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Identification of the eddy current method features in the implementation of computer simulation algorithms for controlling the characteristics of the food production equipment parts

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ABSTRACT

Purpose: The purpose of this article is to study the theoretical provisions of the operation of a vortex device in the implementation of a non-contact method of controlling the details of brewing equipment using computer simulation algorithms.

Design/methodology/approach: The theoretical positions of thermal ECT operation with a copper product are obtained, which is controlled while maintaining a constant value of the magnetic field frequency $f_1 = 70.0$ Hz, with small values of the generalized parameter $x \leq 1.1$ and increasing the parameter x due to the increase in the frequency of thermal ECT, that is, at $x \geq 3.5$.

Findings: On the basis of computer simulation algorithms the results of the joint measuring control of diameter d, electrical resistance ρ and temperature t of the sample made of copper (in the temperature range from 20-160°C) and the results of determination of thermally dependent thermal ECT signals with the sample of equipment details and the values of specific normalized values that relate the ECT signals to the physical and mechanical characteristics of the samples of the equipment being monitored.

Research limitations/implications: Product diameters range is 5 mm to 50 mm. The lower boundary is limited by the frequency of the magnetic field $f = 20$ Hz and the upper boundary by the diameter of the frame of the thermal eddy current transformer transducer is 50 mm. Perspective positions of work require further development in the direction of extending the limits of control of geometrical parameters of the samples due to the use of automated control systems based on overhead eddy current transformer transducers.

Practical implications: The practical value of the work is to increase the overall likelihood of control of the parameters of brewing equipment parts by increasing its instrumental component D_i, due to the reduction of measurement errors due to instrumental techniques and on the basis of computer modelling algorithms for three-parameter control of parts of brewing equipment, electrical and temperature parameters, allows to obtain the value of the overall control probability $D_z = 0.998$.

Originality/value: The originality of the article is the study of the theoretical provisions of the eddy current transformer transducer and the implementation of a non-contact method of controlling the details of brewing equipment using computer simulation algorithms that take into account the modes of joint three-parameter control: at high values of the generalized parameter x (with three-parameter surface control), at small values of x (while controlling the value of the average cross section geometry, electrical, temperature settings) at a fixed frequency magnetic field (get information on the diameter d, resistivity ρ and temperature t with a certain depth of penetration of the magnetic field in the sample Δ).

Keywords: Computer simulation, Food production modernization, Quantitative indicators, Coefficients influence, Errors of aggregate measurements

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ANALYSIS AND MODELLING

1. Introduction

Today, there is a need to implement food production modernization and food production management system improvement on a modern technological basis, by implementing computer modelling algorithms, as well as by meeting modern requirements for environmental standards and product quality [1-3]. At the same time, water resources occupy the first place in the degree of negative impact of food industry enterprises on environmental objects. The food industry occupies the first places among domestic industries in terms of water consumption per unit of output. All these tasks are the most relevant for the domestic industry. In Ukraine, the most modern branches of the food industry are those related to the production of non- and low-alcohol beverages, so brewing products reaching a significant pace. In the EU countries, the successful development of the industry, traditionally associated with the directions of integrated use of raw materials, reducing waste and losses, the creation of low-waste technological processes of brewing production [1,2].

Particularly important, in terms of production loads of appropriate equipment, is the control of geometric, electrical and temperature parameters of parts of quite inexpensive brewing equipment: cylinder graders, connecting hoses, conical fermenters, distillation tubes, tube coils, chillers for cooling worts, gas seals, cylindrical vessel, tank body, yeast deposit reducers and other parts and structures of cylindrical equipment [1,2].

Thus, during studying modern issues of food production equipment, the general problem of computer modelling and predicting of food production equipment condition, in accordance with international standards, remains relevant. It should be noted that the modern technological system is mapped to a specific mathematical model using a wide range of methods to control the quantifiable object values, which are determined the characteristics of the technological system and identify procedure irregularities in a certain period of time. Thus, through the use of additional information methods, devices and systems, it becomes possible to simultaneously identify the causes of product characteristics deviations from the specified quality parameters and to take measures performing appropriate adjustments.

