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АЛГОРИТМ ОПРЕДЕЛЕНИЯ НАЧАЛЬНЫХ КООРДИНАТ РОБОТИЗИРОВАННОГО БЕСПИЛОТНОГО ЛЕТАТЕЛЬНОГО АППАРАТА В УСЛОВИЯХ ИСКАЖЕНИЯ НАВИГАЦИОННОГО ПОЛЯ

ALGORITHM FOR DETERMINING THE INITIAL COORDINATES OF A ROBOTIC UNMANNED AERIAL VEHICLES UNDER NAVIGATION FIELD DISTORTION

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Аннотация. *Роботизированные беспилотные летательные аппараты (РБЛА) широко применяются в военном деле, главным образом в разведке. Крупные аппараты могут быть оснащены вооружением и вести боевые действия.*

Материалы и методы. *Применение РБЛА в гражданских целях также может быть весьма эффективным (мониторинг лесных пожаров, составление топографических карт и т. д.). Большую роль играет метод определения положения и ориентации аппарата в пространстве во время его полета. Чаще всего для этого применяются системы позиционирования GPS/ГЛОНАСС. Однако использование подобных технологий позиционирования может быть затруднено или вообще невозможно. Работа таких систем может быть нарушена в результате целенаправленного подавления либо из-за искажения навигационного поля за счет переотражения навигационного сигнала от искусственных объектов и за счет ограничения видимости горизонта. Сигнал GPS/ГЛОНАСС может оказаться недоступным из-за рельефа горной местности или городских зданий. Использование GPS/ГЛОНАСС может быть неприемлемым по причине секретности или недостаточной точности.*

Результаты и обсуждения. *Поэтому разработка систем позиционирования БПЛА, независимых от данных спутниковых систем навигации, является актуальным направлением исследований. Перспективный способ решения такой задачи – разработка алгоритма определения начальных координат РБЛА в условиях искажения навигационного поля за счет переотражения навигационного сигнала от искусственных объектов и за счет ограничения видимости горизонта. Глобальные навигационные спутниковые системы (ГНСС) являются основным средством навигации для многих подвижных систем и, в частности, для современных роботизированных беспилотных летательных аппаратов. Однако применяемые в навигационных комплексах РБЛА приемники ГНСС обладают крайне низкой помехоустойчивостью, как следствие ограничивают их применение в сложных радиоэлектронных условиях. Практически все виды помех сигналам ГНСС можно разделить на искажения навигационного поля за счет переотражения навигационного сигнала от искусственных объектов и за счет ограничения видимости горизонта. Данные искажения «разрушают» навигационное поле ГНСС. В такой ситуации даже по заранее известны характеристикам каналов навигационных сигналов наблюдается крайне низкий уровень полезного сигнала (минус 161…155 дБВт).*

Заключение. *В статье приведены основные положения математической модели определения точности координат положения объекта со спутников в декартовых координатах. Рассмотрен процесс накопления ошибок позиционирования объекта. Сделаны выводы о параметрах ошибок, влияющих на точность позиционирования объекта, относительно уровня сигнала, принимаемого со спутника.*

Данные исследования выполнены при поддержке научного проекта «Разработка роботизированного беспилотного летательного аппарата мультироторного типа с использованием бесплатформенной инерциальной навигационной системы» Федеральной Целевой Программы на 2014-2020 годы (уникальный идентификатор RFMEFI57818X0222) при финансовой поддержке Министерства Науки и Высшего Образования России, на базе ЦКП СКФУ.

Ключевые слова: матрица положения, матрица точности позиционирования, дисперсия, средняя квадратическая погрешность, GPS, ГЛОНАСС.

Annotation. *Robotic unmanned aerial vehicles (RBLA) are widely used in the military, mainly in intelligence. Large vehicles can be equipped with weapons and conduct combat operations.*

Materials and methods. *The use of RBLA for civilian purposes can also be very effective (monitoring forest fires, drawing up topographic maps, etc.). The method of determining the position and orientation of the device in space during its flight plays an Important role. Most often, GPS/GLONASS positioning systems are used for this purpose. However, using such positioning technologies may be difficult or impossible. The operation of such systems can be disrupted as a result of targeted suppression or due to distortion of the navigation field due to re-reflection of the navigation signal from artificial objects and by limiting the visibility of the horizon. The GPS/GLONASS signal may not be available due to mountainous terrain or urban buildings. The use of GPS/GLONASS may not be acceptable due to secrecy or lack of accuracy. Therefore, the development of UAV positioning systems that are independent of satellite navigation systems data is an important research area.*

