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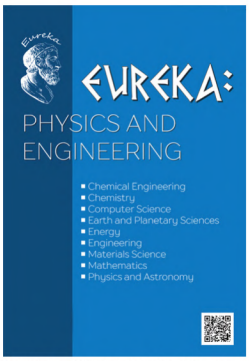

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Original Research Article: full paper

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IMPROVEMENT OF METHODS OF THE PROPERTY VALUATION BASED ON MATHEMATICAL AND NUMERICAL MODELING

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Abstract

The conducted researches aimed to analyze modern models and methods of implementation of the comparative approach in property and real estate appraisal, to investigate and evaluate their effectiveness, to suggest ways of further improving the methods of property valuation.

To achieve this aim, the authors carried out a series of computational experiments on a computer. The essence of these experiments was the comparative evaluation of the cost of test properties based on the following methods: expert evaluation, solving systems of linear algebraic equations, based on the normalized distances in the space of pricing factors and the correlation-regression method. An analysis was made of the influence of methods of digitizing the initial data (pricing factors) on the final cost of real estate.

On the basis of the studies, prospective ways and directions for further improvement of the methods of property valuation are determined.

Keywords: real estate, valuation of property and real estate, digitization of source data, property valuation method, comparative approach in real estate appraisal, real estate value.

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1. Introduction

In conditions of active reformation of property relations, the need for services for valuation of property and property rights is regularly growing. The problems of property valuation related to property alienation, property disputes, the problem of land reform, the formation of an alternative model of partnership between the public and private sectors, require objective decisions of the appraisal expertise [1–6]. Accordingly, there is a need to improve the toolkit of the procedure for conducting property valuation by applying modern mathematical models and methods to obtain an objective market value of property and to make effective management decisions.

2. Literature review and problem statement

To date, property valuation in Ukraine [7], as in the countries of Europe [5], Australia [6] is conducted according to 3 main approaches: comparative, profitable and costly, each of which has advantages and disadvantages (**Table 1**).

Table 1

Comparative analysis of different approaches to property valuation

Approach	Advantages	Disadvantages
profitable	– the cost of the valuation depends on the profit that the valuated object can generate – takes into account the market aspect through the discount rate; – takes into account the economic aging; – is universal.	– cumbersome calculations; – the results are of a probabilistic nature; – the difficulty of obtaining information for making calculations; – high degree of risk; – valuation subjectivity.
comparative	– a completely market-based method; – in the total cost reflects the opinion of typical sellers and buyers; – allows to take into account the uniqueness of each object; – simplicity of interpretation of results.	– does not take into account future expectations; – dependence on market stability; – the complexity of reconciling sales data is significantly different; – cumbersome calculations; – the possibility of the absence of analogical objects; – difficulties in gathering the necessary initial information.
costly	– is based on real assets; – the only possible for some types of enterprises; – allows to display the actual costs incurred by the enterprise [5].	– does not take into account future expectations; – does not take into account some intangible assets; – does not take into account the effectiveness of the use of assets; – the book value of the property never corresponds to its market value.

To date, for the valuation of property and real estate, the most common is the comparative approach, which involves determining the value of the valuated object by comparing the prices of recent sales of similar properties. The approach is based on taking into account the principles of supply and demand in the real estate market.

This approach is implemented in 4 stages [7]:

1. Study of the state, development trends and features of the real estate market segment to which the valuated object belongs.

2. Collection and verification of information about analogical objects, analysis of collected information.

3. Choosing a method for implementing a comparative approach.

4. Reconciliation of adjusted prices of analogical objects and determination of the value of the market value of the property being valued.

One of the most difficult stages in implementing a comparative approach in valuation of property and real estate is the stage of choosing the method of its implementation (stage 3), which requires the definition of certain scientifically grounded criteria for choosing a particular method.

Therefore, it is important to analyze modern methods of implementing a comparative approach in valuation of property and real estate, assess the effectiveness of existing methods and models, and offer the most effective tools for performing valuation activities.

3. The aim and objectives of research

The conducted researches aimed to analyze modern models and methods of implementation of the comparative approach in property and real estate appraisal, to investigate and evaluate their effectiveness, to suggest ways of further improving the methods of property valuation.

To achieve this aim, the following tasks are solved in the work:

– to conduct an analysis of methodological approaches to the valuation of property and real estate;

– to analyze the methods of implementing a comparative approach in the valuation of property and real estate;

– to conduct a comparative analysis of the calculation of the property value on the basis of expert valuation methods, solving the system of linear equations, the method of calculating corrective corrections based on the normalized distances in the space of pricing factors and on the basis of the correlation-regression method;

– to carry out computational experiments to investigate the effect of the process of digitizing the original data on the final value of the real estate object when implementing the studied methods.

4. The essence and methods of research of modern methods of implementing a comparative approach in valuation of property and real estate

4. 1. Object, subject and methods of research

The objects of this research are real estate objects.

The subject of this research is methods for determination of the value of real estate objects in the framework of a comparative approach.

Research methods are mathematical and numerical modeling.

The research is carried out in two main directions:

1. Computational experiment on the study of existing methods for implementing a comparative approach in the valuation of property and real estate, the essence of which was the comparative valuation of test real estate objects obtained by different methods.

2. Computational experiment to study the sensitivity of the methods under consideration to implement a comparative approach in the valuation of property and real estate according to the procedure for digitizing the initial data (pricing factors).

4. 2. Investigated methods for implementing a comparative approach in valuation of property and real estate

Expert method of determining corrective corrections

The simplest and most popular method for implementing a comparative approach in real estate valuation is the expert method of determining corrective amendments. It is based on making corrections to the cost of analogical objects for certain pricing factors, by comparing them with the valuation object. Most often, amendments are introduced to: terms of sale, location, technical condition and others. At the same time, a certain step is chosen, based on the vision of a specific expert. Most often this step is 5 %. The final value of the valuation object is derived as the arithmetic mean, modal or median value [2–4, 6].

It is clear that this method is very dependent on the qualification of the expert and the choice of the calculated step.

The method of calculating corrective corrections based on the solution of a system of linear algebraic equations (SLAE)

The method of calculating corrective corrections based on the solution of a system of linear algebraic equations (SLAE) is more substantiated and formalized [6–8]. According to this method, the value of the property is based on the formula:

$$V_0 = P_i + \sum_{i=1}^{m} \Delta P_{ij}, \quad (1)$$

where V_0 – the value of the valuation object, P_i – the price of the i-th counterpart; ΔP_{ij} – adjustment of the price of the i-th analogue to the difference in the object of estimation by the j-th pricing factor.

According to the model (1), it is necessary to compare the object in succession with each of the selected analogs. As a result, let's obtain a system of linear equations:

$$\begin{cases} V_0 - \Delta x_{11}\Delta P_1 - \Delta x_{12}\Delta P_2 - ... - \Delta x_{1m}\Delta P_m = P_1; \\ V_0 - \Delta x_{21}\Delta P_1 - \Delta x_{22}\Delta P_2 - ... - \Delta x_{2m}\Delta P_m = P_2; \\ ... \\ V_0 - \Delta x_{n1}\Delta P_1 - \Delta x_{n2}\Delta P_2 - ...\Delta x_{nm}\Delta P_m = P_n. \end{cases} \quad (2)$$

It is more convenient to find the solution of this system by the matrix method.

The main drawback of this method is that the number of analogs should exceed by 1 number of factors. This certainly causes certain difficulties in the implementation of this method, related to the need to search for additional analogues or a reduction in the number of pricing factors.

The method of calculating corrective corrections based on the normalized distances in the space of pricing factors

Another formalized method has no limitations on the number of pricing factors and analogical objects is the method of calculating corrective corrections based on the normalized distances in the space of pricing factors [8]. According to it, the definition of the value of the property is carried out in 4 stages.

Preparatory stage. At this stage, the state matrix M is formed:

$$M = \begin{pmatrix} x_{01}x_{02} & \cdots & x_{0m} \\ \vdots & \ddots & \vdots \\ x_{n1}x_{n2} & \cdots & x_{nm} \end{pmatrix}, \quad (3)$$

where n is the number of analogical objects; $x_{01}, x_{02}, \ldots, x_{0m}$ – the object of valuation; $x_{n1}, x_{n2}, \ldots, x_{nm}$ – i-th analogue.

The first stage is the formation of a matrix of congruences

At this stage, let's form the matrix of comparisons ΔM by subtracting the value of the first row of the matrix from the corresponding elements of all subsequent rows:

$$\Delta M = \begin{pmatrix} \Delta x_{11}\Delta x_{12} & \cdots & \Delta x_{1m} \\ \vdots & \ddots & \vdots \\ \Delta x_{n1}\Delta x_{n2} & \cdots & \Delta x_{nm} \end{pmatrix}. \quad (4)$$

Thus, each element of the comparison matrix Δx_{ij} characterizes the difference between the i-th analogue object and the object of estimation by the j-th factor.

The second stage is the normalization of the matrix of congruences

In order to move away from the different units of measurement of the columns of the matrix ΔM, each element of the matrix is normalized as follows:

$$\Delta k_{ij} = \frac{\Delta x_{ij}}{\sqrt{\sum_{i=1}^{n} \left(\Delta x_{ij}\right)^2}}. \quad (5)$$

Thus, let's obtain a normalized comparison matrix +ΔM.

The third stage is the determination of weight coefficients

On the basis of the matrix +ΔM let's calculate the distance l_i from the formula:

$$l_i = \sqrt{\sum_{j=1}^{m} \left(\Delta k_{ij}\right)^2}, \; i = \overline{1,n}. \quad (6)$$

In an n-dimensional Euclidean space, the object of estimation acts as the center of coordinates, and to each analogue object there corresponds a separate point, remote from the center of coordinates (the object of valuation) by the distance l_i.

To each quantity l_j. it is possible to compare the reciprocal quantity $P_i = \frac{1}{l_i}$, which can be transformed into a weighting coefficient by the formula:

$$v_i = \frac{p_i}{\sum p_i}. \quad (7)$$

The fourth stage is the determination of the value of the valuation object. Taking into account the found weight coefficients, the value of the valuation object is determined by the formula:

$$C = \sum_{i=1}^{n} v_i \cdot C_i, \quad (8)$$

where C_i – the cost of the i-th analogue object.

This method is guaranteed to give the result of the value of the valuation object, does not exceed the limits of the cost of used analogs.

The advantage of this method is that it takes into account the degree of proximity of the valuation object to the analogue objects.

Correlation-regression method for determining the value of real estate objects

If there is a significant amount of information on analogous objects, then it is reasonable to determine the market value of a real estate object within the framework of a multifactor regression analysis that allows one to assess the degree of influence on the investigated performance indicator of each of the factors introduced into the model with a fixed position at the middle level of other factors [9–18].

Mathematically, the task is reduced to finding an analytical expression, it would better reflect the connection of the factor characteristics with the resultant:

$$Y = f\left(X_1, X_2, ..., X_n\right). \quad (9)$$

The most difficult problem is choosing the form of communication. However, taking into account that any function of many variables can be reduced to a linear form by logarithmation or substitution of variables, the multiple regression equation can be expressed in a linear form:

$$Y = a_0 + a_1X_1 + a_2X_2 + ... + a_nX_n, \quad (10)$$

where Y – the calculated values of the effective indicator; X_1, X_2, …, X_n – the factors; a_0, a_1, a_2,…a_n – the equation parameters.

The equation parameters are calculated by the least squares method. So, in the case of two-factor regression:

$$\begin{aligned} \sum Y &= na_0 + a_1\sum X_1 + a_2\sum X_2 \\ \sum YX_1 &= a_0\sum X_1 + a_1\sum X_1^2 + a_2\sum X_1X_2 \\ \sum YX_2 &= a_0\sum X_2 + a_1\sum X_1X_2 + a_2\sum X_2^2 \end{aligned} \quad (11)$$

Each coefficient of the equation indicates the degree of influence of the relevant factor on the score for a fixed position of other factors.

In order to identify the relative strength of the influence of individual factors and their reserves, it is advisable to calculate the partial elasticity coefficients and beta coefficients by the formulas:

$$\varepsilon_i = a_i\frac{\overline{X_i}}{\overline{Y}}; \beta_i = a_i\frac{\sigma_{X_i}}{\sigma_Y}, \quad (12)$$

where a_i – coefficients of regression at the i-th factor; $\overline{X}_i$ – the average value of the i-th factor; $\overline{Y}$ – the average value of the effective indicator; σ_{X_3} – the standard deviation of the i-th factor; σ_Y – the standard deviation of the result.

Partial coefficients of elasticity show how many percent the result on the average will change with 1 % change of each factor for a fixed position of other factors.

5. Analysis of the results of a computational experiment on the methods of realizing the comparative approach in real estate valuation

In order to valuate and compare various methods of calculating the value of real estate in the comparative approach, a number of test cases are examined, a fragment of one of which is given below.

Let's suppose that it is necessary to evaluate the property (living quarters), which is characterized by the indicators shown in **Table 2**. For comparison, 5 analogical objects are selected, the characteristics of which are also given in **Table 2**. Let's assess the value of the object for such pricing factors: technical condition, location, availability of improvement, the presence of a parking slot.

Table 2

Output data on the subject of valuation and analogical objects

No.	technical condition	Location	Accomplishment	Parking slot	The cost of 1 sq.m, UAH
Valuation object	good	Central	water supply lighting	yes	
Analogue 1	good	Central	all the benefits	yes	13500
Analogue 2	excellent	middle	all the benefits	yes	13500
Analogue 3	satisfactory	middle	water supply lighting	no	12900
Analogue 4	satisfactory	middle	lighting	yes	12850
Analogue 5	satisfactory	Central	without accomplishment	yes	12900

According to the expert method of calculating the cost of the valuated object, a standard step of 5 % was chosen. As a result of the calculations, the following results are obtained (**Table 3**).

Table 3

Result of calculation of cost of valuated object by a method of an expert estimation

No.	Corrective amendments, %			Amount of amendments, %	Adjusted cost of 1 sq. m, UAH
Analogue 1	0	–5	0	–5	12825
Analogue 2	5	–5	0	–5	12825
Analogue 3	5	0	5	15	14835
Analogue 4	5	5	0	15	14777,5
Analogue 5	0	10	0	15	14835
Object		average			14019,5
		median			14777,5

Further, the cost of the same property is calculated using the SLAU solution method. For this purpose, the initial data were digitized (**Table 4**).

As a result of the implementation of this method, a solution is obtained in this form (**Table 5**).

Element V_0 – this is the market value of 1 square. m (for the estimated property – 13362.5 UAH.).

Other elements of the obtained matrix V can be interpreted as follows:

ΔP_1 =187,5 UAH – correction to the cost of 1 square. m of the property while improving its technical condition by one point;

ΔP_2=187,5 UAH – correction to the cost of 1 square. m of the property with a hypothetical improvement in its location by one point;

ΔP_3=137.5 UAH – correction to the cost of 1 square. m of the property while improving the improvement;

ΔP_4=87.5 UAH – correction to the cost of 1 square. m of the property when there is a parking lot.

In order to reveal the dependence of the choice of the method of digitizing the initial data on the final cost of the valuation object, a computational experiment is carried out, a fragment of the results of which are given in **Table 6**. In the course of the experiment it turned out that the method of digitizing data in this method affects the final result of the cost. In this case, even corrections may occur with a negative sign, contrary to the physical meaning of the problem.

Table 4

Initial data for calculating the value of an object by the SLAU solution method

pricing factor	Technical condition (TC)	Location (L)	Accomplishment (A)	Park slot (PS)
		Ranking		
0				Yes
1	Satisfactory	outskirts	without accomplishment	No
2	Good	middle	lighting	
3	Excellent	Central	water supply lighting	
4			all the benefits	
		Output factors (pricing factors)		
Valuation object	2	3	2	1
Analogue 1	2	3	3	1
Analogue 2	3	2	3	1
Analogue 3	1	2	2	0
Analogue 4	1	2	2	1
Analogue 5	1	3	0	1

Table 5

The result of calculating the value of the property by the method of SLAU solution

State matrix					Inverse matrix					Vector of values, UAH
1	0	0	1	0	0,5	0,25	0	–0,25	0,5	13362,5
1	1	–1	1	0	–0,5	0,75	0	–0,75	0,5	187,5
1	–1	–1	0	–1	0,5	–0,25	0	–0,75	0,5	187,5
1	–1	–1	–1	0	0,5	–0,25	0	0,25	–0,5	137,5
1	–1	0	–2	0	0,5	–0,25	–1	1,25	–0,5	87,5

Further, the cost of this real estate object is calculated by determining the weight coefficients based on the normalized distances in the space of the pricing factors. For this purpose, data are digitized similar to the previous method and calculations are performed. The obtained results can be interpreted as the value of the object of valuation and the degree of remoteness of the object from the analogical objects (**Table 7**).

To determine the dependence of the choice of the method of digitizing data on the final cost of the valuation object, a computational experiment is conducted to study this method, a fragment of the results of which are given in **Table 8**. In the course of the experiment it turned out that the method of digitizing data in this method also affects the final result of the value of the valuation object (**Table 8**).

Table 6

Fragment of the results of the computational experiment on the investigation of the method of SLAU solution in valuation of the real estate object

Object	Output data: Pricing factors				Cost, UAH	Calculation result, UAH
	TC	L	A	PS		
Experiment 1						
Valuation object	2	3	2	1		
A1	2	3	3	1	13500	13362,5
A2	3	2	3	1	13500	187,5
A3	1	2	2	0	12900	187,5
A4	1	2	1	1	12850	137,5
A5	1	3	0	1	12900	87,5
Experiment 2						
Valuation object	3	3	2	1		
A1	3	3	3	1	13500	13268,8
A2	5	2	3	1	13500	93,75
A3	1	2	2	0	12900	187,5
A4	1	2	1	1	12850	137,5
A5	1	3	0	1	12900	87,5
Experiment 3						
Valuation object	2	5	3	1		
A1	2	5	5	1	13500	12900
A2	3	3	7	1	13500	–87,5
A3	1	3	3	0	12900	93,75
A4	1	3	1	1	12850	137,5
A5	1	5	0	1	12900	225

Table 7

Calculation of the value of the property by determining the weighting coefficients on the basis of the normalized distances in the space of the pricing factors

Object	$\sum_{j=1}^{4}\left(\Delta k_{ij}\right)^2,\ i=\overline{1,n}$	$l_i=\sqrt{\sum_{j=1}^{4}\left(\Delta k_{ij}\right)^2},\ i=\overline{1,n}$	$p_i=\frac{1}{l_i}$	$v_i=\frac{p_i}{\sum p_i}$	Cost, UAH
A1	1,14	1,07	0,94	0,15	2049,768
A2	1,41	1,19	0,84	0,14	1846,032
A3	0,36	0,60	1,68	0,27	3506,582
A4	0,50	0,71	1,42	0,23	2955,381
A5	0,60	0,77	1,29	0,21	2703,884
Sum			6,17	1,00	13061,65

Table 8

Fragment of the results of the computational experiment on the study of the method of determining the weight coefficients on the basis of the normalized distances in the space of the pricing factors

Object	Output data					Calculation	
	Pricing factors				Cost, UAH	Weight coefficients	Cost, UAH
	TC	L	A	PS			
Experiment 1							
O	3	3	3	1			
A1	3	3	4	1	13500	0,15	2049,768
A2	5	2	4	1	13500	0,14	1846,032
A3	1	2	3	0	12900	0,27	3506,582
A4	1	2	2	1	12850	0,23	2955,381
A5	1	3	1	1	12900	0,21	2703,884
Sum						1,00	13061,65
Experiment 2							
O	3	3	2	1			
A1	3	3	3	1	13500	0,16	2201,839
A2	5	2	3	1	13500	0,14	1954,778
A3	1	2	2	0	12900	0,33	4207,167
A4	1	2	1	1	12850	0,25	3170,576
A5	1	3	0	1	12900	0,21	2754,347
Sum							14288,71
Experiment 3							
O	2	4	2	1			
A1	2	4	3	1	13500	0,16	2100,039
A2	3	5	3	1	13500	0,13	1774,683
A3	1	3	2	0	12900	0,25	3251,81
A4	1	3	1	1	12850	0,21	2693,404
A5	1	3	0	1	12900	0,21	2754,347
Sum							12574,28

Next, the cost of the property is calculated using the correlation-regression method (**Table 9**).

Table 9

Calculation of the value of the real estate object by the correlation-regression method

Object	X_1	X_2	Y	YX_1	YX_2	X_1^2	X_2^2	Y^2	X_1X_2
A1	3	4	13500	40500	54000	9	16	182250000	12
A2	4	3	13500	54000	40500	16	9	182250000	12
A3	2	3	12900	25800	38700	4	9	166410000	6
A4	2	3	12850	25700	38550	4	9	165122500	6
A5	2	4	12900	25800	51600	4	16	166410000	8
Sum	13	17	65650	171800	223350	37	59	862442500	44
Average	2,6	3,4	13130	34360	44670	7,4	11,8	172488500	8,8

Determinant X				Determinant X1			Solution of the system		
5	13	17	65650	65650	13	17	a0	a1	a2
13	37	44	171800	171800	37	44	11600	357,9	176,3
17	44	59	223350	223350	44	59	Object cost, UAH		
19				220400			13378,95		

A computational experiment to investigate the correlation-regression method shows that the choice of the method of digitizing the initial data practically does not affect the final result of the cost, which is by far the most significant advantage of this method (**Table 10**).