That is why, among informative methods totality, methods of eddy current non-destructive testing (NDT) have proven themselves as a reliable tool for quality management during the production and operation of food production equipment parts [4,5]. At the same time, the most important advantages of eddy current methods are the possibility of joint control of quantifiable values, which is related to the physical and mechanical properties of equipment parts, units and structures of machines and apparatus of food and chemical industries.

In the current technical literature, eddy current methods and devices based on eddy current primary converters for multi-parameter control of magnetic and non-magnetic cylindrical shape products have been considered [5-12]. However, despite the significant contribution of these scientific works, the issue of increasing the probability of controlling the quantitative values of the food industry equipment parts, which is related to the instrumental component of this important characteristic, is almost neglected [9]. It should be noted that in order to increase the component of D_{gen} control probability, it is necessary to create theoretical provisions of the eddy current transformer (ECT) operation with equipment parts samples during the implementation of multi-parameter eddy current methods.

In this case, the increase of the methodological component of the control probability D_m is caused by the increase in the number of parameters to be controlled, in turn, the increase of the instrumental component of the control probability D_i, due to the decrease of measurement errors (increase of measurement accuracy) of equipment samples quantifiable values by reducing the error, the source of which related to heating the sample with eddy currents. It is also related to the thermal conductivity of the structural components of the equipment, to the thermal conductivity of the environment, to the convective component of the medium, to the input power of the heat supplied to the sample. It is also necessary to take into account the amount of current that heats the converter windings, so that all this introduces an error source that has an influence on the instrumental component of the controlling probability the geometric, electrical and temperature parameters of the samples of the parts being controlled.

It should be noted that the difficulties in the development of thermal eddy current devices were also associated with the creation of a complex mathematical apparatus that would sufficiently justify the dependence of the geometric, electromagnetic and temperature parameters of the equipment samples on the components of the thermal ECT signal. In this case, the application of thermometry contact tools is also associated with the measurement inaccuracies of temperature parameters, since contact thermometers are able to measure temperature only on the sample surface, and eddy-current components allow to control the temperature in the inner sample layers, on the sample surface and the average cross section product temperature of the sample [5].

At present, there are no theoretical rules and methodology for the creation of multi-parameter thermal eddy current devices and methods for controlling the quantitative characteristics of food production equipment parts. The possibility of improving the accuracy of temperature measurements of the equipment sample is not considered due to the implementation of multi-parameter eddy current methods developed on the basis of measurement and calculation procedures, which are based on the computer modelling algorithms of temperature fields in sample.

Thus, the creation of new informative methods and instruments for measure controlling of quantitative physic-mechanical parameters during the serial and mass production and parts operation and structures of food production equipment is an important scientific and practical problem and needs further research.

The purpose of the article is to investigate the theoretical rules of the eddy current device operation during implementing of a non-contact controlling method of brewing equipment parts using computer modelling algorithms. The following tasks must be solved to achieve the goal:

1. Obtain basic relationships that describe the theoretical rules of the thermal eddy current transformer with cylindrical equipment samples.
2. Describe algorithms for modelling process of diameter d measuring control, specific electrical conductivity σ (specific electrical resistance ρ) and temperature t of the controlled equipment samples.
3. Using algorithms related to the sample heating during controlling process and compensation for the parasitic magnetic flux influence (which passes in the air gap between the sample and the sensitive element of the eddy current transducer), to develop algorithms for measuring and calculation procedures for electrical, geometrical and the temperature parameters of the samples.
4. To investigate theoretical rules of errors estimation of aggregate measurements of geometrical, electrical and temperature sample parameters (copper M1), during implementing the thermal multi-parameter eddy current method.

2. Result of investigation

Below, we investigate the method and the thermal eddy-current device realizing it for joint informative control of diameter *d*, specific electrical conductivity σ (specific electrical resistance ρ) and temperature *t* of brewing equipment parts. In [5-8], we introduced the parameter *N*, which characterizes the different normalized reflected value of ECT EMF E_{vnt}:

$$E_{vnt} = E_{\Sigma t} - E_0, \quad (1)$$

where E_0 and $E_{\Sigma t}$ – EMF of thermal ECT in the sample absence and total EMF, index *t* – indicates that the value is temperature dependent.

