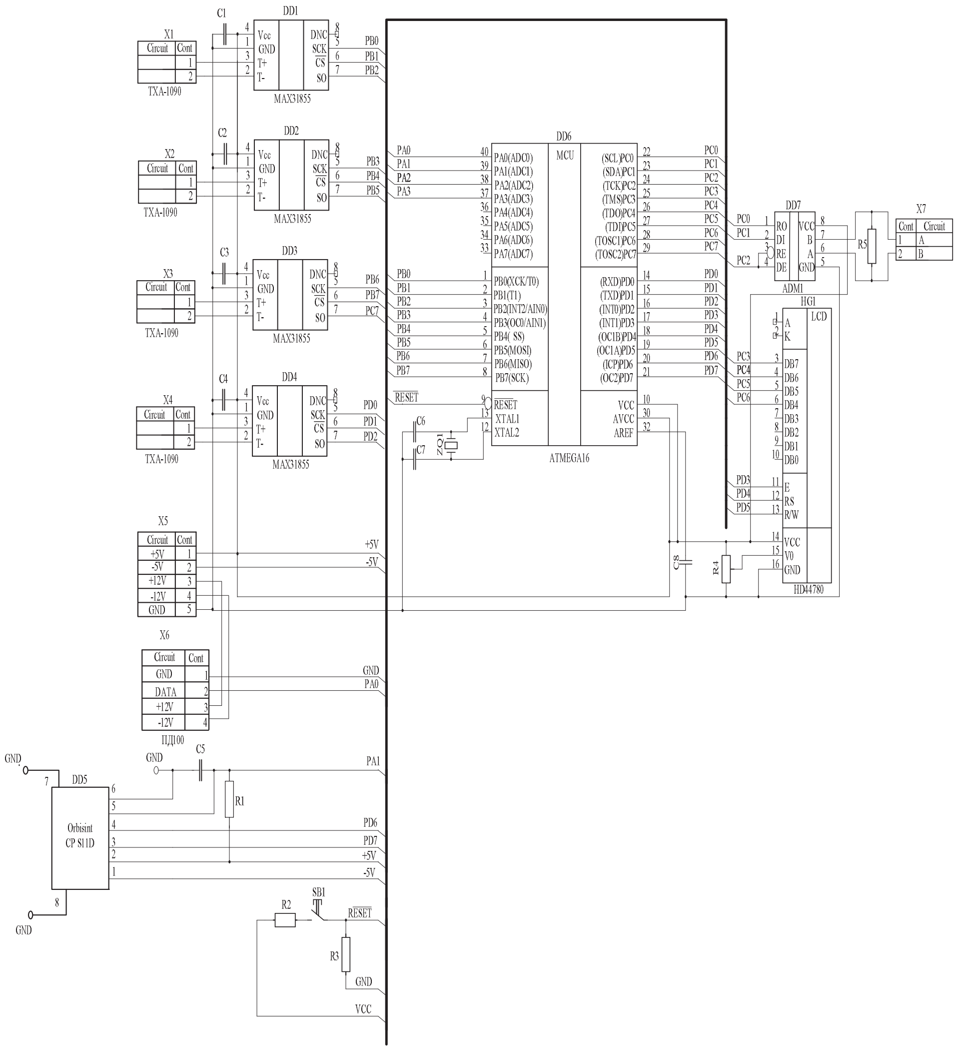

Fig. 2. Electrical schematic diagram of the IMS

To measure the temperature during cheese melting and sterilization, TXA-1090 temperature sensors were used, connected to the disconnections X1, X2, X3, X4, respectively, which are connected to the microcontroller via high-precision digital converters MAX31855 (DD1 – DD4). The sensor for measuring the vapor pressure during cheese melting – OVEN PD100-DG1,0-137-0,5.100 is connected to the disconnector X6. The pH level control sensor Orbisint CPS11D, which includes the DD5 circuit, is directly connected to the DD6 microcontroller bus. ATmega16 was used as the microcontroller. The measurement results are displayed on the DRD, represented by the HD44780 (HG1) chip. The measurement results are transmitted to the PC via the X7 disconnector, thanks to the RS485 serial interface (DD7). The microcontroller is reset by the SB1 button. Capacitors C6 and C7 set the operating mode of the quartz resonator ZQ1. Power is supplied to the control system via the X5 disconnector.