Table 10

Fragment of the results of a computational experiment on the investigation of the correlation-regression method of property valuation

Experiment 1									
	X_1	X_2	Y	YX_1	YX_2	X_1^2	X_2^2	Y^2	X_1X_2
O	3	4							
A١	3	4	13500	40500	54000	9	16	1,82E+08	12
A٢	4	3	13500	54000	40500	16	9	1,82E+08	12
A٣	2	3	12900	25800	38700	4	9	1,66E+08	6
A٤	2	3	12850	25700	38550	4	9	1,65E+08	6
A٥	2	4	12900	25800	51600	4	16	1,66E+08	8
Sum	13	17	65650	171800	223350	37	59	8,62E+08	44
Average	2,6	3,4	13130	34360	44670	7,4	11,8	1,72E+08	8,8
Valuation object, UAH									
13378,95									
Experiment 2									
	X_1	X_2	Y	YX_1	YX_2	X_1^2	X_2^2	Y^2	X_1X_2
O	3	3							
A1	3	3	13500	40500	40500	9	9	1,82E+08	9
A2	5	2	13500	67500	27000	25	4	1,82E+08	10
A3	1	2	12900	12900	25800	1	4	1,66E+08	2
A4	1	2	12850	12850	25700	1	4	1,65E+08	2
A5	1	3	12900	12900	38700	1	9	1,66E+08	3
Sum	11	12	65650	146650	157700	37	30	8,62E+08	26
Average	2,2	2,4	13130	29330	31540	7,4	6	1,72E+08	5,2
Valuation object, UAH									
13378,95									
Experiment 3									
	X_1	X_2	Y	YX_1	YX_2	X_1^2	X_2^2	Y^2	X_1X_2
O	4	3							
A1	4	3	13500	54000	40500	16	9	1,82E+08	12
A2	5	2	13500	67500	27000	25	4	1,82E+08	10
A3	3	2	12900	38700	25800	9	4	1,66E+08	6
A4	3	2	12850	38550	25700	9	4	1,65E+08	6
A5	3	3	12900	38700	38700	9	9	1,66E+08	9
Sum	18	12	65650	237450	157700	68	30	8,62E+08	43
Average	3,6	2,4	13130	47490	31540	13,6	6	1,72E+08	8,6
Valuation object, UAH									
13378,95									

6. Discussion of the research results on methods for implementing a comparative approach in real estate valuation

To date, the main methods that implement a comparative approach in the valuation of property and real estate is the method of expert evaluation, the method of calculating corrective corrections based on the solution of a system of linear equations, the method of calculating corrective corrections based on the normalized distances in the space of pricing factors, and the correlation-regression method.

Comparison of the results of calculations of the value of the object valuation by various methods has shown that the expert method, as the most subjective, gives the most overestimated value of real estate objects; the method of SLAE solution and the method of determining the weight coefficients on the basis of the normalized distances in the space of the pricing factors show a somewhat understated valuation (**Fig. 1**).

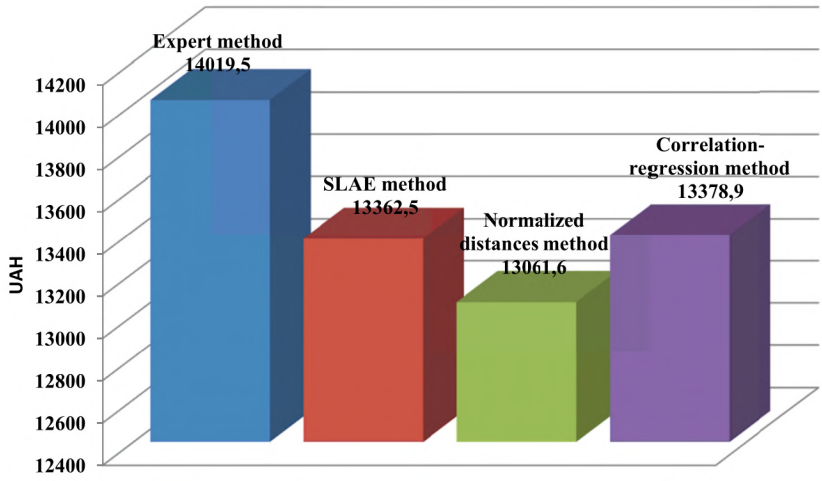

Fig. 1. The results of calculating the value of the property by different methods

In addition, the analysis of the results of a computational experiment on the influence of methods of digitizing the initial data on the final value of the real estate object when implementing various methods has shown that the method of calculating corrective corrections based on the solution of a system of linear equations and the method of calculating weight coefficients on the basis of the normalized distances in the space of pricing factors essentially depend on the method of digitizing the initial data, while the correlation-regression method does not exert addiction is without suspended its advantage.

7. Conclusions

Valuation of property and property rights is an important prerequisite for the functioning and development of civilized market relations. Therefore, the problems associated with the improvement of valuation and appraisal activity are always topical.

Modern practice of valuation of real estate has a significant methodological and calculating apparatus for making sound management decisions. However, the proposed economic and mathematical models in most are aimed at reflecting the general trends in the development of the real estate market, while the real estate market is characterized by variability and multifactoriness, which makes it necessary to take into account its stochastic nature in computational models.

On the basis of the research carried out in the work, it can be concluded that today the most expedient in valuation of real estate is the development and improvement of methods of correlation and regression analysis, it allows not only to determine the current market value of real estate objects, but also to establish investigative causality. Obligations between pricing factors , predicting qualitative and quantitative changes in the real estate market, is an integral part in making the most effective management solutions.

The methods and results of scientific research presented in this work are used in the evaluation of real residential and non-residential real estate LLC “Tasador” (Kyiv, Ukraine).

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DE BRUIJN STRUCTURED ILLUMINATION STUDYING WITHIN THE TASK OF RESTORING HANDS RELIEF

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Abstract

In the course of studies on the problem of restoring hands relief, using the de Bruijn structured illumination, methods of solving this problem are proposed. This is a method of simple quantitative detection of Hough segments on the skin of the hand, a method of qualitative visual evaluation of the effectiveness of the color palette using the dominant color, and a method of the weight coefficients of the components of the color palette.

The proposed methods make it possible to quantitatively determine the optimal choice of the color scheme for generating the de Bruijn bands when illumination of the hand, to restore its relief.

The work describes the stages of this study, led from visual observation to a full quantitative calculation of the quality of calibration illuminations, with the possibility of their optimal choice.

In the course of experiments and observations, the requirements for the technical support of research were developed to achieve the best quality of the images of the hands. Also, the paper presents a high-speed de Bruijn sequence generating algorithm using Lyndon's words, which excludes the search for Euler chains or Hamiltonian cycles, for various kinds of de Bruijn graphs. With its help, the generation of structured light patterns with various color schemes was carried out, with the purpose of further analysis of their use in 3D reconstruction systems of hands.

Keywords: 3D scanner, image convolution, color scheme, Hough transformations, de Bruijn sequence, Lyndon words, ROI (Region of Interest).

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1. Introduction

To date, in the problems of scanning volumetric surfaces, many different variants of patterns of structured illumination have been developed. Most often, in practice, a series of changing pictures (pictures with time multiplexing) and unchanging pictures are used, using various color-coding options.

In the present study, to detect the relief of the hand, colors with color coding based on M-sequences or de Bruijn sequences are used.

De Bruijn sequence of order m in the alphabet of n symbols is a circular sequence of length n^m that contains any substring of length m only once. This sequence is used, in particular, in systems for recording 3D objects in real time (3D scanners) using structured illumination.

The aim of research is studying the behavior of the de Bruijn bands on the hand, with the possibility of choosing the optimum color palette for structured illumination using the weighting method. This will allow the most qualitative restoration of the three-dimensional relief of the hand for further use in 3D scanning systems, in particular, in systems for recognizing gestures. Since, as a result of correctly selected color sets in the illumination patterns, minimal mutual influence of the components of the entire color scheme is provided and overall recognition accuracy is increased.

The main task of the image processing algorithm is determination of the correspondences between points on the registered image, and points on the illumination pattern. The result of the work of algorithms is a cloud of points in three-dimensional space, on which a three-dimensional

visualization of the surface of an object is constructed. The structure of the processing algorithm is determined by the type of used template [1, 2].

The implementation of the illumination used in the work is carried out using the Lyndon words, since there is a direct link between the de Bruijn sequences and the Lyndon words. The software implementation uses recursive and iterative algorithms to generate such words (roughly the same performance). The result of the work is the generation of a pattern of structured illumination for the tested color schemes [3, 4].

In many image processing systems, it is necessary to solve the problems of searching or identifying objects of a given form: straight lines, circles, ellipses, etc., in real time [5, 6]. The relief of a given surface in real time can be obtained only using pictures of structured illumination with spatial or color coding, which can't be achieved with the use of pictures with time multiplexing.

In the course of the study, color coding was chosen. So, as a criterion of optimality of the color scheme of illumination, the number of detectable objects (color segments) on the hand, obtained with the help of Hough transforms (HoughLinesP function from the OpenCV library) was chosen. Obviously, such criterion is not optimal, since the effectiveness of using the selected illumination is determined visually - these are segments of a certain color unfilled by Hough segments. Therefore, it was used as an auxiliary, when choosing the initial color schemes, for further quantitative analysis [6, 7].

Thus, a method was developed for calculating the weight coefficients of colors and their percentage losses, described in detail in the study. The application for the study is implemented in the C# programming language in the Microsoft Visual Studio 2015 environment, using the Emgu-CV library (OpenCV for .NET).

At the moment, working with the OpenCV library is well documented, there are many examples and practical advice [7, 8].

The practical value of this research consists in the possibility of choosing the optimal color scheme of structured illumination, for the most effective investigation and restoration of the relief of the hand.

2. Review of the problem state

Detection and analysis of bands of structured illumination by color is an accurate and simple way of obtaining image depth (surface relief) [9–13].

There are many color patterns developed for the rapid identification of the relief of the object under study, achievable in one video frame.

Structured illumination methods used in modern 3D scanners and suitable for real-time operation use finite color sequence templates. To increase the resolution of the resulting point cloud (the quality of the result), an increase in the number of unique subpatterns in a single projection pattern is required [14, 15].

Fig. 1 shows the de Bruijn sequence pattern based on the RGBCMY color alphabet, with a length of a non-repeating subsequence of 3.

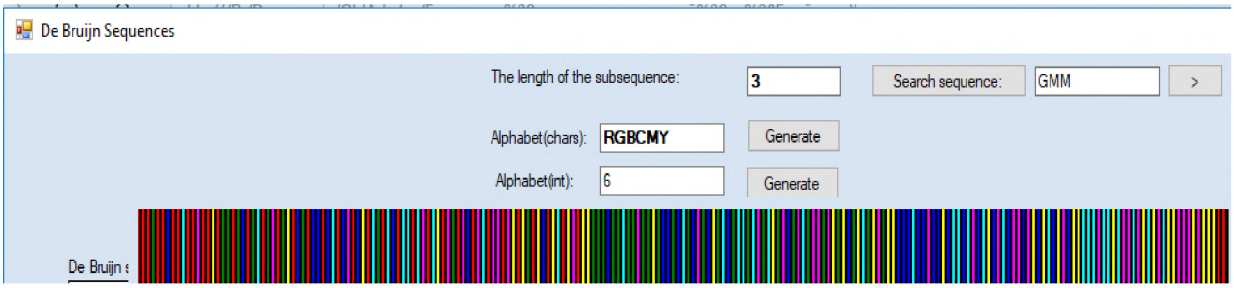

Fig. 1. De Bruijn sequence of 216 characters in length (color bands)

Methods for generating de Bruijn sequences, using various algorithms, are widely represented in many sources [16–18].

Color coding uses only one picture. The position of each pixel, uniquely, is encoded by the color value of the given pixel and several of its "neighbors". When creating a color-coded picture, it is tend to get the minimum size of the neighborhood (the number of "neighbors") of the pixel required to uniquely restore, and the minimum number of different colors (to increase the reliability of determining each color). It is precisely these properties that the M-sequences or de Bruijn sequences have realized in the study using Lyndon words [19].

3. Materials and methods

In accordance with the logic of scientific research, the research methodology is developed. It is a complex of theoretical and empirical methods, the combination of which makes it possible to study, with the greatest certainty, the object of behavior of the de Bruijn bands of structured illumination on the hand (the specific structure and color of the skin) in order to select the optimal color scheme for restoring its relief.

In the course of solving the problem, studying the behavior of the de Bruijn bands on the hand, a number of methods have been applied that made it possible to comprehensively study the investigated problem, all its aspects and parameters. Among them let's select methods of theoretical research (abstraction, analysis and synthesis) and empirical research.

The empirical study consisted in observing the investigated object, without being influenced by the observer, under various conditions of illumination and background. In the end, this led to the conclusion that it was necessary to use an absolutely black color for it, which made it possible to improve the contrast as much as possible.

In the course of the experiments, a 3D scanning machine was used. The choice was made in favor of a mini projector Samsung H03 (South Korea) and web cameras Logitech HD Pro 920 (China). The use of devices provides both the most acceptable illumination of the investigated object, and the excessive resolution of the resulting video frame in the process of video capture.

Experiments with the resulting set of images, OpenCV tools, allowed to choose the optimal parameters and threshold values for maximally complete and high-quality processing. Below are the values of such parameters. Accordingly, the modeling method was used to create and study a copy (model) of the object that imitates the original. A comparison method was also used, which, at this stage, allowed to abandon the use of some color schemes.

4. Experiments

The developed Windows application allows to load images of a hand made in approximately the same conditions (the known corners of the projector-camera system, the distances between them) with different illumination (color scheme).

To obtain the maximum number of Hough sections, empirical studies were conducted, during which the optimal set of tools that exist in the OpenCV library was determined. For Hough transformations, threshold values were used, specially selected for the existing set of images.

Initially, the image is smoothed (or blurred) using the GaussianBlur function, which blurs by calculating a convolution of an image with a discrete Gauss core with standard deviations equal to sigmaX and sigmaY along the Ox and Oy axes respectively (the deviations are 2).

It should be noted, without going into details and terms, that when calling this function, a restriction on the parameter kSize is imposed (empirically selected value = 3). The width and height of the core must be positive and odd, or zero if the core size is determined from standard deviations. Also, a median filter with a core size of kSize=7 is used.

The threshold values for the Kenny boundary detector are empirically chosen. The discrete Sobel differential operator, which calculates approximate values of derivatives of different orders for the brightness function of pixels, uses a second-order derivative of X (in Y, there is no need to differentiate, since vertical and close segments are detected).

Detection of segments is performed using the application's public LineSegment2D GetVerticalLines (Bitmap bmp) method, which calls the library function CvInvoke.HoughLinesP. Basic operations of working with images are described in many sources, and do not require additional explanations [20].

Thus, the algorithm for processing the original image can be represented by the block diagram fragment in **Fig. 2**.

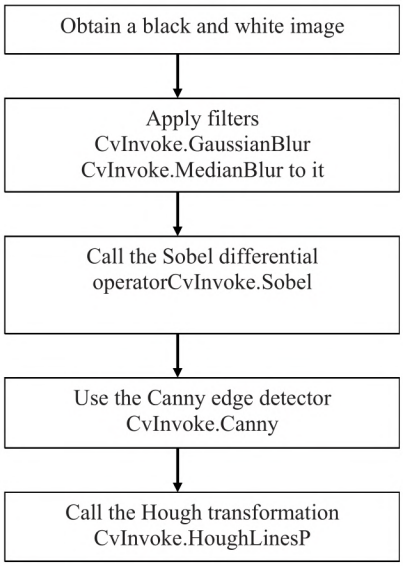

Fig. 2. Algorithm for processing the original image

The GetVerticalLines method defines a set of vertical lines in the image, using the optimal empirical parameters transferred to the designer, for filters and boundary detectors.

Some fragments of the text application are shown in **Fig. 3**.

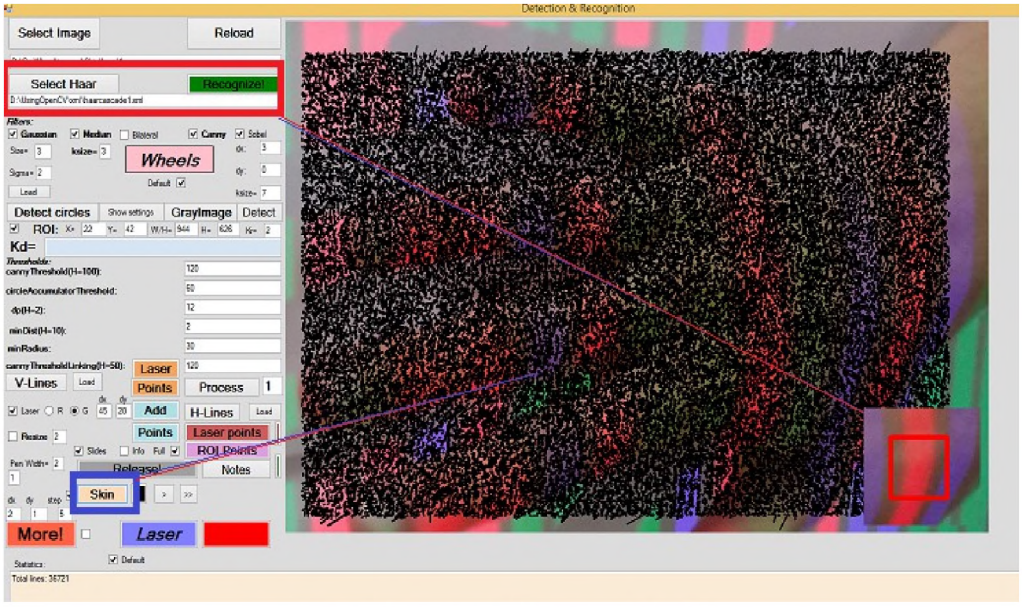

Fig. 3. Fragment of the test application

It should be noted that the developed application is able to detect hand with the help of existing trained Haar cascades used in pattern recognition. For more accurate localization of the hand, it is possible to select ROI (the area of interest) with the help of mouse.

5. Results

The results of detecting segments on the hand, using the Hough transforms for various de Bruijn illumination (black segments), are shown in **Fig. 4, 5**.

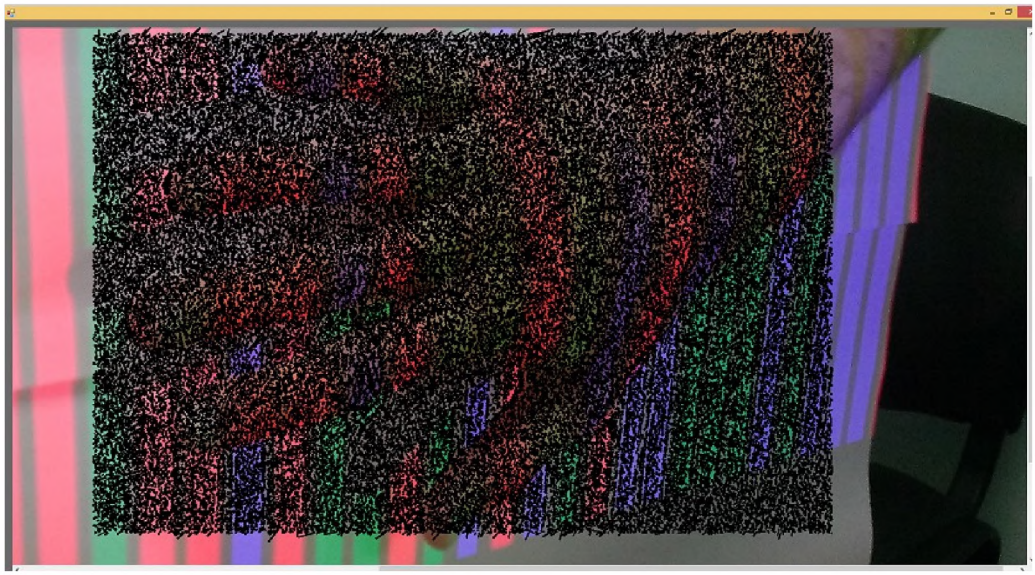

Fig. 4. De Bruijn RGB illumination

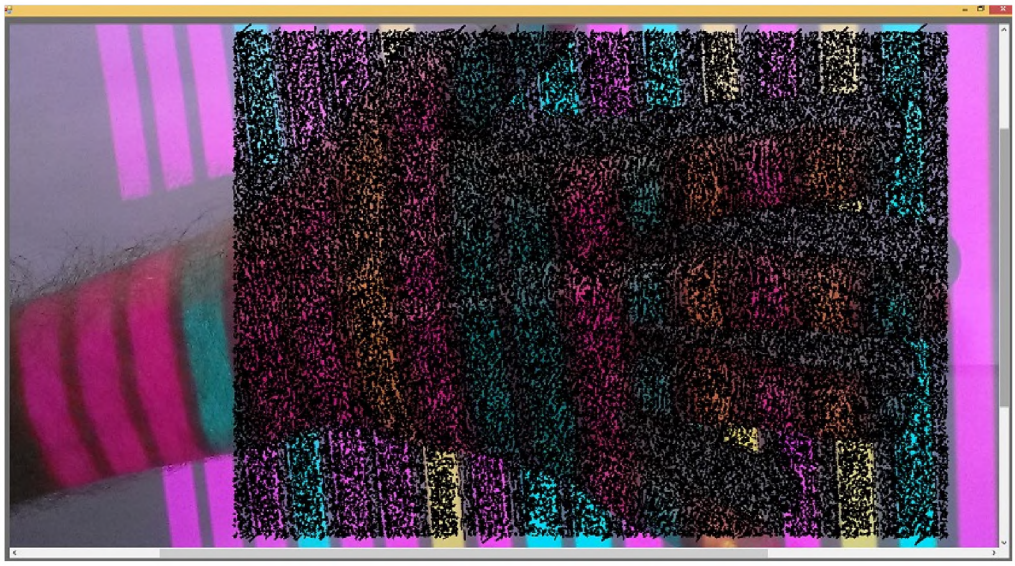

Fig. 5. De Bruijn CMY illumination (Cyan-Magenta-Yellow)

The visual analysis allows to leave just these palettes for further research.