The *N* phase angle ϕ_{vn} for the equipment cylindrical shape sample is determined using the relations [5-12]:

$$N_t = \frac{(E_0 - E_{\Sigma t})\cdot {d_p}^2}{E_0 d^2}, \tag{2}$$

$$\mathrm{tg}\phi_{vnt} = -\frac{1-k_t \cos\phi_t}{k_t \sin\phi_t}, \tag{3}$$

where d_p is the diameter of the measuring transducer coil, k_t is the specific normalized characteristic that is related to the electrical and magnetic properties of the sample.

The formula for determining the complex parameter N has the following form [5-13]:

$$N = \frac{2}{\frac{d}{2}\sqrt{2\pi\mu_0 f \sigma\sqrt{j}}}\frac{I_1(x\sqrt{j})}{I_0(x\sqrt{j})}, \tag{4}$$

where x – thermally dependent generalized parameter; μ_0 – vacuum permeability; f – the frequency of field probing ramp; σ – sample conductivity; I_1 and I_0 – modified Bessel function of order one, first and zero order; j – complex number, $j=\sqrt{-1}$ [5-12].

Further, using computer modelling algorithms, it is necessary to approximate expressions that relate the temperature t with the characteristics N and φ at a fixed frequency of the magnetic field f_1 and in the approximation for the low and high values of the generalized parameter x.

In the case of constant frequency maintenance of the magnetic field $f_1 = 70$ Hz, the sample diameter d (that is heated during the control process) is determined by the conversion function $N_t = f\left(\varphi_{vnt}\right)$:

$$d = d_t\sqrt{\frac{E_0 - E_\Sigma}{E_0 N_t}} \tag{5}$$

Further, electrical conductivity σ_t should be determined by the formula:

$$\sigma_t = \frac{2\cdot {x_t}^2\cdot E_0\cdot N_t}{\mu_0\cdot {d_p}^2(E_0 - E_{\Sigma t})\pi\cdot f} \tag{6}$$

Taking into account the dependence of σ on the temperature t [5]:

$$\sigma_t = \frac{\sigma_1}{\left(1+\frac{\alpha}{1+\alpha t_1}\left(t-t_1\right)\right)} \tag{7}$$

where t_1 – initial temperature, $t_1 = 20^\circ C$.

The formula for determining the controlled sample temperature is as follows:

$$t = \left(\frac{\sigma_1}{\sigma_t}-1\right)\cdot\frac{1+\alpha t_1}{\alpha}+t_1 \tag{8}$$

where α – temperature resistance coefficient.

At high values of the generalized parameter x, the three-parameter control is carried out on the sample surface, at low values of x, the values average over cross-section of geometric, electric, and temperature parameters are controlled and at a fixed frequency of the magnetic field – information is obtained regarding the diameter d of the specific electric resistance ρ and temperature t from a certain depth of penetration Δ of the magnetic field into the controlled sample.

The formula for determining the temperature for low values of the generalized parameter x (x ≤ 1.1) has the following form:

$$t = \left(\sqrt{\frac{1-N_1}{1-N}}-1\right)\left(\frac{1+\alpha t_1}{\alpha}\right)+t_1, \tag{9}$$

where N_1 – corresponds to the value x_1, at $t = t_1$.

Applying the dependence of the phase angle between the flow Φ_0 and N parameter, we have:

$$t = \left(\frac{tg\varphi_1}{tg\varphi}-1\right)\left(\frac{1+\alpha t_1}{\alpha}\right)+t_1, \tag{10}$$

where φ_1 is determined at x_1.

Increasing the values of the generalized parameter $x \geq 3{,}5$, we obtain:

$$t = \left(\frac{4\cdot {N_1}^2}{x^2}-1\right)\left(\frac{1+\alpha t_1}{\alpha}\right)+t_1 \tag{11}$$

When the values of the generalized parameter are increased, the temperature dependence of the sample equipment t on $tg\varphi$ has the following form:

$$t = \left(\frac{1-tg\varphi}{1-tg\varphi_1}\right)\cdot\left(\frac{1+\alpha t_1}{\alpha}\right)+t_1 \tag{12}$$

There is no general approach to the errors estimation of total measurements of geometric, electrical and temperature parameters of food processing equipment parts in the implementation of multi-parameter methods of eddy current non-destructive testing in the existing technical literature.