Results and discussions. *A promising way to solve this problem is to develop an algorithm for determining the initial coordinates of the RBLA in conditions of distortion of the navigation field due to re-reflection of the navigation signal from artificial objects and by limiting the visibility of the horizon. Global navigation satellite systems (GNSS) are the main means of navigation for many mobile systems and, in particular, for modern robotic unmanned aerial vehicles. However, GNSS receivers used in rbla navigation systems have extremely low noise immunity, which consequently limits their use in complex radio-electronic conditions. Almost all types of interference to GNSS signals can be divided into distortions of the navigation field due to re-reflection of the navigation signal from artificial objects and by limiting the visibility of the horizon. These distortions "destroy" the GNSS navigation field. In this situation, even if the characteristics of the navigation signal channels are known in advance, there is an extremely low level of the useful signal (minus 161...155 dBW).*

Conclusion. *The article presents the main provisions of the mathematical model for determining the accuracy of the coordinates of the object's position from satellites in Cartesian coordinates. The process of accumulating object positioning errors is considered. Conclusions are made about error parameters that affect the accuracy of object positioning, relative to the signal level received from the satellite.*

These studies were carried out with the support of the scientific project "Development of a multirotor type robotic unmanned aerial vehicle using a strapdown inertial navigation system" of the Federal Target Program for 2014-2020 (unique identifier RFMEFI57818X0222) with the financial support of the Ministry of Science and Higher Education of Russia, based on the NCFU Central research center.

Key words: position matrix, positioning accuracy matrix, variance, mean square error, GPS, GLONASS.

Introduction. When determining the position of an object in Cartesian coordinates, special signals are used. Each GPS satellite constantly transmits navigation messages containing, in particular, the coordinates of the satellite at the time of sending the message and the time of sending. A GNSS receiver receiving such a message from a satellite navigation system (SNS) can calculate the distance to the satellite:

$$d = (t^{(\text{пр})} - t^{(\text{отпр})}) \cdot \text{с}. \quad (1)$$

In this formula, the transit time of the signal (from the time of sending $t^{(\text{отпр})}$ to the time of receiving $t^{(\text{пр})}$) multiplied by the speed of propagation of the radio signal, i.e. the speed of light *c*.

The geometric interpretation of the system for determining the position of an object in Cartesian coordinates is as follows. A message in the form of a signal area from one satellite selects a part of the space in which the consumer is located - a sphere determined by its center-satellite and radius. The information from the second satellite is another sphere of the signal space. The message from the third satellite adds more parameters of the signal space and uniquely determines the coordinates using the method of comparison. The condition that all three spheres have a common point follows from the design of the navigation system itself. Of the two solutions (intersections of the circle and the third sphere), one is implausible, and the second contains the true coordinates of the object's position in Cartesian coordinates.

Thus, the problem of determining the initial coordinates of an UAV under conditions of distortion of the navigation field due to re-reflection of a signal from artificial objects and by limiting the visibility of the horizon is relevant and significantly affects the efficiency of processing GPS / GLONASS data and the accuracy of determining the location of objects (for example, unmanned aerial vehicles).

It is necessary to develop a methodology that allows determining the initial location of the SSV, assessing the quality of the navigation signal, for making a decision on entering the initial coordinates into the inertial navigation system (SINS) in conditions of shading and receiving the reflected signal from the SNS.

Materials and methods. In [1–4], methods are given that allow determining the initial location of an SSV, but do not explain the effect of satellite geometry on the accuracy of object positioning.

Figure 1 shows the distances R_i (i = 1…4) from satellites to the user.