6. Discussion of research results

The essence of the approach is the determination of the dominant color from the illumination palette on the skin of the hand.

The illumination palette on the skin of the hand is shown in **Fig. 6**.

By ROI scanning (in this case, the area of the hand), let's analyze the color composition of each pixel and determine the dominant color, for example, for red color. The algorithm for the ROI scanning of the hand region is shown in **Fig. 7**.

Also, with the formation of lists of pixels for each color from the illumination panel, let's determine their number to calculate the specific weighting coefficients.

For visual control, the dominant color is displayed in "clean" color. The definition of the dominant color of the RGB illumination in quantitative terms is shown in **Fig. 8**.

Fig. 6. RGB palette of the de Bruijn sequence

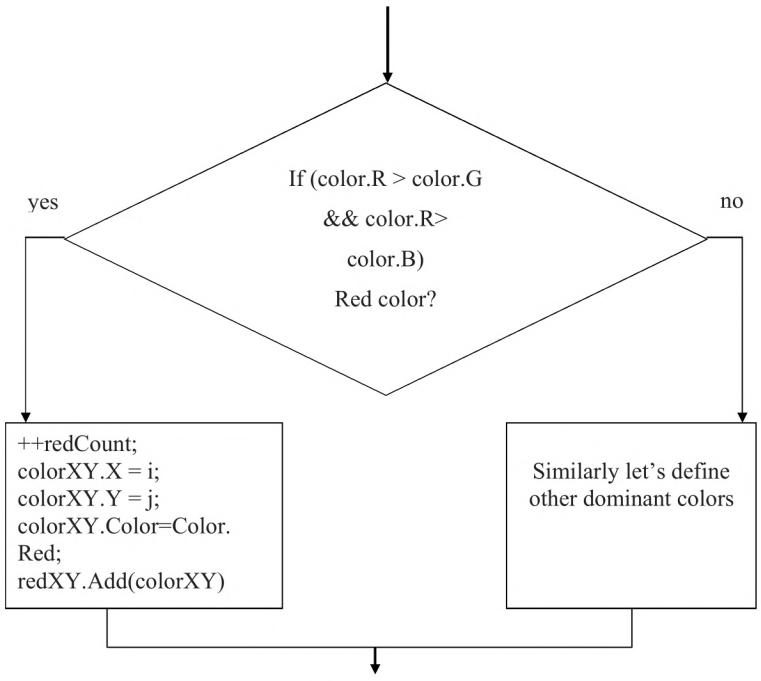

Fig. 7. Algorithm for ROI scanning of the hand area

Weighting factors for RGB illumination are presented in **Table 1**.

Table 1
Weighting factors for RGB illumination of the hand

Color shade	Coefficient
Red (Kr)	0,64
Green (Kg)	0,09
Blue (Kb)	0,27

Fig. 8. Determination of the dominant color of RGB illumination in quantitative expression

Weighting coefficients are displayed in the Statistics field of the application. This approach does not require the use of the OpenCV library. The illumination of the de Bruijn sequence, based on the CMY color alphabet (cyanmagenta-yellow) is characterized by the fact that this set of colors is completely filled with 2 bytes and one zero, respectively, the determination of the color dominant, for example, for yellow:

if (color.R > color.B && color.G > color.B)

The result of determining the color dominant (magenta) and the weighting coefficients for this palette are shown in **Fig. 9**.

Fig. 9. Determination of the dominant color of the CMY illumination

Table 2 shows the weighting coefficients for CMY illumination.

Table 2
Weighing factors for CMY illumination of the hand

Color shade	Coefficient
Cyan (Kc)	0,22
Magenta (Km)	0,65
Yellow (Ky)	0,13

The mutual influence of colors entering the palette can be investigated by choosing the appropriate ROI (in the limit of a single color band). **Fig. 10** shows that the color shade of magenta, in practice, is not subject to such influence.

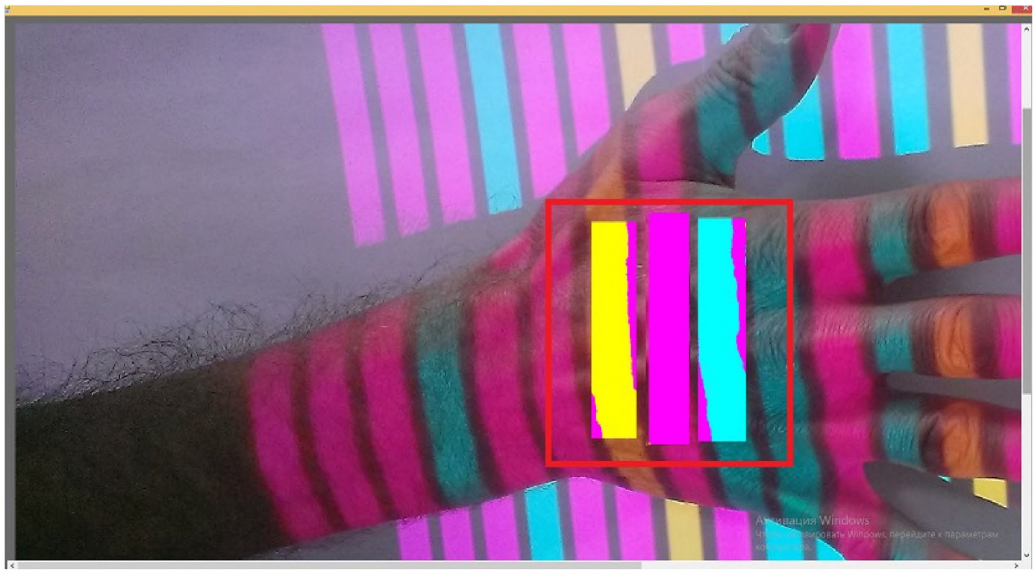

Fig. 10. The mutual influence of CMY illumination colors

In the RGB palette, let's observe the largest loss in color – green in the neighborhood with the red. The study of color loss using ROI selection is shown in **Fig. 11**.

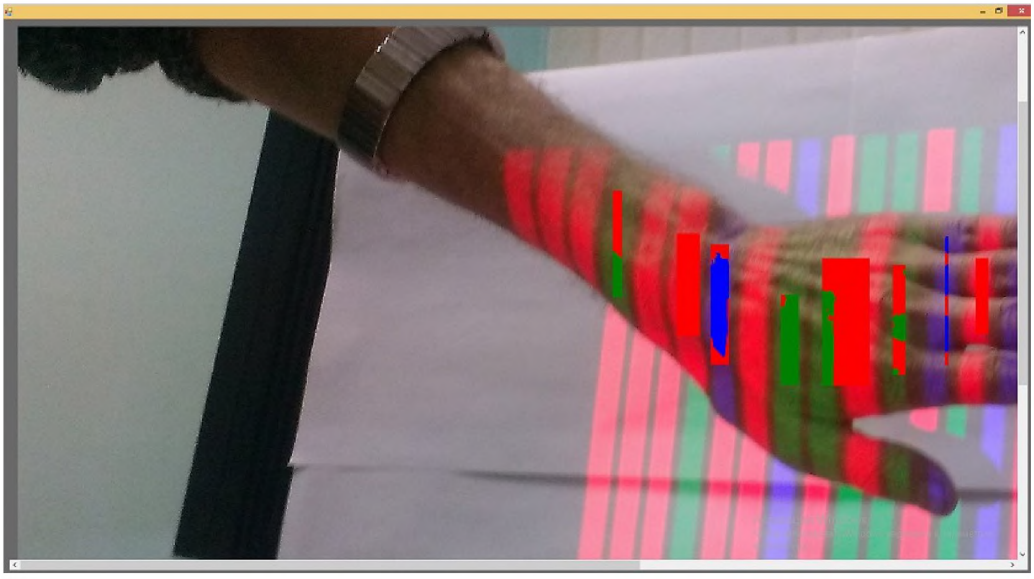

Fig. 11. Investigation of color loss by choosing ROI

In the course of further research, in order to obtain accurate quantitative indicators of the behavior of different colors of a certain pattern on the skin of the hand, it is suggested to perform its pictures on a black background – to accurately detect the hand, by clipping the background pixels.

Calculation of quantitative indicators of losses and color acquisitions that make up the palette is based on the idea of filling with pure colors. Applied palette with a given ROI (black background) allows to use the threshold value to cut it.

These indicators are implemented by the method private bool IsHandColor (Color color, int threshold)

```
{
return !(color.R < threshold  && color.B < threshold && color.G < threshold);
},
```

with the possibility of setting threshold (the threshold value for the component colors of the palette) parameters in the application, as shown in **Fig. 12**.

Fig. 12. Filling of the hand with the dominant colors of the palette (CMY)

The whole process and the general view of the used application is shown in **Fig. 13**.
In this case, the calculation of the necessary parameters looks like this:
Weighting coefficients:
Kc = 0,5880984
Km = 0,2836871
Ky = 0,1282145
Weighting coefficients:
Kc = 0,4807465
Km = 0,3814434
Ky = 0,1378101 Colors(+/-)
Cyan: – 18,25408%
Magenta: + 34,4592%
Yellow: + 7,484046%

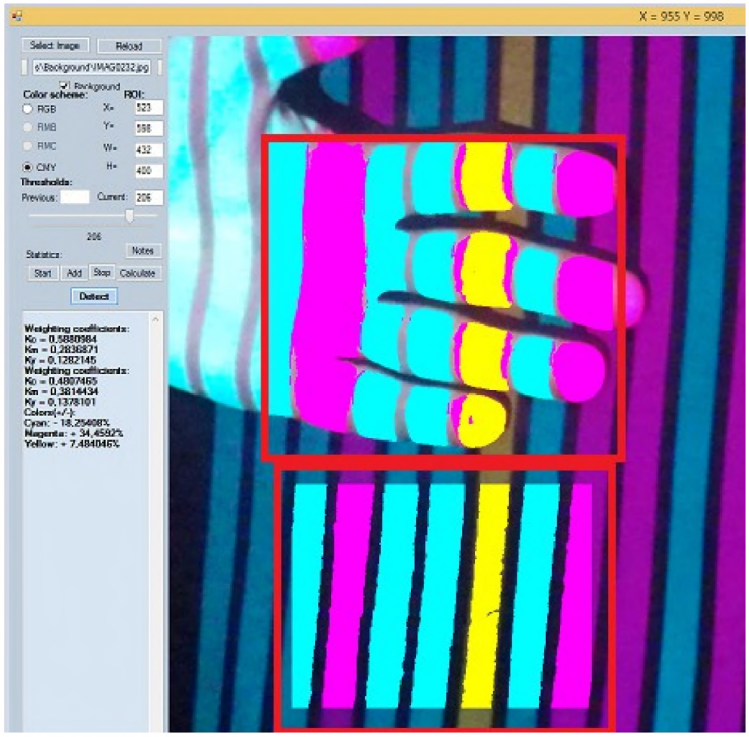

Fig. 13. Change of the palette colors on the skin of the hand (CMY)

The results of changing the palette color on the skin of the hand for the color RGB scheme are shown in **Fig. 14**.

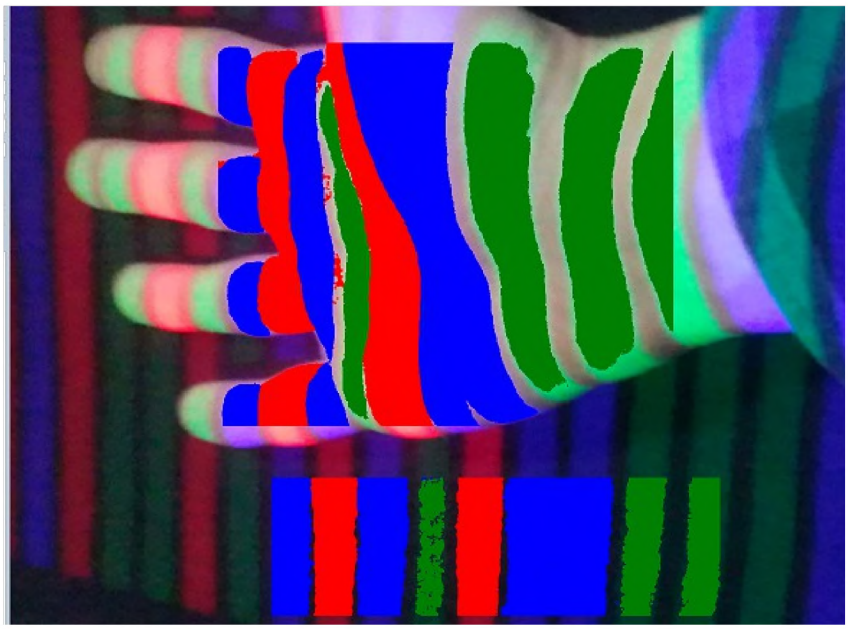

Fig. 14. Change of the palette color on the skin of the hand (RGB)

Analysis of calculated coefficients and percentage values demonstrates their greater dispersion for this scheme, in comparison with CMY illumination.

In **Fig. 13, 14** it is possible to see the absorption of green and blue colors in red in RGB illumination, as well as yellow and cyanic magenta (CMY).

The processing of the file statistics for each palette gives the results shown in **Table 3, 4**.

Table 3

Change of CMY illumination color on the hand

Color shade	Value, %
Cyan	–10,84
Magenta	18,77
Yellow	–13,88472

Table 4

Change of RGB illumination color on the hand

Color shade	Value, %
Red	58,90
Green	–25,79
Blue	–23,89

Thus, changes in the color of the illumination on the hand indicate that the color loss in the CMY illumination is less (do not exceed 15 %), for RGB illumination they are more than 25 %.

7. Conclusions

1. A review of the existing complexes of theoretical and empirical methods is performed, the combination of which makes it possible to study the object under study with the greatest certainty by analyzing the behavior of the de Bruijn bands of structured illumination on the hand, in order to select the optimal color scheme for restoring its relief.

2. To obtain the maximum number of detectable Hough segments, empirical studies using a 3D scanner are carried out, during which the optimal set of tools that existed in the OpenCV library is determined. For proper Hough transforms, empirically selected threshold values are used.

3. As the statistics on color loss gradually accumulated, and the results were fixed, we can make an unambiguous conclusion in favor of using CMY illumination for the hand, which is optimally suitable for these purposes.

The obtained results help to choose the optimal color scheme of the structured illumination, in order to most effectively illuminate the hand to restore its relief. There is also a wide opportunity for experimenting with all sorts of other color schemes for such illumination. It should be noted that in many cases the advantages of such scheme can be assessed by visual analysis.

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DEVELOPMENT OF A MULTI-AGENT COLLISION RESOLUTION SYSTEM AT THE SUPPLY OF SPARE PARTS AND COMPONENTS TO THE PRODUCTION EQUIPMENT OF INDUSTRIAL ENTERPRISES

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Abstract

The approach to the creation of computer facilities for the automation of the technical maintenance of production equipment (TMPE) at industrial enterprises (IE) is outlined. Meaningful and formal statement of the problem of forming solutions for identifying and eliminating collisions that arise when delivering spare parts and components for TMPE are presented. The method of formation of coordinating decisions on maintenance with spare parts and accessories for carrying out TMPE at IE is described. The organization of intellectual support of formation of coordinating decisions by recognition of potential collision in the TMPE process is offered. This procedure involves checking the real existence of the collision and issuing a coordinating decision. In this case, the decision is formed in the event of a disagreement between the need for spare parts and components for the TMPE maintenance, with their availability in the PP warehouse. The ways of software implementation of this method in the environment of multi-agent system are considered. In particular, the description of the multi-agent system developed during the prototype research is given. The prototype is implemented using CORBA technology, in accordance with DSTU ISO/ EC 2382-15:2005. The calculation of the efficiency of the application of the developed computer tools in production is shown. To assess the quality of the system, a sliding control method based on leave-on-out cross-validation (LOOCV) is applied.

Keywords: maintenance, production equipment, industrial enterprise, spare parts and components, collisions; intelligent agents.

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1. Introduction

Currently, the effectiveness of business processes in various areas of material production is largely determined by the failure-free operation of production equipment. This fact determines the relevance of tasks related to computer support for the supply of industrial enterprises (IE) spare parts and components for technical maintenance of production equipment (TMPE). Issues related to the use of information technologies and systems for IE automated management are devoted to a significant number of publications, for example [1–7]. The activity of modern IE takes place under very dynamic conditions, therefore, the efficiency of their operation largely depends on the overall technical state of the production equipment, minimization of failures, and also the efficiency of the processes of restoring the working condition of machines and mechanisms. The abovementioned necessitates the timely ordering of spare parts for the timely TMPE. Significant achievements in this direction have been achieved by research centers of such developers as Dassault

Systemes (France), Siemens PLM Software (Germany), Unigraphics (USA), etc. Along with this, the specificity of IE functioning does not allow directly using the corresponding standard means of automation of TMPE processes. Therefore, there is a need for further research on methods and tools for informational support of IE management processes, in terms of ensuring the proper technical condition of production equipment, with a view to developing special applied information technology. Thus, at the present time there is a scientific and applied problem, the essence of which is increasing the efficiency of IE production by ensuring the reliability of production equipment by developing and implementing information support technology for providing spare parts and components for TMPE.

The aim of research is development of an approach to improving the efficiency of IE functioning by creating a technology for informational support of TMPE processes based on special data processing and knowledge tools. The application of this approach in the process of computerization of logistics processes will make it possible to reduce the risks of failures and downtime of production equipment.

2. Materials and Methods

Let's imagine formally the process of providing spare parts and components G of a certain piece of industrial equipment S to the IE with a set of objects:

$$G_S = \left\langle A_S, D_S, C_D, I_A, A^D, C^D, A^I \right\rangle, \quad (1)$$

where $A_S = \{a_r\}, r \in \Omega_S$ – set of all routine maintenance operations for a piece of equipment S;

$A_S \subset A, A = \{a_1, a_2, ..., a_n\}, n = \overline{1, N}$ – set of all operations for the TMCE in the IE;

Ω_S – set of maintenance operations indices for a piece of equipment S;

$D_S = \{d_t\}, t \in \sigma_S$ – set of parts and accessories for a piece of equipment S, $D_S \subset D$;

$D = \{d_1, d_2, ..., d_m\}, m = \overline{1, N_D}$ – the nomenclature of all parts for the maintenance of production equipment in an industrial enterprise;

σ_S – set of parts indices in a piece of equipment S;

I_A – set of components for maintenance of a piece of equipment S;

$C_S = \{c_{x_C}\}, X_C \in C_E$ – component suppliers from the set D_S, $C_S \subset C$;

$C = \{c_1, c_2, ..., c_r\}, r = \overline{1, N_C}$ – set of all suppliers of spare parts and components for production equipment at IE;

A^D, C^D, A^I – corresponding relations on sets D_S, A_S, C_D, I_A.

Statement 1. For any technological operation $a_i \in A_S, i \in \Omega_S$ of the maintenance process of a piece of equipment S, there are mappings $A^D : D_S \to A_S$, $C^D : D_S \to C_S$, and these mappings are surjective (for example, for each element of the set A_S there exists an element of the set D_S or $f^{-1}(A_S) \neq \varnothing$).

Statement 2. The mapping $A^I : I_A \to A_S$, by virtue of the specifics of the maintenance processes of the production equipment, is bijective.

The proofs of statements 1 and 2 follow directly from the existing principles of the organization of TMPE at IE.