In accordance with the general errors theory in the metrological characteristics estimation of eddy current means of non-destructive test role, the methods of determination of direct and indirect measurements are generally applied. At the same time, theoretical rules related to the errors estimation theory of total measurements of converters informative signals and physical and mechanical characteristics of equipment parts, that is, systematic measurement errors of the majority function, which represent the dependences of normalized transducer characteristics (EMF, phase angles, magnetic field frequencies f and other signal components) from important informative parameters of the test object, namely: outer and inner radius of tubes and pipes, longitudinal and the width and connecting elements; tangential tension of parts; units and structures of equipment τ; specific electrical conductivity σ; temperature t of equipment parts and couplings during operation; surface roughness of object R_a, fluctuations in temperature deflection of the DGV device; oscillations of instrumental radial temperature-deformation deformation Dg6; vibration velocity V_m; the size of the gap and the tension of the connecting elements of food production equipment – need further development.

At the same time, determination of total errors measurements of physical and mechanical parameters of equipment parts, allows to establish rational operating modes of thermal multi-parameter eddy current transducers, to increase the control probability of equipment parts and, accordingly, to significantly improve the control quality of new technological processes of food production.

Thus, to determine the functions measurement errors of many variables $N = f\left(\varphi_{vn}\right)$ and $\varphi_{vn} = f\left(x\right)$, it could be written determine the systematic error expression of measuring the cylindrical equipment diameter, through the signals of thermal ECT at a probability $P = 0{,}95$:

$$\gamma_d = 1{,}1\sqrt{\left(C_{E_{vn}}\gamma_{E_{vn}}\right)^2 + \left(C_{E_0}\gamma_{E_0}\right)^2 + \left(C_N\gamma_N\right)^2} \tag{13}$$

where 1,1 – reliability coefficient at $P = 0{,}95$; γE_{vn}, γE_o, γN – are the fractional measurement errors of the thermal ECT components signals: E_{vn}, E_o and N; $C_{E_{vn}}$, C_{E_o}, and C_N are the influence coefficients that are determined at the universal conversion function operating points.

Formula (13) indicates that the fractional measurements error is subject to the normal law of errors measurements distribution under different errors distribution laws of arguments under the root, if the number of arguments is not more than three (uniform distribution, trapezoidal law, Rayleigh distribution) [14].

Applying the function $\varphi_{vn} = f\left(x\right)$, and also considering that the electrical resistivity ρ is the inverse of σ, we obtain an expression to determine the absolute systematic error of the measurement of the electrical sample resistivity ρ:

$$d\rho = \rho'_{t_1}dt_1 + \rho'_{\alpha}d\alpha + \rho'_{t}dt + \rho'_{\rho_1}d\rho_1 , \tag{14}$$

«stroke» denotes partial derived function ρ by the corresponding arguments dt_1, $d\alpha$, dt, $d\rho_1$ and differentials t_1, α, t and ρ_1.

Below partial function derivatives under the following arguments are found:

$$\rho'_{t_1} = \left[\frac{\alpha\rho_1(t - t_1)}{1 + \alpha t_1}\right]'_{t_1} = \frac{\alpha\rho_1\left[(-1)(1 + \alpha t_1) - \alpha(t - t_1)\right]}{(1 + \alpha t_1)^2} = \tag{15}$$

$$= \frac{\alpha\rho_1(-1 - \alpha t_1 - \alpha t + \alpha t_1)}{(1 + \alpha t_1)^2} = -\alpha\rho_1\frac{1 + \alpha t}{(1 + \alpha t_1)^2};$$

$$\rho'_{\alpha} = \rho(t - t_1)\,\left(\frac{\alpha}{1 + \alpha t_1}\right)'_{\alpha} = \rho_1(t - t_1)\,/\,\frac{(1 + \alpha t_1) - \alpha t_1}{(1 + \alpha t_1)^2} = \tag{16}$$