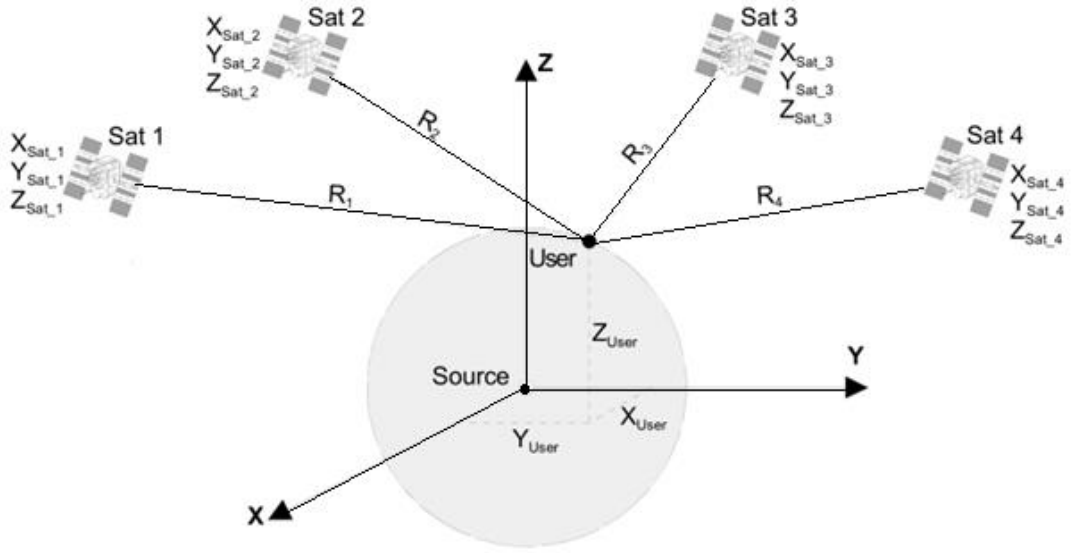

Fig. 1. Description of the satellite and the position of the UAV in Cartesian coordinates

Distances R_i (i = 1…4) can be determined using the formula:

$$R_i = \sqrt{(X_{Sat\_i} - X_{User})^2 + (Y_{Sat\_i} - Y_{User})^2 + (Z_{Sat\_i} - Z_{User})^2}. \quad (2)$$

Using the coordinates shown in Figure 1, we obtain the position matrix P [] of the object in Cartesian coordinates:

$$P = \begin{bmatrix} \frac{X_{User} - X_{Sat\_1}}{R_1} & \frac{Y_{User} - Y_{Sat\_1}}{R_1} & \frac{Z_{User} - Z_{Sat\_1}}{R_1} & 1 \\ \frac{X_{User} - X_{Sat\_2}}{R_2} & \frac{Y_{User} - Y_{Sat\_2}}{R_2} & \frac{Z_{User} - Z_{Sat\_2}}{R_2} & 1 \\ \frac{X_{User} - X_{Sat\_3}}{R_3} & \frac{Y_{User} - Y_{Sat\_3}}{R_3} & \frac{Z_{User} - Z_{Sat\_3}}{R_3} & 1 \\ \frac{X_{User} - X_{Sat\_4}}{R_4} & \frac{Y_{User} - Y_{Sat\_4}}{R_4} & \frac{Z_{User} - Z_{Sat\_4}}{R_4} & 1 \end{bmatrix}. \quad (3)$$

Required:

1. Determine the indicators describing the influence of satellite geometry on the positioning accuracy of the object Ri.

2. To develop a methodology for determining the initial coordinates of an UAV in conditions of distortion of the navigation field due to re-reflection of the navigation signal from artificial objects and due to limiting the visibility of the horizon.

Results and discussion. Applying sequentially the transposition of the position matrix, multiplication and inversion, we calculate the inverse matrix DOP D [1], designed to determine the influence of satellite geometry on the positioning accuracy of an object:

$$D = \left[[P]^T \bullet [P] \right]^{-1}. \quad (4)$$

Using the matrix calculation rules, the 16 elements of the DOP D matrix are denoted as follows:

$$D = \begin{bmatrix} D_{11} & D_{12} & D_{13} & D_{14} \\ D_{21} & D_{22} & D_{23} & D_{24} \\ D_{31} & D_{32} & D_{33} & D_{34} \\ D_{41} & D_{42} & D_{43} & D_{44} \end{bmatrix}. \quad (5)$$

The following DOP indicators are known that describe the effect of satellite geometry on the positioning accuracy of an object [1, 3]:

– GDOP (Geometric DOP): describes the effect of satellite geometry on positions in 3D space and time;

– PDOP (Positional DOP): describes the effect of satellite geometry on positions in 3D space;

– HDOP (horizontal DOP): describes the effect of satellite geometry on position in plane (2D);

– VDOP (Vertical DOP): describes the effect of satellite geometry on altitude (1D);

– TDOP (Time DOP): describes the effect of satellite geometry on time measurement.