The above formal description of the TMPE process is idealized, since in real production conditions there are often factors that impede the fulfillment of all the requirements of the technological regulations.

As a result of the study, the most common collisions in the implementation of the TMPE are identified, from which a representative set was formed, covering practically all possible mismatches. In this case, all collisions (and their characteristic features) arising in the process of maintenance are proposed to be divided into two groups:

1) determined and resolvable in the automatic mode;

2) insoluble in automatic mode.

The resolution of situations classified as insoluble in the automatic mode, in each individual case, is separated (and according to the individual scenario), also significantly depends on the situation itself, and requires direct decision-making by production managers of different levels.

Production situations, which can be attributed to the first group, can be resolved automatically, using the technology of intelligent agents. To develop the nomenclature of agents, it is necessary to acquire knowledge about the subject area "Material and technical support of the technical maintenance of production equipment", the presentation of this knowledge in the form of sets of characteristics, as well as types of coordinating decisions. Knowledge of the formation of these sets can be obtained both by analyzing existing precedents, and by acquiring the knowledge of experts. Consequently, the work of the coordinator is reduced to the selection of the required version of the coordinating decision, provided that the requirements imposed by the maintenance regulations for spare parts and components for each particular unit of production equipment are met. Based on the above considerations, it is advisable to limit the nomenclature of intelligent agents for automatic identification and resolution of collisions in the TMPE process, limited to two types – agent-recognizers and coordinating agents. The structure and functions of both types of agents are similar, only the filling of their knowledge bases is different, therefore, it becomes possible in future, with algorithmic and software implementation, to unify these decision blocks and the whole system as a collection of typical fragments that differ only in the filling of knowledge bases.

For the formation of a knowledge base, standard methods for acquiring knowledge can be used, both in existing solutions (O_T), using them as a training sample, or using methods of extracting expert knowledge.

Intellectual support for the formation of coordinating solutions is in recognition of potential conflicts, verification of the real existence of a collision and issue a coordinating decision in the event of a non-coordination of the need for spare parts and components for the TMPE and their availability in the warehouse of the enterprise.

Let's denote by $Y = \{y_1, y_2, ..., y_{11}\}$ the set of all possible collisions in the TMPE process. Since in the automatic mode only a part of the collisions can be eliminated, the set Y is divided into two subsets, $\widehat{Y}$ solvable and $\widetilde{Y}$ – insoluble collisions. In this way $Y = \widehat{Y} \cup \widetilde{Y}, \widehat{Y} \cap \widetilde{Y} = \varnothing$.

The method of forming coordinating solutions for the provision of spare parts and components for TMPE processes is the following orderly set of procedures:

a) For each of the maintenance operations G_S of a piece of equipment S, highlight (using a mapping K_H) the signs of potential collisions $H^K : K_H \subseteq H_D$ and form a conflictable set of operations from the elements of the set A_S;

b) Determine the type of each potential collision. Form two subsets – signs of solvable K_H^* and insoluble K_H^- collisions in an automatic mode. For unsolvable collisions, execute a request to the user to form possible coordinating decisions;

c) For each soluble collision from K_H^*, determine the spare parts and components required for the TM (the subset $D_S = f^{-1}(K_H^*)$ as the complete prototype of the signs of solvable collisions);

d) By analyzing the appropriate link in the logistics supply chain C^D, identify the supplier C_D of each spare part (or component) involved in the collision and the corresponding resolver;

e) Establish the necessary restrictions O_T for the requirements of the TM operation from the set A_S;

f) verify the real existence of a collision by executing a query to the appropriate resolver (determine the truth $P^O(O_i) = P_j$);

g) In the case of a conflict (if $P^O(O_i) \neq P_j$), determine the method of its resolution on the existing a priori created knowledge base for the resolution of typical collisions;

h) Form a coordinating solution (from the elements of the set O_T) for each identified conflict and record this decision in the repository of use cases.

This method will allow to identify potential conflicts on the basis of components included in the assembly and the requirements of the regulations, and in the event of such collisions, to form coordinating decisions that will eliminate the probable future mismatch and ensure the TMPE in accordance with the technological regulations.

For the software implementation of the multi-agent system, in the course of research, a protocol was developed for the interaction of agents. Based on the method described above, an automaton model of a typical fragment of the multi-agent system for making coordinating

decisions is constructed in the implementation of the TMPE in notation of hybrid models [7] (**Fig. 1**).

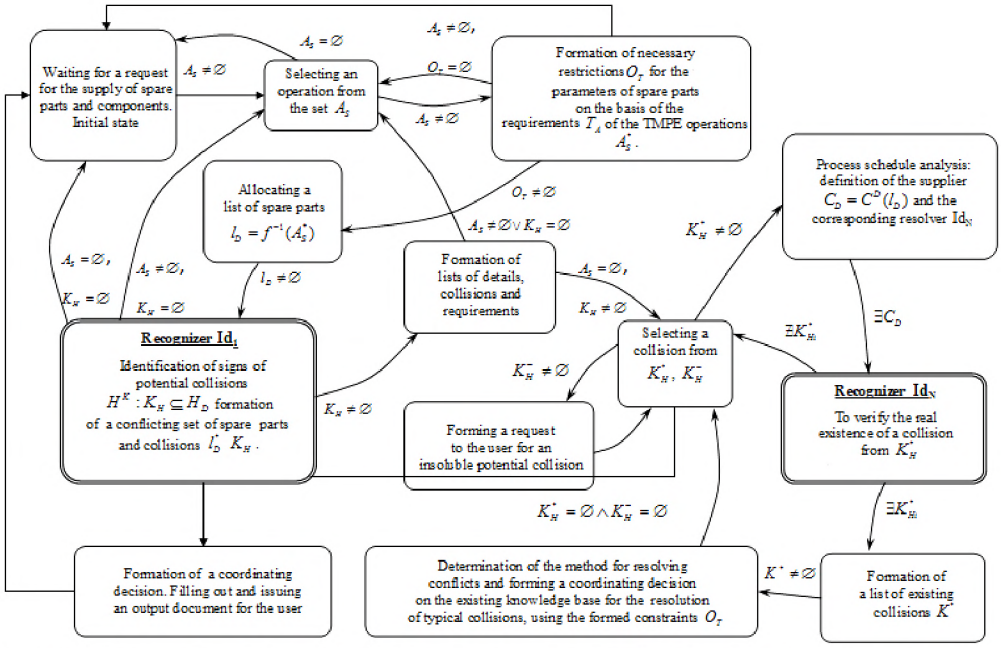

Fig. 1. Implementation of the method of forming coordinating decisions based on a hybrid approach

3. Experimental procedures

To illustrate the hybrid automaton approach to the synthesis of intelligent agents for the automatic formation of coordinating solutions for TMPE, a research prototype of the multi-agent system (MAS) based on the FIPA platform was developed.

Input data: current (actual at a certain point in time) values of variables defined for the domain in the form of a data exchange file; rule of reflection of variables in the form of rules (entered in the database of the rules of the agent).

Results of the agent's work: any changes in the current state of the object, obtained from the monitoring system or from other sources in the form of a change in the current values of the variables, are directly reflected in those functional elements of the MAS that are able to constantly operate with current data.

Agent operating modes:

1. Filling in the rules base and setting up the work parameters (including the connection of specific subsystems) – **Fig. 2**.

2. Autonomous operation in the selected mode (continuously or on request).

Fig. 2 shows the screen form of the interface part of the MAC, where:

– db_equipment.mdb, dmetal.mdb, DB.mdb – databases containing predicates of knowledge bases of the corresponding decision support subsystems (maintenance of equipment for sheet and bulk stamping and surfacing);

– change.csv – file with the current values of the object variables (obtained from the monitoring system);

– rules.mdb – knowledge base in the form of rules, which is used to update the current state of the monitoring object in the knowledge bases of the MAS subsystems.

The operation of the system is reduced to the following:

1. Reading the file with the current data from the exchange directory (having determined the presence of this file beforehand).

2. Syntactic analysis of the read file, deleting comments, possible errors, reading commands (while still under development), obtaining data about the current state (the format is coordinated with the monitoring system), recording them in the internal format of the agent.

3. Processing of each data record of the current state consists in changing predicates of the knowledge bases of the corresponding subsystems and is performed on the basis of the rules that fill the agent's database (thus, the data is completely independent of the code and the flexibility of configuring the agent for a specific knowledge base). During the output, it is possible to reflect the change of one parameter in several knowledge bases, and also reflect changes in several parameters in one database at once. Procedure of the agent in this step:

– definition of the subsystem in which the current state is updated;

– search for the necessary database (as a structural component of the knowledge base of the corresponding subsystem);

– identification of a variable object in the database;

– performing the necessary actions on the object (update, add, delete);

– recording of each update in the general database of the current state, indicating the date and time of data receipt (forming a database of the current state with the history of changes);

– recording the results of actions in the report file (**Fig. 3**);

– in case of a call on the request of the program that performs monitoring, send this message to the program about the results of processing the received data.

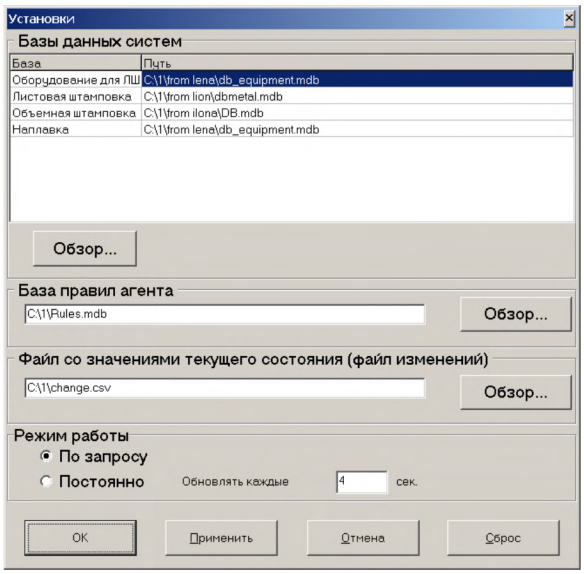

Fig. 2. Monitoring agent configuration interface – the mode of connection selection with update databases and selection of rule bases and change file

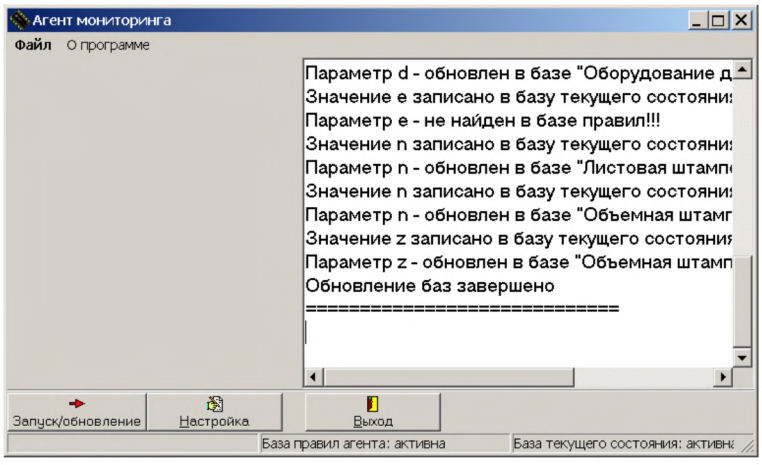

Fig. 3. Maintaining the report of the monitoring agent

Logically, the system of reflecting the current state is a community of agents, each of which serves a certain decision-making subsystem.

For the sake of ease of administration in the prototype of the system, all agents are structured in the form of threads of one application that performs all of the above actions. There is a possibility to start simultaneously several processes that process data (with increased load per module), as well as separate the agent into several modules, to ensure the functioning of subsystems on physically different platforms.

When developing the system, a prototype was also implemented based on the CORBA technology, which is prescribed by DSTU ISO/IEC 2382-15:2005 for the construction of distributed systems.

The quality of the coordinating decisions generated by the MAS prototype was evaluated on scenario examples for training and testing the system (rules for the training and predicates for the control sample), and a comparison was made with the results of solving these situations by several experts.

Quality was determined by the general error of making the wrong decision, obtained by weighted averaging of the errors of the first kind (unrecognized situations) and the second kind (situations classified as collisions, but not so).

To assess the quality of the system, the sliding control method [8] was applied, namely, a leave-on-out cross-validation (LOOCV).

Analysis of the cost statistics for the occurrence of errors of the first and second kind (according to the training sample) shows that the costs of correcting the wrong solution for the errors of the first and second kind are $P(y = +1) = 73\ \%$ and $P(y = -1) = 27\ \%$, respectively (if we take the sum of these costs for 100 % for the same situation), so losses from an unrecognized collision are much greater than losses from a "false" collision (provided that the decision to eliminate it is taken, that is, the process of TMPE will be changed in some way).

Since the errors are not equal, to estimate the total error of the system it is necessary to take the weighted values of errors of the first and second kind with weights 0.73 and 0.27 respectively.

For testing, a sample was made of 30 typical precedents that occurred in the statistics of failures of production equipment at a typical printing enterprise for 2015 [9–12]. With the involvement of experts for each case, the training rules that were used for modeling were identified, as well as the predicates that were used as the initial ones for testing at each step of the partition.

To compare the simulation results, these situations were proposed to two experts (IE technologists with at least 10 years of experience). Summary results are presented in **Table 1**. (the weighted error was calculated using the previously mentioned error weights of the I and II kind).

It can be seen that the rules existing in the prototype of the MAS allow to form solutions, the probability of error in which is at the level of 16 %, which corresponds to the value of the expert's error. It can also be concluded that the quality of the system is determined by the quality of knowledge base training, which it uses to recognize and resolve potential conflicts. Thus, by increasing the sample size, or by conducting additional sessions of extracting expert knowledge, it is possible to finish improving the quality of the system.

Table 1

The results of modeling the process of forming coordinating decisions

	Expert 1	Expert 2	MAS	Expert 1, %	Expert 2, %	DSS, %
Missed collisions (error of the first kind)	7	3	4	23,33 %	10,00 %	13,33 %
Excess collisions (error of the second kind)	4	3	7	13,33 %	10,00 %	23,33 %
Weighted error				20,63 %	10,00 %	16,03 %

According to the available statistics on the costs of repairing the rejection during the TMPE implementation, types of rejections were identified, which are determined by collisions recognized

automatically in the MAS. The level of costs for repairing the marriage relative to direct material costs, as well as the ratio of the costs of repairing the rejection by species is shown in **Fig. 4**. Analyzing this graph, it is possible to say that the average cost of repairing the rejection by situations that are recognized by the system is about 44 %. Therefore, taking into account the general error in the system operation, as the probability of obtaining the wrong decision equal to 0.16, it is possible to predict the possibility of reducing the costs associated with correcting rejects during assembly by an average of 44 %*0.16 = 37 %.

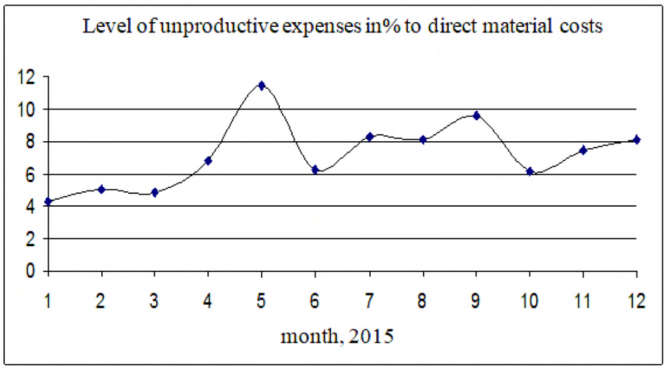

Fig. 4. Correlation of expenses for the correction of various types of rejection in the process of TMPE implementation

As a basis for the preparation of training and control samples were taken: technological regulations for the TMPE in a typical printing company; processes of maintenance of specific units of production equipment, as well as relevant statistics on costs that arose due to collisions related to the lack of spare parts and components.

5. Discussion

The main advantage of the presented approach is the joint application of hybrid models for the formal representation of production situations with multi-agent technology for software implementation of decision support tools.

The disadvantage of the approach is a rather narrow class of manufacturing enterprises, for which the expediency of its application is obvious a priori.

Further research should be conducted in the direction of improving the composition and functionality of the proposed multi-agent system.

The presented theoretical and applied results make it possible in the future to create a methodology for organizing information support for the subsystem of maintenance of production equipment for a wide range of industrial enterprises. The developed prototype of the multi-agent system for the formation of coordinating solutions for the provision of spare parts and components for the maintenance of production equipment can be integrated into the information management system of the ERP level.

6. Conclusions

The approach to the creation of computer means for the formation of coordinating solutions for the provision of spare parts and components for the maintenance of industrial equipment at industrial enterprises is considered. It is proposed to automate the process of recognizing and eliminating collisions that arise in the supply of spare parts and components, by developing a software environment that supports the life cycle of a community of intelligent agents. The nomenclature of agents is described and a hybrid model of their functioning is presented.

The efficiency of the developed means is estimated using the method of leave-on-out cross-validation. (LOOCV). As a result of the simulation, a total error level of about 16 % is obtained, which will, on average, reduce the unproductive costs in the TMPE process by 37 % (according to statistical data on specific types of solvable collisions).

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DEVELOPMENT OF THE IMPROVED METHODS OF FIGHT AGAINST DISTRIBUTION OF SMOKE ON SHIP WITH SYSTEMS OF JET WATER-GAS EJECTORS

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Abstract

The ways of improving the design of ship openings with the implementation of a method for reducing the intensity of the exit of flue gases through an opening (doors, hatches) of the emergency premise of the ship are considered. The output of flue gases from the emergency premise is proposed to be controlled by the control of gas-air currents with the help of a system of jet water-gas ejectors. Ejectors are equipped with devices for collecting flue gases from the emergency premise of the ship and the collectors of the output of the vapor-gas mixture back to the emergency premise.

In case of fire, in the shortest possible time, a high temperature rises in the area of exit from the emergency premise of the ship and a large amount of smoke spreads along the corridors and premises of the ship. These factors require immediate sealing of the emergency premise, which limits the operational access of emergency teams to combat fire.

The considered air suppression methods in the ship's aperture and devices for their implementation contribute to screening of heat energy and localization of flue gases in the emergency premise without its sealing to ensure prompt access of emergency teams.

Keywords: jet water-gas ejector, ship openings, design methods, operational access.

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1. Introduction

Ship's openings on the ship are designed for communication between adjacent premises or for access to the open space of the deck. Closure of the openings is provided by doors and hatches, which are installed in the ship's protective fences (partitions, decks). Specificity of the use of ship's openings puts forward a number of requirements for them, concerning the selection of materials for their manufacture, their reliability, strength, quality.

At present, the design of the openings is carried out according to the methods providing for the fulfillment of the requirements for fire safety of the ship [1].

One of the most important requirements for ship openings (their closure) is their fire resistance and the ability to respond to emergency situations, namely the closing speed and the quality of localization of the consequences of fires [2]. Concerning ship fires, this amounts to sealing the emergency premise [3–5]. However, the accumulated experience in combating ship fires shows that during a period between the onset of a fire (ignition and the onset of formation of combustion products) and the moment of sealing, a significant part of the high-temperature flue gases through the openings go beyond the emergency premise. At the same time, the sealing of this space excludes the operational access of fire brigades.

From the foregoing it follows that in a complex of tasks of providing ship fire protection, an important task is maintaining of openings in the open state while simultaneously preventing gas exchange with adjacent premises. Therefore, the applied scientific and technical task of developing methods for designing ship openings with the suitability of gas exchange in case of fire without their closing is relevant.

2. Literature review

Attempts to protect ship's openings from smoke and high temperatures have been done repeatedly. Thus, on ships of relatively large displacement [6–8], the ladders in the energy compartments (EC) of ships to equip dangerous consequences of the fire are equipped with stationary systems of irrigation of the space at the ladders from the lower sites of the EC. This allows to protect personnel, evacuated, at least from the heat impact. The main disadvantage of the system of irrigation of ship's ladders is the possibility of spreading flue gases through an open aperture beyond the emergency EC on other premises of the ship.

Another known means of reducing the intensity of smoke and toxic gases outside the emergency premise is the rotary curtains, which are irrigated with seawater [9]. Such devices have in their composition two parallel Π-shaped collectors with centrifugal-jet sprayers, which are located parallel to the ship's aperture, one along the perimeter of the opening and the second outer one. Between the collectors on the swivel bars, which can rotate around the longitudinal axis, curtains are fixed that are irrigated when feeding seawater. The disadvantage of this technical solution for ships of small displacement, where small ECs have a large amount of electrical equipment, is the threat of the failure of this equipment as a result of its irrigation.

General issues of fire protection on marine facilities, and in particular on cruise ships and military courts, are discussed in [10–12].

The application of special passive materials, in particular synthetic fibers, to reduce the risk of fire is considered in [13].

Application of systems based on jet gas and water ejection systems (JGWE) can be an effective solution to decrease the intensity of the spread of hazardous fire factors while simultaneously preventing the drawbacks of using open irrigation systems [14].