$$= \rho_1(t - t_1)\frac{1 + \alpha t_1 - \alpha t_1}{1 + \alpha t_1} = \rho_1\frac{t - t_1}{1 + \alpha t_1};$$

$$\rho'_{t} = \frac{\alpha\rho_1}{1 + \alpha t_1}, \tag{17}$$

$$\rho'_{\rho_1} = 1 + \frac{\alpha(t - t_1)}{1 + \alpha t_1} = \frac{1 + \alpha t_1 + \alpha t - \alpha t_1}{1 + \alpha t_1} = \frac{1 + \alpha t}{1 + \alpha t_1}. \tag{18}$$

Thus, the fractional differential has the following form:

$$\frac{d\rho}{\rho} = \frac{-\alpha\rho_1(1 + \alpha t)t_1}{(1 + \alpha t_1)^2\rho}\frac{dt_1}{t_1} + \frac{\alpha\rho_1(t - t_1)}{\rho(1 + \alpha t_1)}\frac{d\alpha}{\alpha} + \tag{19}$$

$$+ \frac{\alpha\rho_1 t}{(1 + \alpha t_1)\rho}\frac{dt}{t} + \frac{\rho_1(1 + \alpha t)}{(1 + \alpha t_1)\rho}\frac{d\rho_1}{\rho_1}.$$

Further identified influence coefficient should be determined:

$$A_{t_1} = \frac{-\alpha\rho_1(1 + \alpha t)t_1}{(1 + \alpha t_1)^2\rho}, \tag{20}$$

$$B_{\alpha} = \frac{\alpha\rho_1(t - t_1)}{\rho(1 + \alpha t_1)}, \tag{21}$$

$$C_t = \frac{\alpha\rho_1 t}{(1+\alpha t_1)\rho}, \tag{22}$$

$$D_{\rho_1} = \frac{\rho_1(1+\alpha t)}{(1+\alpha t_1)\rho}. \tag{23}$$

Applying the dependence of the thermal ECT phase angle on the generalized parameter *x*, i.e. $\varphi_{vn} = f\left(x\right)$, with a constant frequency value, we have:

$$\frac{dx}{x} = \frac{\partial x}{\partial\varphi}\frac{\varphi}{x}\frac{d\varphi}{\varphi}, \tag{24}$$

$$\frac{dx}{x} = \frac{dd}{d} - \frac{1}{2}\frac{d\rho}{\rho} + \frac{1}{2}\frac{df}{f}, \tag{25}$$

where $\partial x/\partial\varphi$ is the partial function derivatives x by argument φ, $\partial\phi$ is differential φ.

Comparing expressions (24) and (25), we have:

$$\frac{dd}{d} + \frac{1}{2}\frac{df}{f} - \frac{1}{2}\frac{d\rho}{\rho} = \frac{\partial x}{\partial\phi}\frac{\phi}{x}\frac{d\phi}{\phi}. \tag{26}$$

It follows

$$\frac{d\rho}{\rho} = 2\frac{dd}{d} + \frac{df}{f} - 2\frac{\partial x}{\partial\phi}\frac{\phi}{x}\frac{d\phi}{\phi} \tag{27}$$

Taking into account formulas (24-27), after simple transformations, we have:

$$\frac{dt}{t} = \frac{1}{C_t}(2\frac{dd}{d} + \frac{df}{f} + \mathrm{A}_{t_1}\frac{dt_1}{t_1} - B_\alpha\frac{d\alpha}{\alpha} - D_{\rho_1}\frac{d\rho_1}{\rho_1} - \\ -2\frac{\partial x}{\partial\phi}\frac{\phi}{x}\frac{d\phi}{\phi}). \tag{28}$$

Denote N_φ by the influence coefficient:

$$N_\varphi = -2\frac{\partial x}{\partial\varphi}\frac{\varphi}{x} \tag{29}$$

Considering of constant measurement errors characteristics γ_α and γ_{ρ_1} considerably small, we receive the formula for determination of temperature error:

$$\gamma_t \approx \frac{1{,}1}{C_t}\sqrt{(2\gamma_d)^2 + \gamma_f{}^2 + (N_\phi\gamma_\phi)^2} \tag{30}$$