In [16] it is stated that when developing a model of factor influence for each of the industrial IMS, it is advisable to use a model that takes into account the simultaneous action of at least five factors from the following factor groups: noise of the analog part of the measuring channel, the effect of electromagnetic interference, noise of the signal switching device, error of digital signal conversion, changes in the set temperature regime of operation. The indicated factor groups are difficult to stabilize to reduce the impact on the control parameter. In such conditions, it is advisable to carry out a procedure for randomizing factors in order to translate the factor influence into a stochastic process with the possibility of using statistical analysis methods. At the same time, each technological process has its own characteristics in determining the sources of factor influence. In [16], a model of multifactor influence on the result of measuring the control indicator is proposed for use. Since the hierarchy in the system of factors' action is unknown in advance, a model with full cross-classification is promising for use. Such a model will have the form

$$\begin{gathered} E_{abcde_i} = \bar{E} + R_a + S_b + T_c + U_d + V_e + (RS)_{ab} + (RT)_{ac} + (RU)_{ad} + (RV)_{ae} + \\ + (ST)_{bc} + (SU)_{bd} + (SV)_{be} + (TU)_{cd} + (TV)_{ce} + (UV)_{de} + (RST)_{abc} + \\ + (RSU)_{abd} + (RSV)_{abe} + (STU)_{bcd} + (STV)_{bce} + (TUV)_{cde} + \\ + (RUV)_{ade} + (RTU)_{acd} + (RTV)_{ace} + (RSTU)_{abcd} + (RSTV)_{abce} + \\ + (STUV)_{bcde} + (RTUV)_{acde} + (RSUV)_{abde} + \varepsilon_{abcde_i}, \end{gathered} \tag{1}$$

where E_{abcde_i} – control indicator determined during the measurement process (for example, noise of the analog part of the measurement channel), and a, b, c, d, e – numbers indicating the levels of factors; $\bar{E}$ – average value of the control indicator; R_a – deviation of the measurement result of the control indicator E from its average value $\bar{E}$, which is due to the influence of the control parameter (processed cheese quality); S_b, T_c, U_d, V_e – deviation of the measurement result E_{abcde} from $\bar{E}$, caused by the action of five factors; $(RS)_{ab}, (RT)_{ac}, (RU)_{ad}, (RV)_{ae}, (ST)_{bc}, (SU)_{bd}, (SV)_{be}, (TU)_{cd}, (TV)_{ce}$ – deviations that are caused by pairwise interactions of factors;

$(RST)_{abc}, (RSU)_{abd}, (RSV)_{abe}, (STU)_{bcd}, (STV)_{bce}, (TUV)_{cde}, (RUV)_{ade}, (RTU)_{acd}, (RTV)_{ace}$ – deviations that are caused by cross-interactions of three factors;

$(RSTU)_{abcd}, (RSTV)_{abce}, (STUV)_{bcde}, (RTUV)_{acde}, (RSUV)_{abde}$ – deviation, which is caused by the cross-interactions of four factors; ε_{abcde_i} – random remainder; i – number of multiple measurements at fixed levels a, b, c, d, e [16].

When using a full factorial influence model, it is very difficult to technically ensure the homogeneity of the measurement experiment with a sufficiently large sample size, therefore it is advisable to simplify model (1) by leaving only the main deviations R_a, S_b, T_c, U_d, V_e, as well as deviations due to pairwise interactions of factors $(RS)_{ab}, (RT)_{ac}, (RU)_{ad}, (RV)_{ae}$, assuming that three-factor and four-factor interactions are equal to zero [16]. The choice of these pairwise interactions is due to the fact that they are R_a a random variable, since they reflect the effect of a priori uncertain levels of the control parameter and must be taken into account in pairwise interactions to increase the reliability of the model.

A simplified model would look like this

$$E_{abcde_j} = \bar{E} + R_a + S_b + T_c + U_d + V_e + (RS)_{ab} + (RT)_{ac} + (RU)_{ad} + (RV)_{ae} + \gamma_{abcde_j}, \quad (2)$$

where γ_{abcde_j} – random residue greater than ε_{abcde_i}.