The aim of the article is improving the design of the fire-fighting system of the ship by applying the system of local air support, formed by the flow of vapor-gas-air mixture directed to the emergency boat compartment, using jet gas-water ejectors.

To achieve the aim, the following tasks must be solved:

– to establish the regularities of the formation of an air curtain at the doors of the projected ship in the control of gas flows in the flow section;

– to formalize processes of formation of an air curtain, at which the output of high-temperature flue gases from the emergency premise of the ship will be reduced without its sealing.

3. Principles of operation of a jet water gas ejector

JWGE is a sparkless driver for the flow of working fluid (water). When the working fluid is supplied to the multi-jet nozzle under pressure, there is a discharge on the input part of the housing (elector). Due to the discharge of the gas-air medium, it is squeezed inside the body. After interacting with the droplets of the micronized liquid, the gas-liquid mixture moves from the inlet to the original (separator with the outlet). The interaction of the gas-air mixture with the droplets of the working fluid is based on the processes of heat and mass transfer, as a result of which a purified, moistened and cooled gas-air mixture is formed at the housing outlet. At the same time, the spent working fluid is discharged into the drain opening.

In experimental and theoretical studies, it is established that JWGE is an effective tool for reducing smoke concentration in an emergency premise [15]. Solid soot particles, when interacting with droplets of working fluid, "stick" on the drops and are removed from the premise together with the spent working fluid.

Minor modernization of the exit part of the JWGE series of experimental studies allows to obtain a number of results that allow to propose a new method of fire extinguishing [16]. The method is based on ejecting combustion products from the top of the premise, cooling and moistening of this medium, deposition of large and small aerosols on a highly developed heat and mass exchange surface and the withdrawal of the resulting inert mixture into the lower part of the premise from the periphery to the center. This is achieved by mixing the gas-air environment of the emergency premise, reducing the volume concentration of oxygen, isolating it from the source of combustion and extinguishing the

fire. Thus, the placement of JWGE on transverse bulkheads makes it possible to realize a method for localizing and extinguishing a fire in a premise with openings without sealing them.

When applying this method, several effects are simultaneously achieved:

– decrease in the temperature in the volume of the emergency premise and the gas-air mixture is introduced into the premise;

– selection of heat from the fire;

– reduction of oxygen concentration in the volume of the emergency premise;

– formation of a gas-air medium cooled with increased moisture content in the volume of the premise;

– low permeability for the radiant component of the heat flux from the source due to the presence of a water spray vapor.

Also, when placing JWGE on transverse bulkheads and during their operation in an emergency premise, the following processes occur [16]: flue gases are intensively withdrawn from the upper part of the premise, the excess pressure is reduced and the flue gas output is reduced through an opening in an adjacent premise; An inert mixture is injected into the lower part of the premise, giving a decrease in the intensity of air sucking from the adjacent premise through an open aperture.

Consequently, this method allows to obtain the effect of "artificial sealing", i. e., a decrease in the gas exchange rate with open apertures. This effect allows to fight fire in the compartment when the bulkheads are open, in particular, unhindered to enter the fire brigade in the compartment.

However, to this day, only the design solutions of JWGE intended for use in the volume (located in the middle) of the emergency premise were considered and investigated.

Disadvantages of the methods of considered design and devices are the following:

– the method of equalization of local static pressures is ineffective for openings located in horizontal floors (decks) of ships and does not exclude the exit of high-temperature flue gases through an open hatch to the premises located above the emergency premise;

– the device is not effective enough to form a retaining stream;

– the complexity of practical implementation, since the design solutions have sufficiently large overall dimensions;

– large overall dimensions make it difficult to install them in the ship's premises, and equipment that ensures operation of the ship as intended.

Thus, it is obvious that the design of JWGEs needs to be improved to be installed in the openings of the premise in order to shield thermal energy and localize flue gases in these premises without their sealing to ensure prompt access of emergency teams.

Moreover, when developing structural solutions and equipping them with ship openings, it is necessary to provide their various applications in both vertical fences (doors) and horizontal floors (hatches).

4. Theoretical foundations of the functioning of jet water-gas ejectors as sources of local air supply in emergency premises of ships

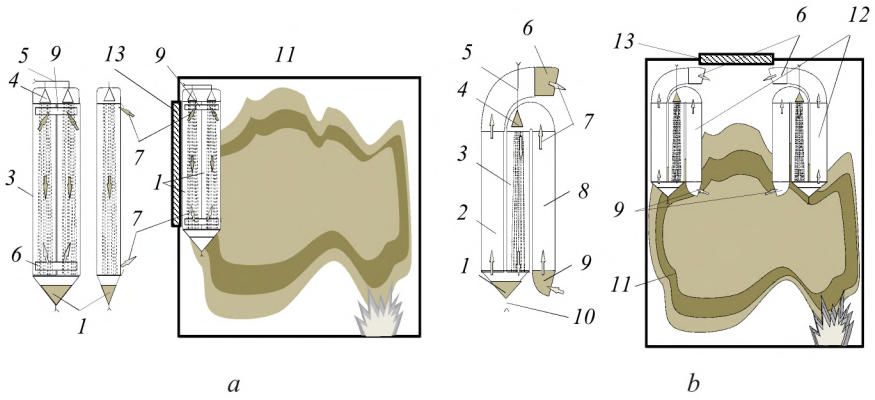
Constructive solutions for providing ship openings with the systems of local air supply for the purpose of "artificial" localization of flue gases in these premises (without their sealing) can be realized in the form of stationary smoke protection systems (**Fig. 1**). The structure and operation of such complexes are considered in detail in [17, 18].

Fig. 1 denotes: 1 – separator; 2 – directing branch pipe; 3 – JWGE body; 4 – multi-jet nozzle; 5 – pipeline of working fluid; 6 – yield of the inert mixture; 7 – motion of the gas phase in the body of the jet water-gas ejector; 8 – directing branch pipe of an entrance part; 9 – air intake; 10 – system for removing spent working fluid; 11 – flue gases; 12 – JWGE; 13 – ship's opening.

To confirm the efficiency of the proposed methods of smoke localization and shielding of the heat flow in the emergency premise area, theoretical studies [17–19] are carried out. The content of these studies stems from the statement that gas exchange is mathematically described by the equation of the material balance of the gas phase for a premise with opening [20]:

$$V\frac{d\rho_m}{d\tau} = G_W + \psi - G_G, \quad (1)$$

where $V\frac{d\rho_m}{d\tau}$ – the change in the mass of the gas over the time interval, kg/s; G_W, G_G – mass flow of air and gaseous combustion products through the opening, kg/s; ψ – the mass combustion rate of the material, kg/s.



a *b*

Fig. 1. Schemes of installation of local air supply systems in the ship openings: *a* – the device of air supply in the doors; *b* – the device of air supply in the emergency hatch

The problem of reducing gas exchange through an open aperture during a fire in the first approximation reduces to the search for conditions under which the first and third terms of equation (1) tend to zero. That is, equation (1) can be written in the form:

$$V\frac{d\rho_m}{d\tau} = \psi, \tag{2}$$

which corresponds to the conditions for the development of fire in the absence of gas exchange with the environment (airtight premise).

During the theoretical studies, simulated zone modeling of the JWGE operation in the openings of the emergency premise is performed, for which the 2D hydrodynamic tasks of the JWGE operation in a semibounded volume are solved and the interband gas exchange equations in the emergency premise are compiled [17, 19].

During the simulation, the development of fire in the ship's premises, isolated from the adjacent premise by metal structures with opening (door – in one version and emergency hatch in the second one), with uneven distribution of the fire load and limited heat and gas exchange with the environment are considered. In the vicinity of the openings, the JWGE is installed to provide shielding:

– flue gases due to their localization in the volume of the emergency premise with simultaneous precipitation;

– radiation of thermal energy due to the processes of heat exchange between the gas phase, eccentricity and dropping flow.

The second task of theoretical studies is determination of the dependence of the distribution mechanism of the velocity fields of the air-gas medium on the cutoff of the opening on the parameters and JWGE operating characteristics, the initial characteristics of the gas-air medium,

It has been established that during the flow of flue gas through the opening, two thirds of the opening is operated to exit the flue gas to an adjacent premise, and one third to the inlet of fresh air [20].

The velocity of the flue gas flow is described by the equation [20]

$$v = \sqrt{2gh\ \frac{\rho_a - \rho_2}{\rho_a}}, \tag{3}$$

where ρ_a – density of air at height h, kg/m^3.

According to the law of Mendeleev-Clapeyron

$$p_2=\rho_2 T_2 R,$$

where T_2 – the average temperature, K; R – the universal gas constant, $R_m \approx 300$J/(kg×K).

Then expression (3) can be reduced to the form

$$v = \sqrt{2gh\ \frac{T_2P_a - T_aP_2}{T_2P_a}}. \quad (4)$$

The volume flow of flue gases and the inflow of air through the opening are described by the equations [20]

$$Q_g = 2/3\, h_o b_o v = 2/3\, h_o b_o \sqrt{2gh_o \frac{T_2P_a - T_aP_2}{T_2P_a}}, \quad (5)$$

$$Q_i = 1/3\, h_o b_o v = 1/3\, h_o b_o \sqrt{2gh_o \frac{T_aP_4 - T_4P_a}{T_aP_4}}, \quad (6)$$

where Q_g, Q_i – the volume flow of flue gases and air inflow through the opening, (m^3).

But when installing in the opening of the operating JWGE, the process of distribution of flue gas flows from the emergency premise and air from the adjacent one occurs. In the part of the opening that is equipped with JWGE air intakes, the flow will move towards the elector, and in the place at the JWGE outlet the inert premise will be supplied to the emergency premise with an enriched inert mixture instead of air.

Therefore, for JWGE operation, the second variant of expressions (5) and (6) will have the form:

$$Q_g = Q_{sum} + Q_{in}, \quad (7)$$

$$Q_i = Q_{ar} + Q_{out}, \quad (8)$$

where Q_{sum} – volume flow of flue gases entering the volume of adjacent premises, m^3/s; Q_{ar} – volume flow of air entering the volume of the emergency premise, m^3/s; Q_{in}, Q_{out} – volume rates of the incoming and outgoing parts of the JWGE case, m^3/s;

The quantities Q_{in} and Q_{out} depend only on the JWGE design productivity and in expressions (7) and (8) they will be constant, and the Q_g and Q_i values will depend on the intensity of the fire development in the emergency premise. In this case, the expressions (7) and (8) are valid for the time instant $\tau=0$, when Q_g and Q_i have the maximum value. Then, as smoke gases enter the adjacent premise, the gas exchange rate decreases with increasing temperature in this premise.

Assuming Q_g = max, and Q_{in} = const, the shielding of the flue gases of interband gas exchange between the emergency and adjacent premise with the acting JWGE in the opening is considered:

$$Q_g = Q_{sum} - Q_{in} \approx 0, \quad (9)$$

$$Q_i = Q_{ar} + Q_{out}. \quad (10)$$

So

$$Q_{sum} \approx Q_{in}. \quad (11)$$

$$Q_{ar} \approx Q_{out}. \quad (12)$$

The development of proposals for the structural arrangement of the implementation of the air backing method in the aperture and the theoretical justification of the JWGE operation processes in the opening of the emergency premise makes it possible to develop methods for designing ship openings using the systems of local air supply, namely:

– a technique for predicting the process of reducing the intensity of smoke entering adjacent premises when using a jet water-gas ejector;

– a technique for calculating the JWGE design parameters.

5. Conclusions

To achieve the research objective, a review and a critical analysis of design methods for combating the spread of smoke on ships in the event of fires are performed and their disadvantages, namely, the exit of high-temperature flue gases through an open aperture to an adjacent premise, and the creation of conditions for the failure of the ship's electrical equipment.

The regularities of the formation of an air curtain in the doors of a projected ship are determined by controlling the gas flows in the flow section. Formation of the air curtain, obtained by selecting a part of high-temperature flue gases in the JWGE case, their heat-exchange treatment and withdrawal back into the flow, is formalized. This, in turn, makes it possible to formulate conditions for the design of ship's apertures with the use of systems of JWGE-based local air supply, in which the output of high-temperature flue gases from the emergency premise of the ship will decrease without its sealing.

The obtained results substantiate the development of the method of design of ship openings using the system of local air supply that is formed by a flow of vapor-gas-water mixture directed to the emergency ship's compartment. This serves as a theoretical basis for improving the design of the ship's fire safety system using jet water ejectors in the openings of emergency premises for the purpose of shielding the thermal energy and localizing flue gases in these premises without sealing them to provide prompt access for emergency teams.

To confirm the theoretical conclusions of the study, a number of practical tests were carried out in 2012 in the volume of the research work "Development of recommendations on the use of jet water-gas ejectors for reducing gas contamination of ship spaces during a fire", "Tambur-2" cipher. Conclusions of practical tests indicate that the placement of the JWGE system in the opening of the emergency premise:

– is an effective means of reducing the intensity of smoke entering adjacent ship space;

– allows to change the motion direction of flue gases, thereby ensuring their effective shielding.

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STUDY OF CONSTRUCTIVE PROVISION OF THE CAPSULE FORMATION PROCESS OF THE «OIL AND FAT RAW MATERIALS – IONOTROPIC SHELL-MAKER» SYSTEM

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Abstract

The effectiveness of fundamental and applied research is realized in the field of technological and hardware solutions, it allows creating a new generation of food products whose quality indicators go beyond those typical of the traditional assortment. This to a certain extent applies to the fat and oil industry.

An important scientific and at the same time practical result is the proposal to consider the encapsulation process not only from the technological point of view. This requires a scientific approach both in the choice of the components of the food system, and in the realization of their properties under the prevailing conditions. From a practical point of view, this determines the given technical and constructive solutions.

To date, there is no theory and practice of extrusion of two fluids through the "air" technological medium, one of which is flowable oil content, and the other is a solution of the ionotropic polysaccharide. There are no scientific and technical principles for the formation of the physical form of the capsule, as well as industrial devices for their production. Food technologies with the use of fat-and-oil raw materials encapsulated are not revealed, and information on the effect of a new food form of fat-and-oil raw materials on the formation of product quality indicators in the technological flow and during storage is not generalized.

To obtain a controlled technological process for the production of fat-and-oil encapsulated raw material, it is important to provide laminar flow of ionotropic shell-maker and fat-and-oil raw materials along the product line of the encapsulation device. This is possible under the condition of special constructive maintenance of the process of capsule formation of the "fat-and-oil raw materials – ionotropic shell-maker" system. This served as the basis for determining the physical parameters of the formation of a thermostable capsule. It is proved that the formation of a final capsule with internal contents of fat-and-oil raw material is possible under the condition of an individual design of an extrusion head and a capsulation device that ensure the circumferential rotation of the capsule in the laminar flow of the receiving medium. This allows to form capsules with given organoleptic, commodity, technological properties and the like.

Keywords: capsule formation process, sodium alginate, calcium alginate, extrusion head, device for encapsulation.

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1. Introduction

The strategic measures of food safety formulated in Ukraine, the growth in the volume of food production and the improvement of the structure of nutrition can't fully resist the vectors of the influence of the world economy on the trends in the development of food markets [1]. This is prompted by the pronounced dependence of Ukraine on the import of a huge number of food products and related products for the creation of food systems. This applies, in particular, to products with pronounced functional and technological properties, which is manufactured with the use of structure-forming agent, foaming agents, emulsifiers, etc. [2]. The use of such food systems allows to quickly enter the Ukrainian market of products in the presence of technologies of modern methods of food production. But this leads to absolute dependence in the food sphere and, as a result, the need for forced "copying" of technologies that are built on such principles.

In our opinion, the only opportunity to resist the importation of food systems and technologies in the Ukrainian market is the development of new technologies with high added technological value. Such technologies, as shown by marketing research, include technology of encapsulation of food products and systems in edible shells based on polysaccharides that can be called as encapsulation of fat-and-oil raw materials [3].

Capsule formation is inherently a transition of homogeneous or microheterogeneous polymer systems with a freely dispersed gel-free state of the gel, a non-flowing two-component system. This system is formed by molecular dispersion of a low molecular weight liquid in a polymer, between which chains there are transverse bonds. The driving forces of such processes are the presence of physical, chemical or simultaneously present physical and chemical potentials and energy interactions.

Common to the known processes of capsule formation of hydrophobic substances is the use of film-forming materials (shell-maker). The basis of this process is the conclusion of substances in the shell that performs the function of disconnecting the components from each other and isolating them from the external environment. This is achieved by phase liquid-liquid separation, polymer crosslinking, polycondensation and polymerization at the interface. The consequence of these processes is the formation of capsules, which are two-phase systems and consist of a shell, preferably solid or gel-like, and internal contents that can be in any aggregate state. But the distinguishing feature of all methods of encapsulation is the thermodynamic incompatibility of the internal environment and the shell-maker, which are traditionally represented by the unipolar non-mixed liquids.

Encapsulation of multi-polar liquids in food technology is a complex technological process. As a rule, this process is reduced to extrusion of a compound mixture with hydrophilic properties ("water") to a hydrophobic medium ("fat and oil raw materials"). In this case, "hot water" is understood as a hot solution of thermotropic gelling agent, which after dosing enters a cooled hydrophobic by the properties phase, where there is an unauthorized formation of the structure with the appearance of the "oil (internal component) – water (gelling agent) – oil (forming medium)" technological system. But because of the difficulties in ensuring the stability of the process of capsule formation, this method leads to a complication of the technological process. This facilitates the extraction of substances into the forming medium with the adjustment of its properties, which results in an increase in the relationship of "water" to the forming medium – "oil" with a disruption in the stability of the process. This necessitates the utilization of the used oil or its purification, the washing of the product made from the oil, significantly limits the spectrum of substances that can be encapsulated, requires strict control of temperature conditions, increases the cost of the final products. An additional restriction on the use of this method is the requirements for "oil" (internal contents): it must consist of triacylglycerides and do not contain fat-soluble surfactants, which include phospholipids of fats and oils.

The first developed and thoroughly studied encapsulation technologies were methods based on the use of gelatin as a film-forming material. It, upon cooling, forms gels with the binding of a considerable amount of moisture and is capable of forming a hard shell of the shell on the surface of the capsules. [4] Providing a limited wetting of the capsule material (fat-and-oil raw material) of the film-forming materials (gelatin solution) during the encapsulation, droplets are formed. As a result of the action of the surface forces, the capsules acquire a spherical shape, the surface of which is enveloped by the shell-formed material, which is incompatible with the contents of the capsule. [5] From the physical and chem-

ical point of view, it is the limited ability to mix reactants that ensures the formation of a clear interface that prevents the spreading of the film-forming material over the surface of the droplets [6].

In the literature [7] it is indicated that the formation of gelatin capsule shells in practice is most often carried out by cooling them in solutions of nonpolar substances (oil). The purpose of this is dissolution prevention of the capsule shell. The mechanism of phase transformations of the gelatin solution consists in changing the conformation of the polymer macromolecules upon cooling and forming a spatial grid of the gel, which is stabilized by hydrogen bonds, hydrophobic and other intermolecular forces. Due to the transition of the system from the liquid to the solid-state, a gel-like capsule shell forms and a spherical shape is fixed.

Unfortunately, the spectrum of substances that can be encapsulated in gelatinous membranes is limited by their polarity, and the capsules themselves have a high lability to the effect of temperature-they are not thermostable, which is due to the gelatin's property of passing into the solution.

The majority of encapsulation technologies are based on the implementation of the principle of thermodynamic incompatibility of components of shell-maker and encapsulant. To encapsulate hydrophobic substances, including fat-and-oil raw materials, use polar solutions of polymers capable under certain conditions to controlled film formation, that is, the formation of the capsule shell. The indicated principle is the basis for the implementation of encapsulation processes and is based on surface phenomena occurring at the interface between phases of non-mixed liquids [8].

When using ionotropic poly-saccharides, for example, sodium alginate (AlgNa) as a reference, there is a need to co-axially extrude, according to the pipe-in-tube principle, a solution of the shell-maker (outer tube) and the hydrophobic substance (inner tube) into the forming medium through air in the state of the formed quasi-stable capsules. Upon entering the receiving environment, chemical potentials are realized and the capsule acquires a commodity state in texture.

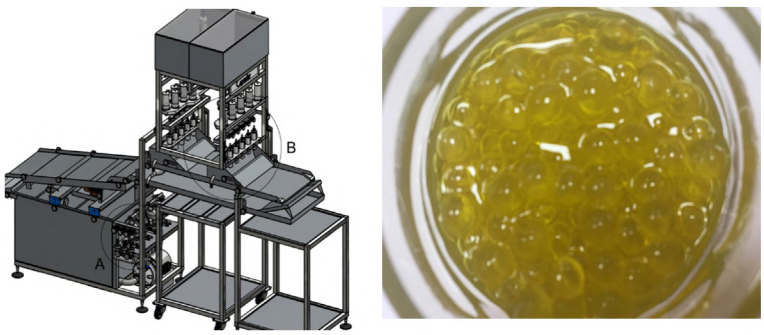
The scientific and technical prerequisite for the realization of the direction of encapsulation of food products is the systematic research of the authors [9–11], thanks to which scientific bases of encapsulation based on aqueous solutions have been created. There are no system studies with the purpose of scientific justification of the technology of encapsulation of fat-and-oil raw materials and products with their use.