In Figure 1, taking into account the results of works [5-12], a diagram of the inclusion of thermal ECT for controlling the geometric, electrical and temperature parameters of the equipment parts is given. The scheme includes: working transducer – WT, generator – G, frequency counter – F, barretter – B, voltmeters – V_1, V_2 and V_3 (B_1, B_2, B_3), model resistance - R_0, phasemeter – Ph, mounting eddy current transducer – MT. The scheme also contains a compensating ECT – CT, with WT, CT and MT have the same number of coils, as well as each geometrical parameters of the primary and secondary windings (the primary windings of the WT, CT and MT are connected in series, and the secondary WT and CT connected inverted in series). The CT is intended to compensate for the parasitic EMF E_1 in the sample equipment absence in the WT [5]. The scheme also provides a heater H to simulate the process of heating the sample in the range from 20 to 160°C. Nickel thermistors – NT, which are fixed to the sample surface (at both ends of the sample) were used as a control method for temperature measurement. In the temperature measurement control method was used nickel thermistors – NT, that are locked on the sample surface (on both sample side). Initially, the scheme is configured as follows: during absence in WT sample, the signal recorded by voltmeter B_2 is zero, and then the compensation operation of the air gap effect is performed by picking up the secondary windings of the CT. In this case, the EMF E_0 is registered by voltmeter B_3. Thus, at the output of the secondary coil block of the CT mutual inductance appears EMF E_{20}, which is equal to the EMF of the opposing coils WT and CT. In WT sample, a differential EMF E_{vnt} appears which is determined using a B_2 voltmeter during matching. Phase angle φ_{vnt}, measured by phasometer Ph. Thermal ECT performs simultaneously the following functions: creates a coherent magnetic flux Φ_{2t} in the equipment sample, provides registration of EMF E_{vnt}, and also provides a change in the sample temperature during controlling by heater, H located directly in the ECT. Thus, the temperature-dependent difference EMF of E_{vnt} is measured with B_2 voltmeter during operation, and then the phase angle φ_{vnt} between EMF E_0 and E_{vnt} is recorded using Ph. The excitation current is determined using voltmeter B_1. The scheme (Fig. 1) also provides a current stabilizer B. The use of this device is due to the elimination of the error source in the measurement of thermally dependent ECT parameters E_{vnt} and φ_{vnt}, due to the influence of ambient temperature and sample heating directly from the ECT. This, in turn, leads to an increase in the probability of D_{gen} control due to an increase in its instrumental component of D_i [5]:

$$D_{gen} = D_i \cdot D_{\text{м}}. \tag{31}$$

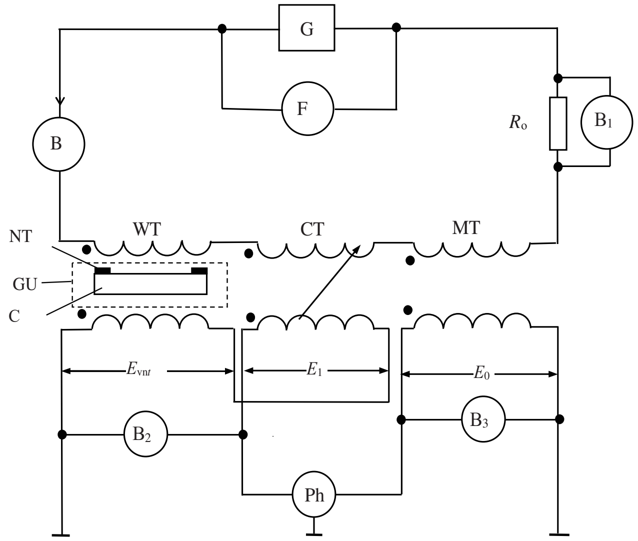

Fig. 1. Scheme of inclusion of thermal ECT with the controlled

Sufficient homogeneity of the magnetic field in the eddy current transducer is ensured by performing the inequality, which is a condition of the length ratio of the magnetic winding of the thermal ECT to the diameter $l_p / l_d \geq 12$. The average magnetic field stress in the WT did not exceed 280 A/m [5].