The advantage of the simplified model proposed in [16] is that it makes it possible to estimate the amount of expected information about the parameter levels for the information indicator E, taking into account the levels of both influencing factors and their compatible interactions [16]

$$I = \log_2 \sqrt{1 + \left(\frac{\sigma_E}{\sigma_{\Delta E}}\right)^2}, \quad (3)$$

$$\text{where } \sigma_E^2 = \frac{1}{(N-1)} \sum_{i=1}^{n} (E_i - \bar{E})^2, \quad (4)$$

$\bar{E} = \frac{1}{N} \sum_{i=1}^{n} E_i$, $\sigma_{\Delta E}^2$ – is a function of the sums of squares of deviations.

For the technological process of making processed cheese, the factors that affect the quality of the final product are five main factors: the temperature during melting of the cheese mass, the pH level of the cheese mass, the vapor pressure during melting of the cheese mass, the temperature during sterilization of the cheese mass, and the noise of the analog part of the measuring channels.

For the research, the measurement results obtained during the production process with multiple observations of the change in: temperature during melting of the cheese mass and during its sterilization, pH level, vapor pressure during melting of the cheese mass were used. 35 observations were obtained in each series. The observation results are considered independent and equally accurate (under the experimental conditions). There is no systematic error component. Under the production conditions, a confidence probability of P = 0.95 (significance level α = 0.05) of the measurement results was established. A graphical representation of the process of measuring the temperature during melting of the cheese mass is presented in Fig. 3.

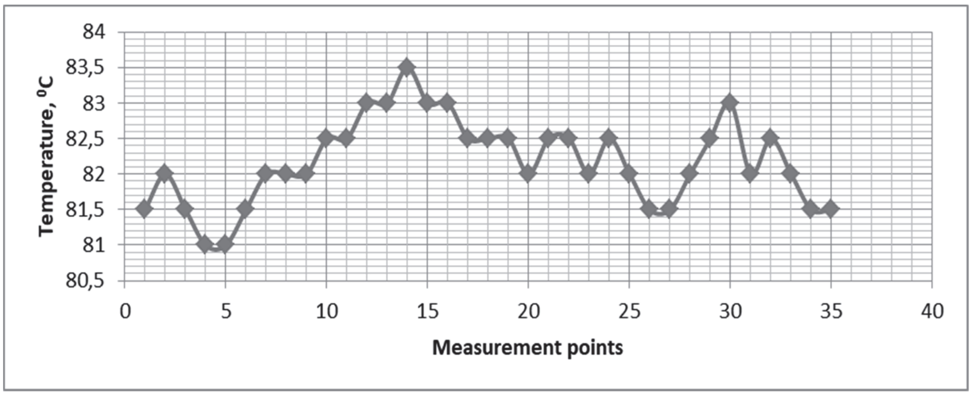

Fig. 3. Results of observations of temperature changes during cheese melting

A graphical representation of the process of measuring vapor pressure during cheese melting is presented in Fig. 4.

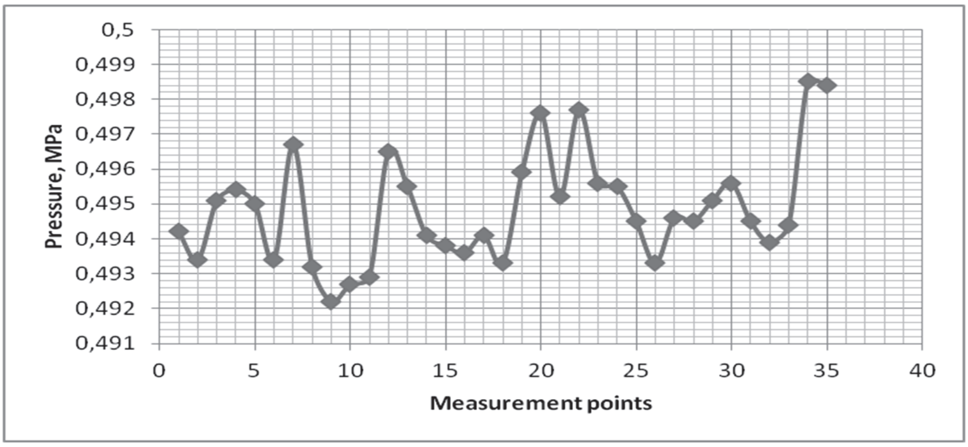

Fig. 4. Results of observations of changes in the vapor pressure level during cheese melting

A graphical representation of the process of measuring the pH level of cheese mass is presented in Fig. 5.