In connection with the foregoing, the scientific substantiation and development of the principles of constructive provision of the process of capsule formation of the "fat-and-oil raw materials – ionotropic shell-maker" system as an obligatory condition for providing a controlled technological process with obtaining products of specified quality is relevant.

2. Materials and Methods

In the framework of the study of the structural support of the capsule formation process of the "oil and fat raw materials – ionotropic shell-makers" system, as a subject of research, a device with two-tube extrusion heads is chosen according to the "pipe-in-pipe" principle (**Fig. 1, *a***). Also, the subject of research is encapsulated food products with internal contents of fat-and-oil raw materials.

The photographic image of the investigated samples is shown in **Fig. 1, *b***.



a *b*

Fig. 1. Photographic image of research objects: *a* – industrial two-tube device for encapsulation of food lipids, *b* – investigated encapsulated food lipids

3. Results

Development and implementation of the principles of encapsulation of fat-and-oil raw materials coincides with the world trends in the development of the food industry. According to these trends, the improvement in the structure of nutrition, along with other factors, is determined by the technological stability of oils, fats in time and extended shelf life due to ensuring their intactness with the external environment.

From the practical point of view, the preparation of encapsulated food lipids is achieved by simultaneous coaxial vertical extrusion according to the pipe-in-pipe principle, where an aqueous solution of AlgNa is fed through an outer tube, and oil, fats or mixtures, lipid-based extracts are fed along the outer tube. A method for the capsule formation of hydrophobic substances is developed and the technical solutions for obtaining capsules with internal hydrophobic contents is patented [12, 13].

To ensure a stable process of obtaining encapsulated food lipids, it is important to organize laminar flow of shell-maker and lipids through the product line of the extruder head. Also, it is necessary to ensure the physical formation of quasi-stable capsules during its detachment from the head with a uniform and symmetric distribution of lipid content relative to the center of the capsule by a distribution of lipid content and shell-maker. Ensuring the formation of a physically correct shape and uniform distribution of shell-maker on the surface of the encapsulant is a complex technological and constructive task because of the different density (ρ, kg/m^3) of shell-maker and internal contents. This is the reason for the appearance of defects quasi-stable droplet capsules, which are manifested in the case of the lower bridging of the shell-maker with simultaneous loss of thickness in the upper and lateral parts of it. The appearance of physical disproportion of the capsule leads to a complication of the technological process: a decrease in the quality of the finished product.

Elimination of the revealed physical disproportions during the formation of the droplet capsule is achieved by using a specially designed head with a controlled movable inner tube of the product pipeline. This allows to monitor and adjust the thickness of the horizontal walls of the capsule.

According to the technical plan, the dose-drop is formed in the air, and then a dose-drop is formed through the air and is supplied to the forming medium, in which the capsule formation process is completed. The cross-section of the extrusion head of the device for providing a dose-droplet formation is shown in **Fig. 2**.

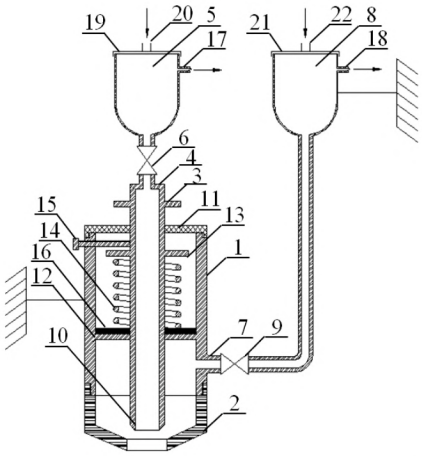


Fig. 2. Cross-section of an extrusion head for encapsulation of food lipids by the “pipe in pipe” principle

In this case, the flow of two liquids proceeds in a continuous flow that obeys the Bernoulli equation for the continuity of jet flow [14].

It has been established that, with justified parameters, the leakage of both liquids and the homogeneity at the outlet 3 and the nozzle will be constant values. This makes it possible to calculate the conditions for a monodisperse controlled rupture of liquids by jet extrusion to droplets with

constant dimensional characteristics and the phase relationship within the process flow of capsule formation and one batch.

The analysis of **Fig. 2** allows to evaluate the principles of action that are placed in the design of the extrusion head for encapsulation and the possibility of regulating the physical symmetry of the shell-maker and the encapsulant. By lowering or lifting the nozzles, the thickness of the horizontal shell parts is quasi-stable capsules. In the lower part of the head there is a confuser 2 with an outlet 3, and the confuser 2 is removable from the lower part of the body 1. The inner content feed pipe 4, which is connected on its one side to the body 1 and, on the other, to an intermediate unsealed seal a container for internal contents 5, with which the internal contents enter the inner content feed pipe 4. The supply branch of the shell-maker 7 is connected to an intermediate unsealed container for shell-maker 8. The supply of the shell-maker 7 contains a flow control valve of the obturator. The orifice 10 is located coaxially with the outlet 3 and is mounted above it, with the possibility of adjusting the distance between the orifice 10 and the outlet 3. This design solution is a feature of the extrusion head and comes out of the physical laws, density (ρ) of the encapsulant and gellant, which results in the formation of a "one-sided" capsule, it is possible to compensate by the position of the orifice 10 to the outlet 3. Also, the orifice 10 is installed with the possibility of removing the contents of the inner content feed pipe 4. In the upper part of the body 1 is a detachable cover 11. In the cavity of the body 1 above the branch of the supply of shell-maker 7 are located: the first lower stop 12, adjacent to the inner surface of the body 1, the second upper stop 13, which adjoins to the outer surface of the supply port of the inner contents 4 and a spring 14 which is clad on the inner content feed pipe 4 and is located between the first lower 12 and the second upper stop 13. The fixing means 15 of the inner content supply pipe 4 in the body 1 is made in the form of a locking screw located in the upper part of the body 1. The gasket is 16, which the spring 14 presses against the first lower stop 12. At the top of the intermediate unsealed container for internal contents 5 a lateral branch 17 is located, and a lateral branch 18 is located in the upper parts of the intermediate depressurized container for shell-maker 8. Also, the container for internal contents 5 also contains a cover 19 with the pipe 20 and depressurized orifice for internal contents 5 contains a cover 21 to the nozzle 22. Inlet nozzle 4 comprises internal contents lateral projection 23.

The design and the hydraulic circuit for feeding the extruder head provide spontaneous controlled monodisperse dissolution of liquids in the form of a sphere. The capsules pass through the air into the receiving formation medium of the Ca^{2+} solution.

4. Conclusions

Today, the direction of encapsulation of various raw materials is very relevant in the food and pharmaceutical industry, as evidenced by the numerous scientific studies in the world on this issue. The use of ionotropic polysaccharides allows essentially new properties to be provided to hydrophobic food systems. They provide the production of traditional oils, fats, mixtures in a dosage form and in an independent edible pack. This allows to ensure the perception of lipid raw materials as a product with fundamentally new properties that can change the structure of many technological processes. The method for obtaining seamless capsules with internal contents of fat-and-oil raw materials is substantiated, which made it possible to determine the physical parameters of the formation of a thermostable capsule. It is established that the formation of a final capsule with internal contents of fat-and-oil raw material is possible under the condition of individual structural support of the operation of the extrusion head and the device for encapsulation, the design of which ensures the rotation of the capsule around its axis. This allows to obtain a stable controlled technological process. It has been established that circumcision of the capsule rotation in the laminar flow of the receiving medium allows the formation of capsules with prescribed organoleptic, commodity, technological properties and the like.

Provision of technological and physicochemical stability of fat-and-oil raw materials will meet the growing demand for food products with their use. The new consumer form of a seamless capsule will allow developing both a fundamentally new assortment of culinary products and new technological principles for obtaining food products. The relevance of such research is increasing in connection with the possibility of using new data in the theory and practice of special types of

nutrition by the controlled release of the inner contents of capsules in the zones of the gastrointestinal tract, as well as in adjacent branches of activity related to human health - medicine, pharmacy, microbiology and other.

Design solutions for devices for encapsulation are developed, carried out experimental development is the basis for developing a technological scheme and justifying the parameters of the technological flow of production of fat-and-oil encapsulated products and, accordingly, adaptation of the new technology in real industrial conditions.

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LISCIC/PETROFER PROBE TO INVESTIGATE REAL INDUSTRIAL HARDENING PROCESSES AND SOME FUNDAMENTALS DURING QUENCHING OF STEEL PARTS IN LIQUID MEDIA

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Abstract

In the paper some unusual processes are considered during quenching such as self-regulated thermal process when metallic probe is covered by insulating polymeric layer, oscillation of temperature in surface layers of probe, creation a "shoulder" when quenching in polymer solution, possibility to perform austempering process just in cold liquids. Above mentioned processes build a basis for the new intensive quenching technologies and can bring a great benefit for heat treating industry when further carefully investigated. It is shown that initial temperature gradients, which cannot be governed by classical law of Fourier, can be tested by Liscic/Petrofer probe, *etc*. The paper discusses how organize such international investigation to satisfy contemporary practical needs and solve unsolved problems of science in the field of quenching. Also, the results of investigations can be used for software designing and cooling recipes development during quenching steel parts in liquid media. It makes a great progress because at preset time only cooling curves and cooling rates are available that are used for comparable purpose and cannot be used for recipes development.

Keywords: self-regulated thermal process, coating, temperature oscillation, initial temperature gradients, modified law of Fourier, database development.

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1. Introduction

For the first time Liscic/Nanmac probe and intensive quenching processes were discussed together at the international conference on Heat Treating Processes held in Kiev in 1988. Prof. Liscic introduced to the audience his Liscic/Nanmac probe with three tiny thermocouples which were instrumented on the surface of 50 mm probe made of AISI 304 stainless steel, at the distance 1.5 mm below surface and in the center of probe which was 200 mm long. The probe was produced in collaboration with the American company Nanmac Corp., Holliston, MA [1]. Investigators dealing with intensive quenching processes were exited by Liscic/Nanmac probe since they realized that the probe was an excellent tool for careful IQ processes investigations. At present time similar Liscic/Petrofer probe is available [2]. The matter is that alloy and high alloy steels are quenched in oils without interruption the cooling process. Furthermore, research institutes and universities are developing new expensive alloy steels to be slowly quenched in oils to prevent crack formation and decrease distortion.

Due to enthusiastic work of two companies IQ Technologies Inc., Akron, USA and Intensive Technologies Ltd, Kyiv, Ukraine, it has been established and introduced into the practice the next three main achievements of intensive quenching phenomena which are [3]:

– an Intensive Quenching (IQ) reduces significantly distortion and prevents crack formation during hardening of steels;

– decreasing alloy elements in steel increases service life of steel components when they are intensively quenched;

– alloy and high alloy steel can be intensively quenched by plain water or water solution of optimal concentration if cooling is interrupted at proper time.

Due to these discoveries, situation in heat treating industry cardinally changed. Standard Inconel 600 probe is not more useful for controlling and maintaining quality of IQ processes [3–7]. The most suitable, at present time, is Liscic/Petrofer probe [2] which has to be widely used in heat treating industry. The aim of the current investigation is to show the possibility of using Liscic/Petrofer probe for liquid quenchants database development and accurate experimental review of discovered self-regulated thermal processes.

2. Conventional quenching versus IQ-2 and IQ-3 processes

As known, alloy and high alloy steels are quenched in oils or high concentration of polymers to prevent crack formation and distortion. As a rule, cooling in oils continues to bath temperature that is why heat transfer coefficients are not a big problem and standard Inconel 600 probe is a good tool to obtain cooling characteristics for maintaining oils within the specks quality [4]. Low distortion and elimination crack formation can be achieved by applying intensive quenching too [3]. The matter is that during intensive quenching, a martensitic structure forms quickly and uniformly in the part surface layer creating high current surface compressive stresses which act as a die minimizing part distortion and preventing part cracking [3].

Two IQ processes are currently used in heat treating practice: a batch IQ process and a single-part processing IQ method. When using the batch IQ process, known as IQ-2 method, parts are quenched in batches in IQ water tanks. When using the single-part processing IQ technique (known as IQ-3 method), parts are quenched one by one in high-velocity IQ units. Note that the IQ-2 process is a two- or three-step quenching method. The first step of cooling takes place in agitated water solution and is interrupted at a certain moment of time when the core of the parts being quenched is still hot. The parts are then cooled in the air during the second step of quenching. The part's martensitic layer is self-tempered by the heat coming from the part core. If necessary, the load can be brought back into the quench tank for the completion of the quench. This technology needs special recipes development where heat transfer coefficients are used to calculate correctly time of interruption. The essence of IQ-3 process consists in interruption intensive cooling when at the surface of steel parts maximal compressive stresses appear and optimal quenched layer is formed. To investigate properly both intensive quenching processes, Liscic/Petrofer probes can be successfully used.

3. Austempering process in cold liquids

In this paragraph an austempering process in cold liquids, developed in Ukraine, is considered [8, 9]. The idea is very simple and understandable. When quenching in optimized cold liquid, surface temperature of steel part drops immediately close to saturation temperature (**Table 1**) and maintains at this level relatively a long time until transient nucleate boiling process is finished [3, 10]. The reason of such behavior is inequity $\alpha_{nb} >> \alpha_{conv}$ and is called self-regulated thermal process [10]. The duration of self-regulated thermal process is calculated from the equation (1) [11]:

$$\tau_{nb} = \Omega k_F \frac{D^2}{a}. \quad (1)$$

Here τ_{nb} is duration of transient nucleate boiling process in sec; Ω is parameter depending on Biot number during convection when initial austenitizing temperature is fixed at 850 °C; k_F is form coefficient; D is size of steel part in m; a is thermal diffusivity of a material in m^2/s. The essence of austempering process consists in interruption of cooling at the end of boiling mode and immediate transferring product to tempering at the temperature $T_{sf}>M_S$. Also, during transient nucleate boiling process $T_{sf}>M_S$. There are three major approaches allowing fulfilling austempering in cold liquids:

– use high concentration of water solution to increase boiling point to martensite start temperature M_S;

– use pressure to increase boiling point of water to martensite start temperature M_S;

– use polymer of inverse solubility which creates insulating layer on the surface of steel parts and maintains surface temperature at the end of nucleate boiling at the level $T_{sf}>M_S$.

The most simple and reliable austempering process in cold liquid is the third approach. Its disadvantage is decreasing cooling rate during nucleate boiling due to surface insulating layer.

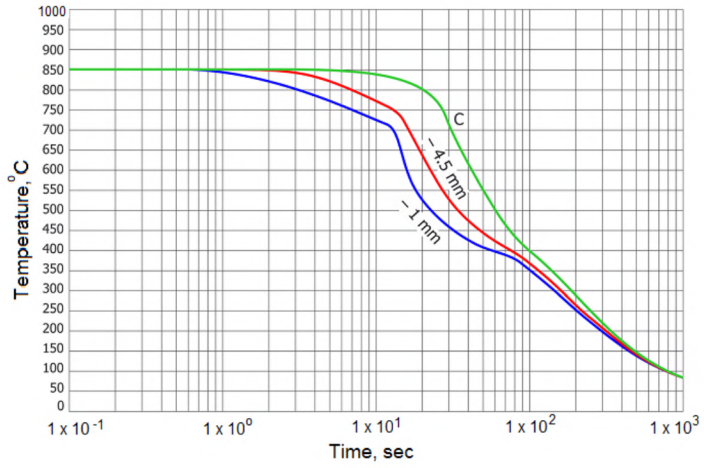
When film boiling is absent, surface temperature of steel parts drops almost to boiling point of liquid (**Table 1**).

Table 1

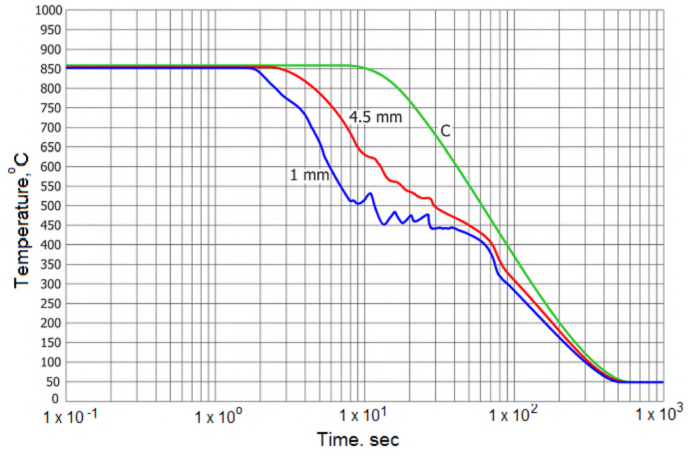
Time required for the surface of steel spheres of different sizes to cool to different temperatures when quenched from 875 °C in 5 % NaOH-water solution at 20 °C and moving at 3 feet per second (0.914 m/s), according to French [12].

Average size	Time, Sec							
	700 °C	600 °C	500 °C	400 °C	300 °C	250 °C	200 °C	150 °C
6.35 mm	0.027	0.037	0.043	0.051	0.09	0.15	0.29	0.69
12.7 mm	0.028	0.042	0.058	0.071	0.11	0.15	0.26	0.60
25.4 mm	0.033	0.042	0.055	0.074	0.13	0.21	0.35	0.82
63.5 mm	0.023	0.039	0.065	0.093	0.14	0.19	0.32	0.59

As seen from **Table 1**, surface temperature of 6.35 mm – 63.5 mm spheres drops 875 °C to 150 °C practically for the same time that is very important when developing austempering processes in cold liquids. Also, **Table 1** shows that film boiling is completely absent.



a



b

Fig. 1. Cooling curves measured by the Liscic/Petrofer probe quenched in liquid media: (*a*) in an accelerated mineral oil of 50 °C, without agitation; (*b*) in a polymer solution of 35 °C, with agitation [2])

As seen from **Fig. 1**, Liscic/Petrofer probe depicted very unusual behavior of temperature in surface layer of the probe when quenching in polymer solution [2]. Initially temperature in this area drops smoothly to 500 °C and then creates a "shoulder" where temperature maintains at the level approximately at 450 °C. More information is provided in **Table 2**.

Table 2

Surface and core temperature versus time when quenching in a polymer solution of 35 °C

Time, s	0	1	10	20	30	40	60	100
T_{sf}, °C	855	850	470	445	445	430	412	280
T_{core}, °C	855	850	840	770	675	600	500	370

Moreover, temperature within the created "shoulder" oscillates extensively at the beginning of it and oscillation stops at the end of "shoulder" [2]. Author [2] didn't explain such interesting behavior. It can be explained by self-regulated thermal process taking place during transient nucleate boiling mode [10, 11]. The matter is that during quenching in water solution of polymers on the surface of steel parts or probes a polymeric coating is formed as shown in **Fig. 2**. Transient nucleate boiling process in this case takes place on the surface of the coating. Since polymeric water solution is agitated, the thickness of the coating varies versus time. As known, cooling rate depends on thickness of the coating and thermal conductivity of polymer and can be calculated using equation (2):

$$v = \frac{aKn}{\left(1 + 2\frac{\delta}{R}\frac{\lambda}{\lambda_{coat}}\right)K}\left(T - T_m\right). \quad (2)$$

Here v is cooling rate in °C/s; Kn is Kondratjev number; a is thermal diffusivity in m^2/s; δ is thickness of insulating layer; R is radius in m; λ is thermal conductivity of metal in W/mK; λ_{coat} is thermal conductivity of coating in W/mK; K is Kondratjev form coefficient in m^2; T is current temperature; T_m is bath temperature.

Varying a thickness of the polymeric coating is a reason for temperature oscillation. Author [13, 14] investigated effect of polymeric coatings on initial heat flux density and temperature fields within the metallic section of the probe. Polymeric coating decreases initial heat flux density and by this way eliminates film boiling [14]. Also, as it was shown by author [14], coating increases the surface temperature of the probe during self-regulated thermal process and by this way delays martensitic transformation during transient nucleate boiling process (**Fig. 2**). Such unusual behavior can be used to perform austempering processes just using cold liquids [8]. It should be also noted that coating decreases temperature gradient between the core and surface metallic layer approaching the cooling in oils. For example, during quenching in oil (**Fig. 1**, ***a***)) at a time 60 seconds temperature difference between surface and core is 100 °C when at a distance 1 mm from the surface temperature is 400 °C. The same difference is observed during quenching in water polymer solution (**Fig. 1, *b***)). Thickness of the polymeric layer is controlled by concentration of polymer in water. The above consideration shows that the great possibilities of polymers are not explored for 100 % yet. Further investigations are needed which can be performed using Liscic/ Petrofer probe.