Thus, the signal components as well as the relative normalized characteristics of thermal ECT in this case are temperature dependent, since such measurement control involves heating the sample in the controlling process (to simulate the process of heating the parts in the conditions of brewing equipment operation). As a control method, a micrometric method of *d* diameter measuring was used, based on electronic digital micrometer EDM. A thermoresistive method was used for determining the temperature *t*, which is implemented on the basis of two nickel thermistors NT. The measuring bridge was used for determining the resistivity ρ during studies. Sample parameters: $d = 15 \cdot 10^{-3}$ m, $l = 0,30$ m, $\rho = 1,75 \cdot 10^{-8}$ Ohm·m, $\alpha = 4,3 \cdot 10^{-3}$ 1/K (copper material), ECT parameters: $f_1 = 70$ Hz, $E_0 = 85$ mV, $l_\rho = 0,35$ m, $d_\rho = 18 \cdot 10^{-3}$ m.

As follows from the data in Table 1, the numerical values of d and d' practically do not change with increasing values of temperature, because the temperature linear expansion coefficient of copper is small enough (10^{-12}-10^{-14} 1/K).

The table also shows the values of the diameter d', the resistivity ρ' and the temperature t' of the test copper sample, which were determined by control methods. It follows from Table 1 that the data of the eddy-current method being investigated, which are implemented on the basis of computer modelling algorithms and the data of known control methods of technical measurements, are sufficiently consistent with each other.

Based on computer modelling algorithms (Tab. 1), the results of joint measurement control of diameter *d*, resistivity ρ and temperature *t* of the sample made of copper, in the temperature range from 20-160°C and the results of determination of thermally dependent thermal ECT signals are presented.

Table 1.
Measurement control results of equipment sample obtained from the implementation of computer modelling algorithms

t, °C	$\rho' \cdot 10^{-8}$, Ohm·m	φ_{vnt}, deg	d	N_t	E_{vnt}, mV	d', mm	t', °C	$\rho' \cdot 10^{-8}$, Ohm·m	γ_t, %	γ_ρ, %
18.72	1.721	36.01	15.003	0.62	23.31	15.001	20.00	1.729	-6.40	-0.46
39.14	1.851	34.32	15.005	0.61	22.85	15.001	40.00	1.858	-2.15	-0.38
65.61	1.875	33.68	15.007	0.60	21.54	15.002	65.00	1.869	0.94	-0.32
85.68	2.129	33.05	15.004	0.59	21.18	15.001	85.00	2.126	0.80	0.14
104.90	2.180	32.10	15.006	0.58	21.02	15.001	105.00	2.177	-0.095	0.14
126.02	2.400	31.80	15.004	0.57	20.81	15.002	125.98	2.397	0.03	0.13
144.97	2.538	31.01	15.004	0.56	20.34	15.003	145.00	2.540	-0.02	-0.08
159.87	2.678	30.60	15.005	0.55	20.18	15.001	160.00	2.680	-0.08	-0.07

3. Results and discussion

The basic relations which describe the theoretical positions of operation of a thermal eddy current transformer transducer (ECT) with details of equipment of cylindrical shape are obtained. The algorithms for simulating the process of measuring control the diameter d, the electrical conductivity σ (electrical resistivity ρ) and the temperature t of the sample are presented. Using the techniques that are associated with the heating of the sample in the process of control and with the use of compensation for the influence of the parasitic magnetic flux (which passes in the air gap between the sample and the sensitive element of the ECT), an algorithm for measuring and calculation procedures for the geometrical control procedures was developed, electrical and temperature parameters of cylindrical equipment parts. When performing three-parameter control while maintaining constant frequency values of the magnetic field $f1$ = 70.0 Hz, at small values x of the generalized parameter $x \le 1.1$ and when the parameter x increases due to the increase in the frequency of thermal ECT, i.e. at $x > 3.5$. On the basis of computer simulation algorithms the results of the joint measuring control of diameter d, electrical resistance ρ and temperature t of sample made of copper (in the temperature range from 20-160°C) and results of determination of thermally dependent thermal ECT signals with sample of equipment details and specific values are obtained normalized values that relate the ECT signals to the physical and mechanical characteristics of the samples of the parts of the monitored equipment. Theoretical provisions of estimation of errors of aggregate measurements of geometrical, electrical and temperature parameters of the sample at realization of thermal multivariable eddy current method are investigated, numerical values of errors of measurements of specific electric resistance γ_ρ and temperature γ_t in accordance with the proposed method are found.