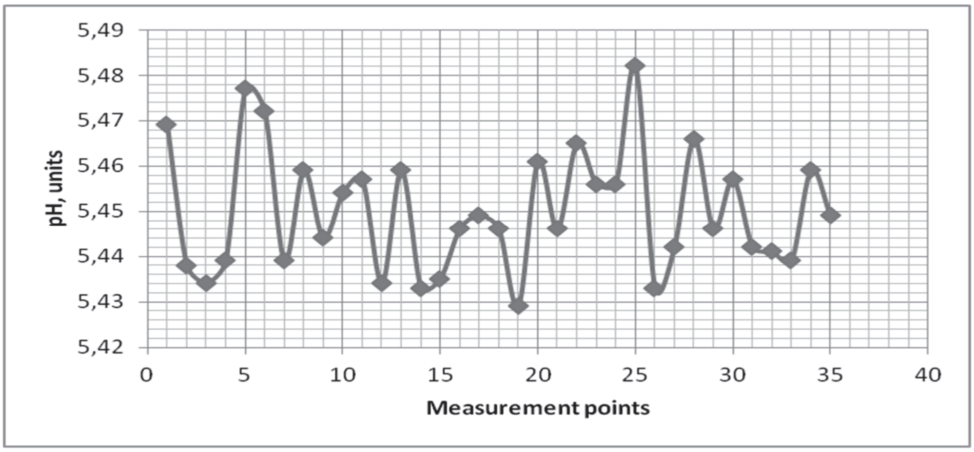

Fig. 5. Results of observations of changes in the pH level of the cheese mass

A graphical representation of the temperature measurement process during cheese mass sterilization is presented in Fig. 6.

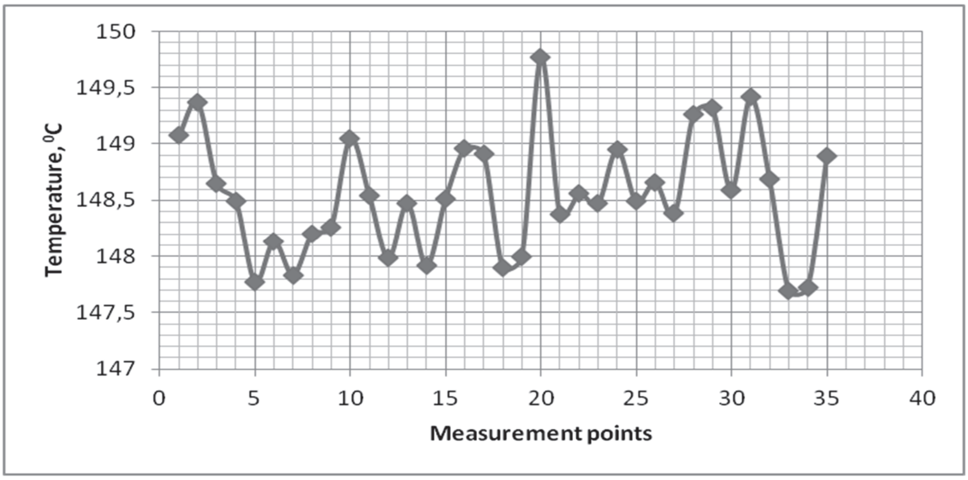

Fig. 6. Results of observations of temperature changes during cheese mass sterilization

The next factor to consider in the production of processed cheese is the noise of the analog part of the measuring channel Δ_{pnoise}. The largest amplitude value among the measuring channels is the noise of the analog part of the pressure measuring channel, which does not exceed the value $3{,}5 \cdot 10^{-3}$ V. This value is taken for further calculations.

A graphical representation of the noise of the analog part of the steam pressure measuring channel is presented in Fig. 7.