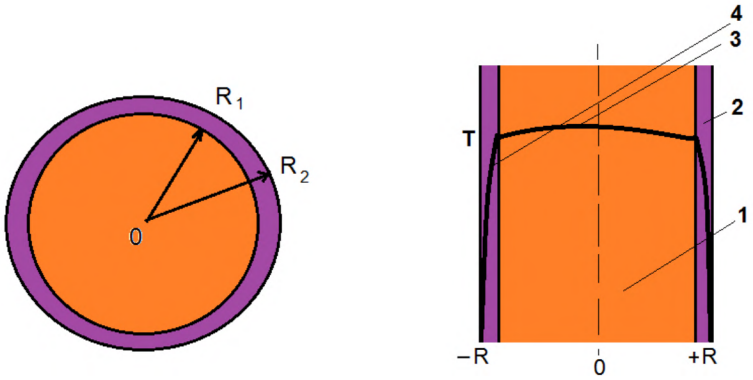
The summarizing differences between standard Inconel 600 and Liscic/Petrofer probes are provided in **Table 3**.

Table 3 shows that along with Inconel 600 probe the Liscic/Petrofer probe should be used for testing liquid quenchants.

Table 3

Summarizing differences between standard Inconel 600 and Liscic/Petrofer probes

Inconel 600 standard probe with one thermocouple at the core	Liscic/Petrofer probe with three thermocouple	Comments
It is impossible to investigate self-regulated thermal process	The Liscic/Petrofer probe with accurately instrumented three thermocouple provides accurate surface temperature behavior during boiling processes.	The Liscic/Petrofer probe allows determining both real HTCs and effective HTCs. Inconell 600 probe provides only effective HTCs for small diameter.
Due to small diameter, the initial heat flux density during immersion the Inconel 600 probe into cold liquid is almost four times larger as compared with the Liscic/ Petrofer probe resulting in different kinds of film boiling.	In many cases film boiling is absent that allows generalization of experimental data.	Film boiling, especially local film boiling, is undesirable since it is a reason for big distortion and non-uniform surface hardness.
It is impossible to investigate accurately initial processes taking place during immersion steel parts into liquid quenchant.	Provides initial temperature gradients during immersion probe into liquid quenchant.	The initial phase of cooling in liquid quenchants is the most important since it dictates the future history of cooling.
Many big companies provide cooling curves and cooling rates of standard probe obtained during its testing in their liquid quenchants. It is nothing to do with such data since in many cases they are far from real steel parts quenching.	In average it provides realistic data taking place during quenching in liquid quenchants.	Based on Liscic/Petrofer probes, it is possible to modify correlation between duration of transient nucleate boiling process and size, form and thermal properties of solid material and liquid.
Due to simple approach in cooling curves and cooling rate obtaining, it looks like customers save time and money when using standard Inconel 600 probe.	Due to more complicated approach, when testing Liscic/Petrofer probe, it looks like customers need to invest some additional money for testing real processes.	In fact, customers don't use 100 % possibilities of their quenchants and sometimes are losing money and effectiveness.
It is impossible to investigate fundamental initial processes during quenching of steel parts heated to high temperatures.	It is possible to investigate fundamental initial processes during immersion of steel parts into liquid quenchants.	Classical heat conductivity law of Fourier doesn't work properly during immersion of heated to high temperature steel parts into liquid quenchant.
There are nowadays in the world several thousands of small standard Inconel 600 probes in use.	There is only one place (the company PETROFER) which has the Liscic/ Petrofer probe and uses it for own experiments.	Unfortunately, it is impossible to investigate self-regulated thermal process using standard Inconel 600 probe.
Standard Inconel 600 probe (12.5 mm in diameter and 60 mm long) is useful for laboratory tests of different oils or polymer solutions to compare their cooling ability, when testing a new delivery or developing a new sort of quenchants, as well as for monitoring of a quenching bath in respect of its deterioration.	The experimental data obtained by Liscic/Petrofer probe are nearer to industrial processes.	The probe of small diameter generates more easily film boiling due to higher initial heat flux density. As a result, the heat extraction dynamic from this small Inconel 600 probe (surface heat flux) is totally different from those at quenching real parts.
No information on temperature field through the section of a probe.	Ability to measure and record the quenching intensity of all different kinds of liquid quenching media (including salt-baths at elevated temperatures), in different quenching conditions and at different quenching techniques (conventional quenching, intensive quenching, delayed quenching, martempering and austempering).	The Inconel 600 probe cannot be used for investigating martempering and austempering processes.



a *b*

Fig. 2. Section of a coated cylindrical probe and typical temperature distribution during quenching in polymer water solution [14]:
a is section of a cylinder; *b* is temperature distribution in cylinder; 1 – heated metal, 2 – coating, 3 – temperature gradient in metal, 4 – temperature gradient in polymeric surface layer

4. Fundamentals to be widely and carefully investigated during initial process of quenching

It is generally assumed that during quenching of heated to 800–1000 °C steel parts, the three heat transfer modes always take place: film boiling, nucleate boiling and convection. This belief is based on classical Fourier's law which predicts an infinity heat flux density during immersion heated to high temperatures steel parts into the cold liquid. In fact, initial stage of quenching is governed by the modified Fourier law [15] which is written as:

$$q = -\lambda \nabla T - \tau_r \frac{\partial T}{\partial \tau}. \quad (3)$$

Here q is heat flux density in W/m^2; λ is thermal conductivity in W/mK; ∇T is temperature gradient; τ_r is constant of a time in sec; T is temperature in °C or K.

The modified Fourier law generates hyperbolic heat conductivity differential equation which was widely considered and solved by authors [16–19]. According to hyperbolic equation, initial heat flux density is finite value which can be less than the first critical heat flux density and that means absence of film boiling at all. This is a theoretical conclusion. Practically, prior to start boiling process in cold liquids, a boundary layer heated to saturation temperature must be formed first. During this short time of forming boundary layer the surface temperature of probe or steel part drops immediately almost to saturation temperature and then maintains relatively a long time at this level. Experimental evidences of such phenomena were provided by French in 1928 (**Table 1**).

5. Discussion

Contemporary hardening processes require optimization liquid coolants to eliminate completely local and full film boiling processes. Optimization goes through maximizing critical heat flux densities. It means that DATABASE concerning different kinds of quenchants should include critical heat flux densities as the characteristics of a liquid. Further heat transfer coefficients should be evaluated depending on forms and sizes of steel parts. For this purpose Liscic/Petrofer probes of different sizes and forms should be prepared which is rather costly procedure. To fulfill such important task for the practice, the big companies should be as sponsors which are greatly interested in such DATABASE. To make simplified calculations, the DATABASE should provide Kondratjev numbers Kn as shown in **Fig. 3**.

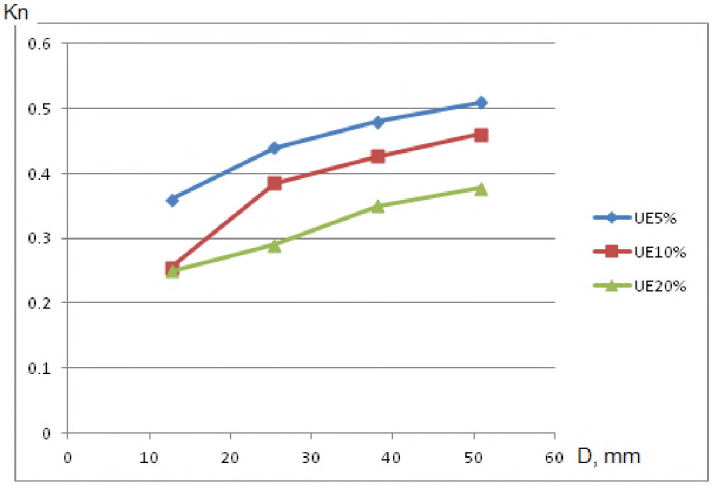


Fig. 3. Effective Kondratjev numbers Kn versus concentration of PAG in water:
UE5 % is UCON E of 5 % concentration at the temperature 43 °C with agitation 0.25 m/s;
UE10 % is UCON E of 10 % concentration at the temperature 32 °C and agitation 0.41 m/s;
UE20 % is UCON E of 20 % concentration at the temperature 43 °C with agitation 0.51 m/s

More information on DATABASE development and testing liquid quenchants, one can find in publication [19, 20]. Cooling characteristics of polymers are discussed in Refs [21, 22]. It should be noted that experimental data obtained by testing Liscic/Petrofer probe provide accurate results of calculations during solving inverse problem which is currently highly developed and used in practice [23, 24]. Along with the database development, the Liscic/Petrofer probe can be used by engineers to investigate deeply and widely self – regulated thermal phenomenon which is the basis for performing austempering processes in cold liquids. This new direction in heat treating industry is very promising and can bring exceptionally benefits to big companies in the world which is currently first patented in Ukraine [8]. Authors hope that many scientists in the world will be interested in investigation theoretically and experimentally the discovered self-regulated thermal process. It makes sense to start such investigations via the EC projects to involve big companies in Europe.

6. Conclusions

1. During quenching in water polymer solution the self-regulated thermal process on the coated surface is observed resulting in creation a temperature "shoulder" in the surface layers of a probe or quenched steel parts.

2. When carefully investigated, the polymers can be used to perform austempering processes with the use of cold polymeric solutions.

3. Oscillation of temperature in surface layers during quenching in polymers is explained by varying the thickness of a coating.

4. Insulating coating on the surface of probe or steel part increases metallic surface temperature of steel part or probe delaying martensite transformation during transient nucleate boiling process.

5. Liscic/ Petrofer probe is an excellent tool for investigation listed in 1–4 processes and can be used for testing the modified heat conductivity law of Fourier.

6. Liscic/Petrofer probe can be used also by engineers to investigate deeply and widely mentioned self-regulated thermal phenomenon during quenching in water and water salt solutions which is the basis for performing austempering processes in cold liquids.

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INVESTIGATION OF THE INFLUENCE OF NANODISPERSED COMPOSITIONS OBTAINED BY PLASMOCHEMICAL SYNTHESIS ON THE CRYSTALLIZATION PROCESSES OF STRUCTURAL ALLOYS

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Abstract

The state of the problem of stabilizing the structure, improving the quality and properties of structural alloys is studied. To solve the problem, it is proposed to modify melts of low-alloyed alloys with nanodispersed compositions obtained by plasma-chemical synthesis. Process technological parameters are developed. Nanopowders of carbide and carbonitride class SiC and Ti (C, N) with a size of 50...100 nm are obtained. The crystallographic parameters of the nanocompositions and the specific surface are determined, and the dependency curves are plotted. The macro- and microstructure of structural steels and alloys was studied before and after the modification. A significant (in 2...3.5 times) grain refinement and stabilization of the alloy structure as a result of nanopowder modification of titanium carbonitride have been achieved. Thermodynamic calculations of the dimensions of crystalline seeds during the crystallization of steels and alloys are carried out. A complex criterial estimation of the efficiency of nanodispersed compositions in a steel melt is proposed. The features of crystallization and structure formation of modified structural steels are studied. The obtained results are of theoretical and practical importance for production of critical parts from structural steels and high-quality alloys.

Keywords: structural steel, aluminum alloy, nanodispersed compositions, plasma-chemical synthesis, crystallization, structure.

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1. Introduction

The field of study of nanodispersed materials is the most rapidly developing in modern materials science, since the production of finely dispersed structures contributes to a fundamental

improvement in the complex properties of structural steels and alloys. The development of nanotechnology is based on the use of physical-mechanical and surface properties of powder materials [1]. The main reason for the appearance of special surface properties of nanomaterials and nanosystems is the high specific surface area and energy activity of nanoparticles. Also, one of the main reasons is the role of size effects, which manifests itself both in individual nanoparticles and in nanosystems [3]. All this is reflected in the mechanisms of ordering of nanomaterials associated with the patterns of changes in their structure and physic-mechanical properties [2–6].

The acquisition of new nanomaterials is inextricably linked with the development of nanotechnologies, which provide the solution of the following problems [4, 6]:

– obtaining materials with a given structure and properties;

– study of the features of the surface properties and structure of nanodispersed compositions that contribute to hardening of structural materials.

2. Literature review

It is noted in [7, 8] that currently used structural steels and alloys do not provide the required durability of machine parts, since they have insufficient strength properties. In the technical literature [9, 10], ways to improve the quality and properties of steels through optimization of composition, microalloying, thermal and thermomechanical processing are considered. The most effective way of obtaining a disperse structure and a high level of strength is modifying [9]. There are several theories of modification, but none of them describes the process completely. Nanodispersed compositions have been used as modifiers of steels and alloys [10–13]. The disadvantage of the work on the modification of structural steels and alloys with nanodispersed compositions is the lack of a comparative evaluation of different methods for obtaining nanocomposites and the thermodynamic analysis of the existence of nanoparticles in the melt.

The aim of the work is refining the grain and stabilization of the structure of structural steels and aluminum alloys by treatment with nanodispersed compositions. This will improve the quality and strength properties of structural alloys, ensuring the required durability of machine parts.

Objectives of the research:

– to choose a method for obtaining nanodispersed compositions;

– to study the granulometric composition and parameters of refractory nanocomposites of the carbide and carbonitride class;

– to conduct a thermodynamic analysis of the crystallization of melts with nanoparticles;

– to study the structural features of steels and alloys modified with nanocomposites.

3. Materials and Methods

The materials of the study are structural low-alloy steels 09Г2С and 09Г2ФБ, these grades of steel are most widely used for the manufacture of parts and building structures, pipe products, as well as aluminum alloys Al-Mg for welded structures. To obtain nanodispersed powders of the fraction of less than 100 nm of pure metals (Ti, Cu, Si), their mixtures and refractory compounds (Ti (C, N), SiC), a high-frequency plasma chemical synthesis device is used [13–16]. The technological process of plasma-chemical synthesis is developed, which includes the following stages:

– preparation of raw materials;

– generation of a plasma jet;

– plasma-chemical synthesis;

– capture of the target product.

Titanium and silicon carbide powders (100...300 μm), obtained from waste from metallurgical and silicon-polymer industries, are used as raw materials. After drying, the powder components are mixed, loaded into the cylinders of a powder feeder, which ensures degassing of the mixture of powders and pneumo-transportation to a slice of the plasma torch [13, 17]. The granulometric composition and parameters of nanocompositions are studied by X-ray diffraction analysis and electron microscopy [4]. The structure of steels and alloys is studied by light microscopy [5].

4. Discussion of research results

Nanodispersed compositions are prepared by the method of plasmochemical synthesis. A high-frequency plasmatron with gas discharge stabilization was used to generate the plasma [12, 13]. In connection with the high ionization potential of nitrogen in the plasma torch, an argon discharge is created by means of an electric pulse of high voltage from a tungsten ignition needle. At the time of the electric discharge, an avalanche-like ionization of argon takes place. Then nitrogen enters the discharge chamber, and the supply of argon ceases. Cooling of the outer surface of the chamber is done by a directed air flow.

Synthesis of nanodispersed titanium boron nitride Ti (C, N) is based on the interaction of titanium, nitrogen and carbon vapors. A mixture of the initial powders is introduced into the zone of the nitrogen plasma flow with an average mass temperature of 5500...7500 °C. At the same time, heating, melting, evaporation of powders and their chemical interaction take place.

At the exit from the reactor, the temperature of the gas-powder flow is 1200...1400 °C. For an intensive reduction in the flow temperature, a heat exchanger system was used that provided a flow temperature of 100 °C at the outlet. From the heat exchangers, the cooled stream enters the trapping chamber, where the nanodispersed target product settles in the bag filters.

To obtain Ti (C, N) from metallic titanium, an effective heat carrier is necessary, as inert as possible with respect to the constituent elements. One of the features of plasma-chemical synthesis is the short-term interruption of the reagents in the reaction zone and the lack of the opportunity, in connection with the short duration of the process, to ensure a high degree of conversion of the raw material into the target product. Argon is used as coolants, which is used to ignite the plasma and nitrogen – to produce nitrogen plasma. The experiments are carried out in the following technological regime: anode power 72 kW, flow of plasma gas 8.5 m^3/g, flow of transporting gas 3.0 m^3/g. The mixture of the initial powders had the composition, % by mass: titanium – 60, nitrogen – 40.

Sampling for analysis is conducted from the reactor walls. X-ray phase, electron microscopic analysis and determination of the specific surface area of nanopowders are carried out. The specific surface is determined from thermal desorption of argon by chromatographic method [10].

The chemical composition of nanocompositions used as modifiers is given in **Table 1**.

Table 1

The chemical composition of synthesized nanodispersed compositions

The formula for compound	Content of elements,% wt.			
	Si	C	N	Ti
SiC	60–65	30–32	–	–
TiC	–	18–21	–	76–80
TiN	–	–	20–23	75–78
Ti(C,N)	–	15–17	19–22	60–65

The generalized results of crystallographic and dimensional topological studies of nanodispersed compositions are given in **Table 2**.

Table 2

Crystallographic and dimensional-topological parameters of nanodispersed compositions

The formula for compound	Crystal system	Phase type	Lattice period, Å		Density, kg/m^3	Melting point (decomposition), °C	Dimension, nm	Specific surface, m^2/g
			a	c				
SiC	Hexagonal	Intrusions	3,080	10,04	3220	2830	55,0	15,5
TiC	Cubic	Intrusions	4,319	–	4920	3140	80,0	14,0
TiN	Cubic	Intrusions	4,243	–	5430	2950	70,0	11,0
Ti(C,N)	Cubic	Intrusions	4,256	–	4950	3120	86,0	14,0

The transition of the material to the nanodispersed state with a decrease in particle size sharply increases the adsorption and catalytic activity of the system, since the surface fraction with respect to the total volume of the particles increases significantly. A sharp increase in surface energy in the transition of particles to the nanodispersed state and a change in the thermodynamic conditions of phase equilibria lead to the appearance in them of phenomena such as high-temperature superconductivity, a super-magnetic and amorphous state [19–21].

The most important task in the process of obtaining nanodispersed modifiers is to maintain a clean surface that provides a large adsorption and catalytic activity. Only in this case the particles introduced into the melt will play the role of active centers of crystallization.

The preparation of nanodispersed compounds (Ti (C, N), TiC, TiN, SiC) by the method of plasma-chemical synthesis is caused by high rates of volumetric condensation of the gas-flame flow, which already at the stage of formation leads to an unstable state of nanodispersed particles:

– nanodispersed powders are characterized by smaller parameters of the crystal lattice in comparison with massive samples of the same alloy;

– different types of amorphous formations take place;

– there is a decrease in the lattice parameters of particles from the center to the surface due to the maximum compression of the surface layer, which causes an inhomogeneous distribution of components and phases along the radius of the particle.

Dispersion of nanoparticles largely determines the properties of a dispersed nanosystem and is quantitatively characterized by linear dimensions and the specific surface area of the particles. The specific surface S_s is expressed by the equation:

$$S_{s=} S_{1-2}/\gamma V, \quad (1)$$

where S_{1-2} – the interphase surface between particle 1 and medium 2; γ – the density of the nanodispersed particle; V – the volume of the nanodispersed system.

Fig. 1 (curves 1–3) shows the change in the specific surface with a decrease in the surface of particles from coarsely dispersed particles (more than 10^5 nm) to systems of molecular degree of dispersion (less than 10 nm). Curves 1–3 have the form of hyperbolas. In the region of coarsely dispersed systems, the curves asymptotically approach the abscissa axis. In the region of the nanodispersed system (NDS), the curves rise sharply. Owing to the large specific surface area of nanodispersed systems, adsorption and surface phenomena are of great importance for them, while the behavior of coarsely dispersed systems is mainly determined by bulk properties [15].

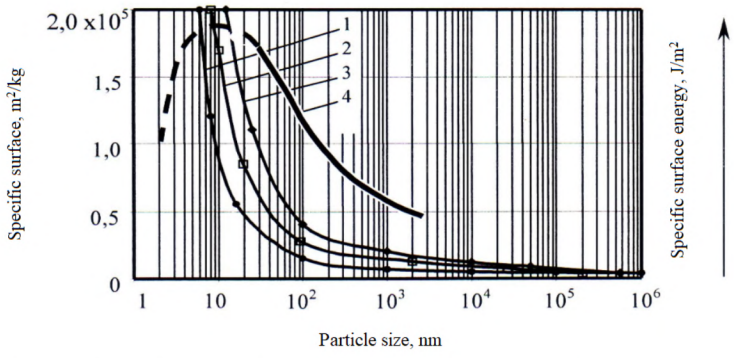

Fig. 1. The influence of the particle size on the specific surface area (1 – TiCN, 2 – SiC, 3 – Mg_2Si), and the averaged surface energy

Curve 4 (**Fig. 1**) characterizes the dependence of the surface energy (SE) on the particle dispersion. It is seen that as the dispersion increases, SE in the region of the nanodispersed system increases. When the particles pass into the nanodispersed state, a sharp increase in the specific surface energy and a change in the thermodynamic conditions of phase equilibria occur. These processes lead

to the appearance in nanodispersed systems of phenomena such as high-temperature superconductivity, a super-magnetic state, and a shift in the temperatures of phase transformations [16–18].