4. Conclusions

Thus, the technological processes of food production are multifactorial control processes. It is necessary to distinguish important informative parameters, which most fully describe the electrophysical properties of the controlled object during applying the test complexes and implementation of computer production processes modelling.

The following parameters should be taken into account during control-ling the products and equipment parts: the electrical conductivity σ and the temperature t of the controlled object. These parameters carry information about the strength characteristics, the results of the various treatments effects in the manufacture of equipment (mechanical, thermal, etc.), defects in food production facilities parts and related equipment of the food and brewing industry. At the same time, methods of eddy current non-destructive testing (ENDT), have proven as a reliable tool for quality management during the production and operation of food production equipment parts.

The article investigates the theoretical eddy current device rules and the implementation of a noncontact method of controlling the brewing equipment parts using computer modelling algorithms, which take into account three operation modes, which in turn helps to increase the controlling the characteristics probability of equipment parts in the context of solving important scientific-practical problems. This problem confined in new informative methods creation and devices of measuring control of quantitative physical and mechanical parameters in the course of serial and mass production and operation of equipment parts of food production.

The basic relations that describe the theoretical rules of thermal eddy current transformer transducer operation (ECT) with cylindrical shape equipment parts are obtained. Algorithms for modelling the measuring control process of diameter d, specific electrical conductivity φ (electrical resistivity ρ) and sample temperature t are shown. Using the techniques that are connected with the sample heating in the controlling process and with the use of compensation for the parasitic magnetic flux influence (which passes in the air gap between the sample and the sensitive element of the eddy current transducer), an algorithm for measuring and calculation control procedures for geometric, electrical and temperature parameters determination of the cylindrical shape equipment. During performing three-parameter control while maintaining a constant value of the frequency of the magnetic field $f_1 = 70$ Hz, at small values of the generalized parameter $x \le 1.1$ and during increasing the parameter x due to the in-crease in the frequency of thermal ECT, at $x \ge 3.5$. Based on computer model-ling algorithms, we obtained the results of a joint measurement diameter d control, specific electrical resistance ρ and temperature t of the copper sample (in the temperature range from 20-160°C) and the results of determination of thermally dependent thermal ECT signals from sample equipment parts and values of specific normalized values that relate the ECT signals to the physical and mechanical characteristics of the sample parts. Theoretical errors estimation rules of total measurements of geometrical, electrical and temperature sample parameters during the implementation of thermal multivariable eddy current method are investigated, numerical values of measurements errors of specific electrical resistance γ_ρ and temperature γ_t are determined in accordance with the proposed method.

The scientific novelty of the article is the theoretical rules investigation of the eddy current device and the implementation of a non-contact controlling method of the brewing equipment parts using computer modelling algorithms that include the modes of joint three-parameter control: at high values of the generalized parameter x (with three-parameter surface control), at small values of x (at the same time, control the across section average values of geometric, electrical, temperature parameters) and at fixed frequency of the magnetic field (information is obtained regarding the diameter d, the specific electrical resistance ρ and the temperature t from a certain depth penetration of the magnetic field into the sample Δ).

The practical importance of article is to increase the total probability of controlling D_{gen} the brewing equipment parts parameters by increasing its instrumental component D_i, due to the reduction of measurement errors due to instrumental techniques and based on computer modelling algorithms for three-parameter control of brewing equipment parts.

Prospects for further research include the creation of automated computerized systems for controlling electrical and temperature characteristics of brewing semi-finished products during implementing new informative methods based on primary heat transducers and improving the quality of the finished product by introducing additional modes, which includes temperature breaks.

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