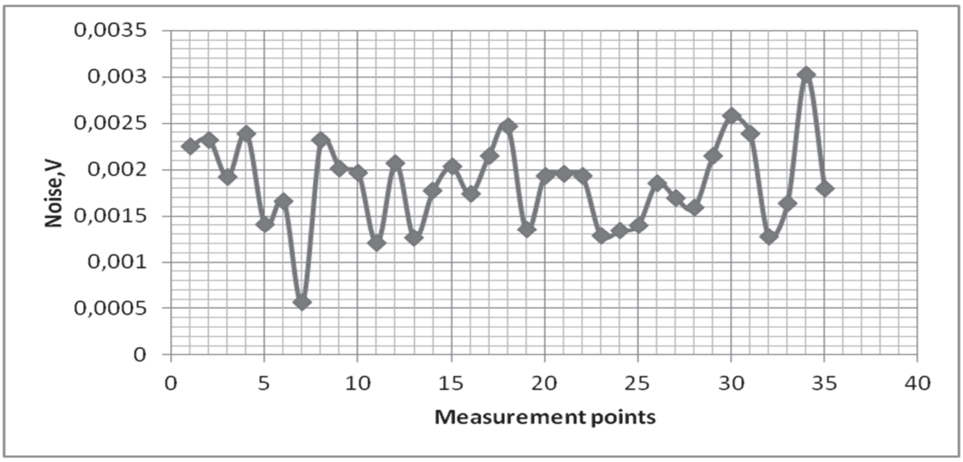

Fig. 7. Graphical representation of the noise of the analog part of the steam pressure measurement channel

The values σ_E^2 are determined by formula (4) for each of the factors.

The results of the calculated values σ_E^2 for the five factors affecting the quality of processed cheese are presented in Table 1.

Table 1. Results of calculated values σ_E^2

Denotation of factors	Factor name	$\overline{E}$	$\sum_{i=1}^{n}\left(E_i-\overline{E}\right)^2$	σ_E^2
E_1	Melting temperature of cheese mass, ^{0}C	82,2 ^{0}C	13,1 $(^0\mathrm{C})^2$	0,38 $(^0\mathrm{C})^2$
E_2	Vapor pressure during cheese melting, MPa	0,49 MPa	$8{,}43\cdot10^{-5}$ (MPa)^2	$2{,}45\cdot10^{-6}$ (MPa)^2
E_3	pH level of the curd mass, units. pH	5,45 units. pH	0,006 (units. pH)^2	$1{,}76\cdot10^{-4}$ (units. pH)^2
E_4	Temperature during cheese mass sterilization, ^{0}C	148,5 ^{0}C	9,65 $(^0\mathrm{C})^2$	0,28 $(^0\mathrm{C})^2$
E_5	Noise of the analog part of the pressure measuring channel, V	$1{,}75\cdot10^{-3}$ V	$7{,}98\cdot10^{-6}$ V^2	$2{,}35\cdot10^{-7}$ V^2

Table 2 shows the calculations of the amount of expected information *I* by the levels of control indicators. The residual mean squares $\sigma_{\Delta E}^2$ are determined from the analysis of variance of the simplified model (2). The indicators in Table 2 are arranged in decreasing order of the value of *I*. The calculation of the amount of expected measurement information *I* was carried out according to equation (3).

Fisher's *F*-statistic was used to test one of the two hypotheses [16]:

$$H_0 : \sigma\left[\overline{E}_1\right] = \ldots = \sigma\left[\overline{E}_m\right], \tag{5}$$

$$H_1 : \sigma\left[\overline{E}_1\right] \neq \ldots \neq \sigma\left[\overline{E}_m\right]. \tag{6}$$

If the statistical conclusions indicate the validity of the main hypothesis (5), then the control parameter does not affect the change in the control indicator *E*. If the alternative hypothesis (6) is valid, then the indicator *E* is informative to the control parameter. Decisions about the validity of the hypotheses are made based on the result of comparing Fisher's *F*-statistic with the critical value of the *F*-statistic – F_{cr} [16].