The process of structure formation of 09Г2С and 09Г2ФБ steels modified with nanodispersed compositions based on Ti (C, N), as well as an aluminum alloy of the Al-Mg system modified with silicon carbide SiC, is studied.

Nanoparticles commensurate with the crystallization centers have a high adsorption capacity and therefore nucleation in the crystallization of the primary phase (in this case, the shell) on their surface is highly probable. The formation (particle-shell-melt) will be stable, since the free energy ΔF of this system decreases [22].

If there is a refractory nanoparticle in the melt, the formation of a solid shell of the primary phase on its surface will be the same as in the formation of the center of the new phase. The change in the total free energy ΔF depends on the sum of the changes in the volume and surface free energies:

$$\Delta F = \sum \Delta F_v + \Delta F_s, \quad (2)$$

where ΔF_v and ΔF_s are the change in the volume and surface free energy of the system.

By changing the ratio of volume and surface free energies, nucleation of the primary phase on the nanoparticles present in the melt is facilitated, and proceeds with decreasing total free energy. While the formation of seed in an unmodified melt requires energy expenditure and becomes thermodynamically unprofitable.

The presence of a large specific surface area of the nanoparticle makes the process of nucleation of the solid phase on their surface thermodynamically advantageous in the absence of such tendency for decay. Such sections of the solid phase, when the melt is cooled to the crystallization temperature, win in competition with spontaneously or heterogeneously arising seeds. As a result, the size of grains in castings from modified steel and alloys is determined by the amount of nanoparticles: the more of them, the more dispersed grain.

Thus, the role of nanodispersed particles is reduced to the creation of additional artificial crystallization centers in the melt. In this case, they must be commensurate with critical embryos for mass input to produce a finely dispersed structure of steels and alloys.

Theoretical and experimental studies have shown that in order to achieve a finely dispersed structure of steels and alloys, it is necessary that in the melt there should be at least 105...108 pieces/cm^3 of crystallization centers with a size of 20...40 nm, which corresponds to 0.08...0.15 % of the introduced nanodispersed Ti (C, N) and SiC.

The investigated steel after modification is characterized by a smaller (in 2.0...3.5 times) austenite grain and a dispersed homogeneous ferrite-pearlite structure.

5. Conclusions

The obtained results are used in the development of technological recommendations and instructions for modifying low-alloy steels and aluminum alloys with refractory nanocomposites of the carbide and carbonitride class.

The preparation of nanodispersed compositions by the method of plasma-chemical synthesis is proposed. The technological process and optimal parameters of the temperature regime for obtaining nanopowders in nitrogen plasma are developed. The chemical composition of the obtained powders, crystallographic parameters and physical properties are given. The sizes of Ti (C, N) TiC, TiN and SiC powders, their specific surface area and specific surface energy are calculated. Conditions for the thermodynamic stability of the system are established under which nanoparticles are the centers of melt crystallization. The grinding of the grain of 09Г2С and 09Г2ФБ steels and aluminum alloys of the Al-Mg system is achieved as a result of modification in 2.0...3.5 times.

Based on the research results, a technological instruction is developed and recommendations are given to industrial enterprises for processing steels with nanodispersed modifiers.

The authors plan to expand the range of structural alloys of various alloying systems, as well as improve the parameters of the technological process of modification.

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RESEARCH AND DEVELOPMENT OF A STEPPED HEAT PUMP UNIT WITH A HYDRODYNAMIC CAVITATION DEVICE IN SYSTEMS COMPLEX

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Abstract

Modern European and Scandinavian countries have advanced very far in the development and application of alternative energy sources. The goal of all modern developments is quality improvement and reducing production costs. The precedent of increasing tariffs for utilities is one of the main problems, so there is a need to create non-volatile, autonomous systems that will be controlled and managed remotely. The creation of combined systems that can operate remotely and independently of direct energy resources will lead to a significant increase in the level of protection from the instability of temperature fluctuations and differences in the electrical network.

The present invention relates to heat engineering, in particular to methods and apparatus for generating heat generated differently from combustion of fuel, and can be used in a heating and hot water supply system for residential and industrial premises, as well as for preheating and improving the rheological properties of oil and petroleum products. The presence of sensors in this system allows to monitor, regulate and signal its status, and also allows to set the necessary parameters.

Keywords: hydrodynamic unit, refrigerant, thermal coefficient, truncated cones, hydrodynamic cavitation reactor.

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1. Introduction

The urgency of developing and creating promising sources of power supply for autonomous electricity consumers has long been recognized in many industrialized countries. The limited availability of fossil energy sources, as well as the current situation with rising prices for hydrocarbon fuels along with the exacerbation of the environmental situation, are the factors that stimulate the introduction and use of renewable natural resources in the production of electricity. The main consumers of all types of energy and energy carriers are enterprises, and an indispensable part of any enterprise is its energy economy. It is a collection of generating, converting, transmitting and

consuming power plants, through which the enterprise supplies all necessary types of energy to the enterprise and uses it in the production process. In addition, the energy sector includes automatic control devices and systems with their information support, non-power plants, buildings, facilities and resources that ensure reliable and economical operation of the company's energy, as well as electric lighting, heating and fuel supply.

The presence of consumers (small towns, villages) located in areas isolated from existing energy networks, or supplied with electricity, for various reasons with interruptions require the organization of autonomous power supply. Let's consider systems in a differentiated form. The first is the heating system of dwelling. The heating and cooling system of a dwelling is exactly that branch of engineering support for buildings, in which the principles of "intelligent building" or "smart house" were first introduced, since this is the main item in the cost of building maintenance. Expensive equipment and installation should be designed for a rather long time to failure. The heating system should itself correct the temperature in the house, reacting to a cooling or thaw. Given the temperature outside the house, the system must regulate the operation of all heating elements so that the room temperature remains as comfortable and optimal as possible. A heating system with built-in intelligence will significantly save money.

Let's consider an example of a heat pump: one liter of water with a temperature of 1 °C is approximately 4.192 kJ of heat. The same energy in 4.192 kJ will have 100 grams of water, but with a temperature of 10 °C. The fact that the heat pump provides hot water with a temperature of 60 °C does not mean that it simply heated it with electricity by 50 °C. The heat pump spends electricity only on compression and heat transfer, and itself is warm – free. Thus, heat pumps produce 10 kW of heat, consuming 1.5–2.5 kW/h of electricity.

And in practice it looks like this: underground water is below the ground. The temperature of such water is stably high – about 10 °C. After the heat pump does its work (compression), the water temperature at the outlet in the heating circuit will be already 60 °C. It should be noted that the water itself can't be compressed. The mediator (freon) is compressed, which is sensitive to temperature. It will easily take heat from the groundwater through the evaporator (from about 10 °C through the freon loop it will be selected about 4 °C) and also gives the received heat to the heating circuit through the condenser. [1] That is, the principle of the heat pump is the reverse Carnot cycle, and when the heat pump is operating for conditioning – the Carnot cycle itself. In the case of a failure of the heating equipment due to a malfunction or power failure, the system will inform and stop the functioning of the faulty components, but this can be avoided.

The second system is an autonomous power supply system. The problem of energy consumption has been and will be relevant at any time. Adding several autonomous energy sources (for example, solar panels, windmills) and battery to the system increases the stability of the system. The production of photovoltaic cells and solar collectors develops in different directions. Solar batteries come in various sizes: from embedded in micro calculators to roof-topping cars and buildings. The sun is an environmentally friendly source of energy that does not pollute the environment. The operation of solar panels does not lead to greenhouse gas emissions or waste generation, solar energy is inexhaustible, unlike traditional fuels, solar panels after installation require minimal maintenance and produce energy without human participation, among other advantages of solar batteries is worth noting the long life time. It is 25 years or more without degradation of performance. And the use of solar energy is subsidized by the state. For example, in France, for installation of the battery at home, up to 60 % of the cost is reimbursed.

The need to install a windmill near a private house can arise in two cases – if there is no centralized power supply at all or it leaves much to be desired, or you decided to save considerably on paying for electricity. The wind is an ecologically clean, endless source of energy that humanity has enjoyed for thousands of years. Trends in the development of technology unequivocally point to the prospect of using a variety of alternative sources for the full or partial supply of electricity and heat to the house: solar panels, wind generators, thermal convectors and new efficient materials for thermal insulation.

According to this work, a system analysis of existing units is conducted and methods of their improvement for creating a certain set of systems are considered. This unit refers to equipment for

heating residential and industrial buildings. The compression heat pump comprises an evaporator, a compressor, a condenser, a throttle valve and a liquid separator. The evaporator and the condenser are made in the form of shell-vortex heat exchangers containing supply and discharge nozzles of the working agent and supply and discharge branch pipes, respectively of low potential coolant and high-potential heat carrier, a cochlear-shaped manifold with a guiding apparatus and end walls, and the casing is installed on the outside.

Another unit relates to heat power engineering [2], in particular, to heating installations, hot water supply for small production facilities, individual houses and individual structures using low-potential natural heat sources, domestic wastewater and other heat waste. The method for utilization of low-potential waste water is realized using a heat pump and an external heat exchanger placed inside the hollow column of the airlift submerged in sewage. This makes it possible to utilize the low-potential heat of sewage that has been unclaimed until recently, in enormous quantities continuously sent to the sewage networks of megacities, small towns and workplaces. At the same time, due to this property of the refrigerant used in heat pumps, as its ability to evaporate at a temperature of 3–5 °C, they can utilize the heat of waste water with a temperature not exceeding 5–8 °C [3].

The heat supply method is considered, which included supplying water for heating to the system, heating water with a single heat pump and delivering the heated water to consumers. To improve the efficiency of the transformation of thermal energy, different methods are used. For example, in the method for achieving the maximum heating coefficient of a heat pump according to the patent [4], the coolant of the heat pump is selected to be liquid so that its critical temperature is close to or equal to the temperature of the cooled medium.

A heat supply method is known which includes supplying water for heating to the heat pump system of the system, heating the water with it and delivering the heated water to consumers. The heat pump system consists of heat pumps, each of which is used as a stage of consecutive water heating. [5] The disadvantage of this method is the organization of the operation of this unit in terms of the heat-transfer cycle, which is close to the quadrilateral Lorentz heat pump cycle. Such cycle, while providing energy savings, but increases the payback period to a value that exceeds the period of economic feasibility, with an increase in capital costs. Thus, the regime of the known heat supply method with such stepwise heating of water does not ensure a positive technical and economic result when it is realized. When using this method of heat supply for heating, the operation of the stepped heat pump system proceeds with large throttle losses of the working fluid in the heat pump circuits, the more the condensation temperature of the working fluid, the greater the throttling losses that can't be eliminated constructively. The disadvantage of this unit is the impulse with the intervals equal to the time of the working cycle, the supply of heat to the heated medium and the inability to use the gas work during its expansion.

The closest is the known heat exchange unit [6] comprising a heat pump including a compressor connected to the compressor heat exchange cavity in which two heat exchangers are arranged: the first heat exchanger is connected to a heat exchanger for performing heat exchange with the external medium and the second heat exchanger is connected to a heat exchanger to perform heat exchange with the consumer. Chlorides are used as a working substance. To move the compressor piston, when compressing the working substance of the heat pump, a hydraulic system is used to supply the working fluid under pressure to the compressor over-piston cavity and the drains of the working fluid from the compressor over-piston cavity. In this heat exchanger, there is no expenditure of energy to push the working medium through the heat exchange circuit of the heat pump, which reduces the energy costs when the heat pump operates.

The aim of this research is development of an efficient source of energy supply, which is a set of systems generating, converting and consuming energy devices, through which the supply of objects with the necessary energy, with further remote control.

2. Methods

The main direction of improving heat exchange systems using heat pumps is an increase in the thermal coefficient: the ratio of the amount of heat (cold) transferred to the consumer, to the energy costs for the heat pump operation.

Therefore, another similar heat exchanger for water heating, containing a closed loop filled with a working substance, is investigated. It includes a compressor for compressing the working medium, a heat exchanger for performing heat exchange with consumers, connected to the compressor outlet, a throttling device at the outlet of this heat exchanger and a heat exchanger-evaporator for performing heat exchange with the external environment [7]. This heat exchange system uses the classic heat pump scheme. A high heating coefficient is achieved by using the swinging in the heat pump of the working substance through a closed circuit, which leads to an increase in the energy consumption for the operation of the heat pump.

Cavitation phenomena, consisting in the formation of local regions in the liquid in which steam-gas caverns are separated and subsequently destroyed, are the result of a fast-flowing process of vapor condensation and collapse of bubbles accompanied by high-frequency hydraulic shocks and high pressure drops in the local area [8].

A hydrodynamic cavitation reactor was studied [9], containing a pipeline in the form of a Venturi pipe, a honeycomb rectifier and cavitators installed in the flow chamber of a Venturi tube. The cavitators are mounted on the axial rod in three rows and are disks or cones serving to turbulize the flow of liquid and the formation of caverns on the rear side thereof. When "collapse" the cavities in their volume, the pressure and temperature increase, which acts on the properties of the treated liquid. Disadvantages of the known device: cavitators have almost no effect on increasing the fluid velocity and, therefore, on reducing the pressure in the liquid, which reduces the intensity of liquid heating and the efficiency of the device will be negligible.

Unit in which, in order to increase the temperature of the liquid heating, an insert is also used, made in the form of a perforated partition installed in the injection pipe. When liquid passes through the channels of the septum, toroidal cavities (cavitation bubbles) are formed in the liquid, pulsating at the outlet of the jets along their periphery. In the caverns, electric discharges occur with a high frequency, the energy of which, when the caverns "collapse", turns into a thermal one, which generates heat in the liquid. The disadvantage is the absence of cavitation in the entire volume.

The device is considered to consist of inlet and outlet nozzles and a cavitator installed in the connecting flanges. In the cavitator, along the concentric circle, channels are formed that expand to the outlet of the liquid. At the entrance to the cavitator there is a reflective cone, which narrows the living section of the inlet branch pipe, entering the inlet, where the liquid increases and the bubbles collapse with the heat release. The disadvantages are: low activity of the cavitation process and a small volume of cavitation zones.

The invention, relating to cavitation generators for dispersing gas (vapor) into a liquid has been investigated. Cavitation bubbles with an energy reserve of up to 100 kcal/kg under conditions close to normal, move through the liquid to the treated surface. The surfaces initiate the collapse of the vapor bubbles and, by giving their energy higher than the binding energy in the liquid and in the crystal lattice, lead to rupture of the surface of continuity in the liquid. The disadvantage of this device is the lack of localization of the place where cavitation caverns originate.

The closest to the technical solution is the hydrodynamic cavitation reactor, which contains a flow chamber with a cavitator installed inside the inlet and reactive components. [10] The disadvantage is the low efficiency and the cavitation degree of the flow.

3. Results

Increasing the efficiency and degree of cavitation of the coolant is achieved by intensifying the process at the interface between phases due to the kinetic energy of the interaction of the fluid flow and the cumulative effect of the collapse of the strings. [11]

Fig. 1 schematically shows a hydrodynamic cavitation reactor.

Reactor contains: a branch pipe of the inlet 1 of the second coolant flow; cover 2; flow chamber 3; cylinder 4; converse truncated cones 5; caverns of collapse 6; nozzle 7; divider 8; separating perforated baffle 9, which serves as a support for the divider; diffuser 10; the outlet pipe of the total flow of the heat carrier 11, consisting of the first and second flows; the inlet pipe of the first heat transfer medium 12. The circulating heat pump 8 passes the heat transfer medium to the separator 9, in which the first flow is directed to the branch pipe 12, and the second flow is directed to the branch pipe 11 (**Fig. 1**).

Fig. 2 shows a laboratory installation for investigating the input and output parameters of the test system.

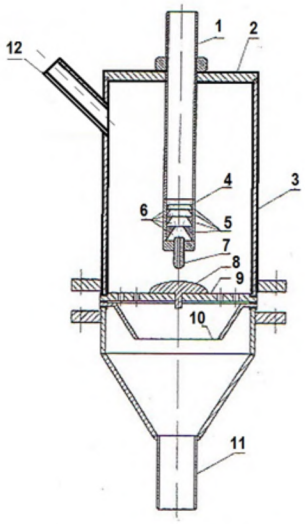

Fig. 1. Hydrodynamic cavitation reactor

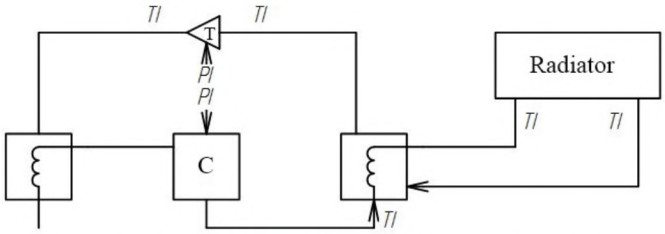

Fig. 2. Test unit of the heating system, where K – compressor, T – throttle, TI – temperature sensor system, PI – pressure sensor system

To move the liquid through the pipes a pump is provided at the entrance of the laboratory unit. Water entering the plant passes through the compressor, where compression and movement of refrigerant vapors occurs, as in refrigeration plants. When the vapor is compressed, not only the pressure but also the temperature increases. After the compressor, the compressed refrigerant enters the condenser, where the compressed gas is cooled and converted to liquid, then the liquid flows through the throttling device to the evaporator (where its pressure and temperature decrease), where it boils, passes into a state of gas, thereby taking heat from surrounding space. After this, the refrigerant vapor is returned to the compressor to repeat the cycle. Thus, at the outlet, water will have a temperature much higher than at the inlet, which ensures the heating of the radiator. [12] Then the used and temperature-lowering liquid passes through the throttle to create a hydraulic resistance to the flow of liquid. Additional hydraulic resistance is created by changing the fluid flow cross-section. By changing the hydraulic resistance, a necessary pressure difference is created, which leads to an even greater reduction in the flow temperature.

4. Discussion

The developed systems complex allows to heat and cool rooms regardless of the source of the centralized power supply, and the addition of a hydrodynamic cavitation reactor provides the system with greater efficiency.

The hydrodynamic cavitation reactor (**Fig. 1**) operates as follows. The first flow along the branch pipe 1 is fed to the cylinder 4, where the reverse truncated cones 5 are installed, which by their horizontal and inclined surfaces form the “caverns” of collapse 6. The horizontal surfaces of the truncated cones act as a brake element in the form of annular projections, in the course of which

n cavities (caverns) are formed [13]. The heated stream is forced into "cavities" and, falling into the zones of their closing due to flow turbulence and the presence of a large number of cumulative microstructures formed during the collapse of cavitation bubbles is subjected to the formation of elevated temperatures. In this case, the nozzles formed by the conical surfaces provide the conditions for the appearance of a "secondary" high-speed jet of the nozzle 7.

At some distance from the end surface of the nozzle 7, the hollow conical shell of the liquid jet at a velocity v_0 collapses and a secondary high-velocity jet of radius r_0 is formed. At the moment of the collapse of the flow of the working medium, the velocity of the secondary high-velocity jet v_c increases by approximately an order of magnitude with respect to the velocity v_0, which follows from the hydrodynamic theory of jets [14].

Further, the secondary high-velocity jet is directed to the divider 8. Attention was drawn to the place of impact of the jets with a flat surface and the appearance of so-called "wings" – structures resembling the feather of an arrow. It is energetically more expedient to implement a collision with a curved surface and achieve a high level of navigation. In addition, the obtained mixture of the first and second flow coolant passes through the separating baffle 9, passes the diffuser 10, and is discharged through the outlet pipe 11. The efficiency of the heat exchange capacity on the surface of the smallest drops is further enhanced by the Thomson effect – the influence of surface tension forces.

At the moment of the bubble disappearance (at the moment of its collapse), the kinetic energy is transformed into collision energy of elementary particles. The energy released when a bubble collapses is several orders of magnitude higher than the binding energy of elementary particles (nucleons) in the nucleus. As a result of the collision of the nuclei of the claimed method, the energy released between the elementary particles is converted into thermal energy in the liquid and it is withdrawn from the processing zone of the hydrodynamic cavitation reactor.

5. Conclusions

The result of this work is development and testing of an experimental laboratory unit. The analysis of the existing developments of autonomous power supply systems and the characteristics of the produced equipment revealed the main trends in the development of this area, to form a promising direction for the practical implementation of the unit itself to take readings from the sensors.

The strong side of this research is the positive effect obtained from reducing the energy load on the compressor. The same decrease in the throttle losses of working heat in the heat pump circuits is achieved at medium condensation temperatures. The increase in the thermal coefficient of the whole unit takes place in a hydrodynamic cavitation reactor, which is considered by the second power plant, which is very important for heating houses, cottages and, in particular, for preheating and improving the rheological properties of oil and petroleum products [15]. The weak side of research is the collection of results for the further development of the mathematical model of the heating installation. To assess the adequacy of a mathematical model, the collection of readings from sensors varies depending on the temperature of the external environment, which requires more detailed observations depending on the time of year and the desired temperature in the room.

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