In Table 2, Fisher's *F*-statistic has the form $F_{4;35}$, where 4 is the number of degrees of freedom corresponding to the largest sample variance ($N-1=5-1==4$); 35 is the number of measurements in the series $F_{4;35}$ is the test statistic of the dispersion relation

$$F_{4;35} = \frac{\sigma_E^2}{\sigma_{\Delta E}^2}, \tag{7}$$

where σ_E^2 – factorial variance per one degree of freedom; $\sigma_{\Delta E}^2$ – residual variance per one degree of freedom.

Since the percentage point of the *F*-distribution $F_{4;35;0,05} = 2{,}61$ for the 5 % level of significance, the hypothesis (5) is rejected for all control indicators.

Based on the obtained values of the amount of information on the control indicators, it is obvious that the greatest influence on the quality of processed cheese is the maintenance of the temperature regime during the melting of the cheese mass ($I = 1{,}56$).

Table 2. Results of determining the amount of expected information by control indicators

Factors	Dispersions		$F_{4;35}$	I, bit
	σ_E^2	$\sigma_{\Delta E}^2$		
E_1	0,38 (^{0}C)^2	0,049 (^{0}C)^2	7,72	1,56
E_2	$2{,}45\cdot10^{-6}$ (MPa)^2	$7{,}29\cdot10^{-7}$ (MPa)^2	3,36	1,06
E_3	$1{,}76\cdot10^{-4}$(units. pH)^2	$2{,}88\cdot10^{-5}$(units. pH)^2	6,12	1,42
E_4	0,28 (^{0}C)^2	0,038 (^{0}C)^2	7,44	1,54
E_5	$2{,}35\cdot10^{-7}$ V^2	$5{,}55\cdot10^{-8}$ V^2	4,48	1,23

Ranking the indicators by decreasing amount of information I makes it possible to present them in the form of a series

$$Q = \{E_1, E_4, E_3, E_5, E_2\}. \quad (8)$$

For all calculated indicators, the F-statistic $F_{4;35}$ is greater than critical $F_{4;35;0,05} = 2{,}61$, which indicates a statistically significant effect of the indicators on the control parameter Q (processed cheese quality).

CONCLUSIONS

1. For the developed information and measuring system for controlling the parameters of the technological process of manufacturing processed cheese, a model of factor influences on the result of determining the control indicator (processed cheese quality) with five influencing factors is proposed. This model takes into account the effects of the simultaneous interaction of such factors as: temperature during cheese melting, pH level of cheese mass, vapor pressure level during cheese melting, temperature during cheese sterilization, noise of the analog part of the steam pressure measurement channel. Based on the presented model, an assessment of the amount of expected information about the levels of the control parameter (processed cheese quality) for the information control indicator was carried out, taking into account the levels of both influencing factors and their mutual interactions.
2. The presence and significance of the factor influence on the quality of processed cheese was proven. The control indicators were ranked by the level of their influence on the control result. It was established that the temperature regime during cheese melting has the greatest influence on the quality of processed cheese.
3. It is promising for further research to implement the proposed factor influence model to analyze the operation of various IMS, regardless of their scope.

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МОДЕЛЬ ФАКТОРНОГО ВПЛИВУ НА РОБОТУ ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНОЇ СИСТЕМИ / І.В. Григоренко, С.М. Григоренко, Ю.Є. Хорошайло, П.М. Білецький

Анотація. Розглянуто розв'язання науково-практичної задачі визначення дії факторного впливу на результат роботи інформаційно-вимірювальної системи для технологічного процесу виготовлення плавленого сиру завдяки використанню моделі факторного впливу, яка враховує одночасну дію п'яти факторів та їх перехресних взаємодій на показник контролю. Завдання дослідження полягає у впровадженні для використання моделі перехресної класифікації, яка дає змогу оцінити кількість очікуваної інформації про рівні параметру контролю за урахування рівнів як факторів, що впливають, так і їх сумісних взаємодій. Розроблено електричну принципову схему системи контролю і виконано її практичну реалізацію, завдяки чому отримано статистичні дані про основні параметри технологічного процесу. Зроблено висновки про можливість подальшого використання запропонованої моделі перехресної класифікації для різноманітних інформаційно-вимірювальних систем незалежно від їх призначення.

Ключові слова: інформаційно-вимірювальна система, контроль якості, факторний вплив, математична модель, дисперсійний аналіз, невизначеність вимірювань, похибка.