The general error in the position of the UAV is determined by the accumulation of errors of the factors considered above, and they, in turn, can be calculated from the elements of the matrix DOP D as follows:

$$GDOP = \sqrt{D_{11} + D_{22} + D_{33} + D_{44}}. \quad (6)$$

$$PDOP = \sqrt{D_{11} + D_{22} + D_{33}}. \quad (7)$$

$$HDOP = \sqrt{D_{11} + D_{22}}. \quad (8)$$

$$VDOP = \sqrt{D_{33}}. \quad (9)$$

$$TDOP = \sqrt{D_{44}}. \quad (10)$$

Therefore, in the case when the elements of the DOP matrix D (5) are known, it is possible to determine the DOP indicators describing the effect of satellite geometry on the object positioning accuracy R_i. These parameters are functions of the corresponding covariance matrices of elements in the global or local geodetic coordinate system. They can be obtained mathematically from the position of the available satellites (navigation signal sources). Many GNSS receivers allow you to display the current location of all satellites ("satellite constellation") along with DOP values.

The method for determining the initial coordinates of an SSV in conditions of distortion of the navigation field due to re-reflection of the navigation signal from artificial objects and due to limiting the visibility of the horizon is as follows:

1. Based on the received signals, it is necessary to compose a matrix of positions P [] of the object in Cartesian coordinates (formula (3)).

2. Calculate the matrix of the influence of satellite geometry on the positioning accuracy of the DOT object according to the formula (5).

3. Determine the DOP indicators according to formulas (6) - (10).

4. Check the accuracy of the assessment of the initial coordinates of the ballistic missile system according to the ratios:

$$PDOP^2 = HDOP^2 + VDOP^2 \text{ и } GDOP^2 = PDOP^2 + TDOP^2. \quad (11)$$

The source [1] shows that the accuracy of measuring the location of an object is proportional to the DOP values. This means that when the DOP value is doubled, the object location error also doubles. The following relationships apply:

– error R_i (1σ) = 1* Total RMS * value DOP;

– error R_i (2σ) = 2* Total RMS * value DOP;

– RMS (Root Mean Square) - root mean square error.

Table 1 shows the types of horizontal errors depending on the mean square error (1σ = 68 %, 2σ = 95 %) with HDOP = 1.3.

Long-term measurements, available from the US FAA, showed that 95% of all measurements had horizontal and vertical errors less than 7.4 and 9.0 m, respectively. The time period for the measurement was 24 hours [1].

In the source [1], the DOP value is defined as the reciprocal of the volume of the tetrahedron, composed of the position of the satellites and the user (Figure 2, volume indicator).

When modeling various situations and drawing up a methodology, the following conclusion was made: the larger the internal volume of the tetrahedron, the lower the DOP value.

Table 1

Types of horizontal errors with HDOP = 1.3

Error type	Error
Total RMS	4 м
Horizontal error Ri (1σ = 68%, HDOP = 1.3)	6 м
Horizontal error Ri (2σ = 95%, HDOP = 1.3)	12 м

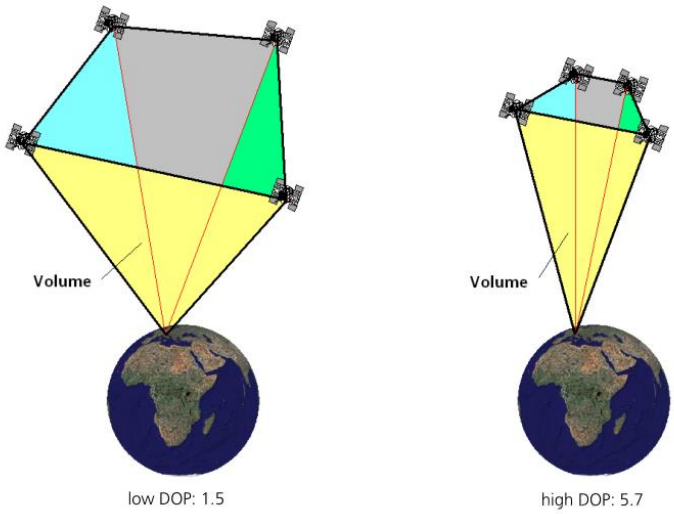

Fig. 2. Influence of satellite geometry on the positioning accuracy of the object (RBV)

Studies have shown that with open and free areas (no shading), the satellite communication area is favorable for DOP values, and they rarely exceed 3 (Figure 3).

In mountainous areas, forests and urban areas, the DOP values, in contrast to the cases discussed above, have values much greater than one, which makes it difficult to determine the position of an object in space.

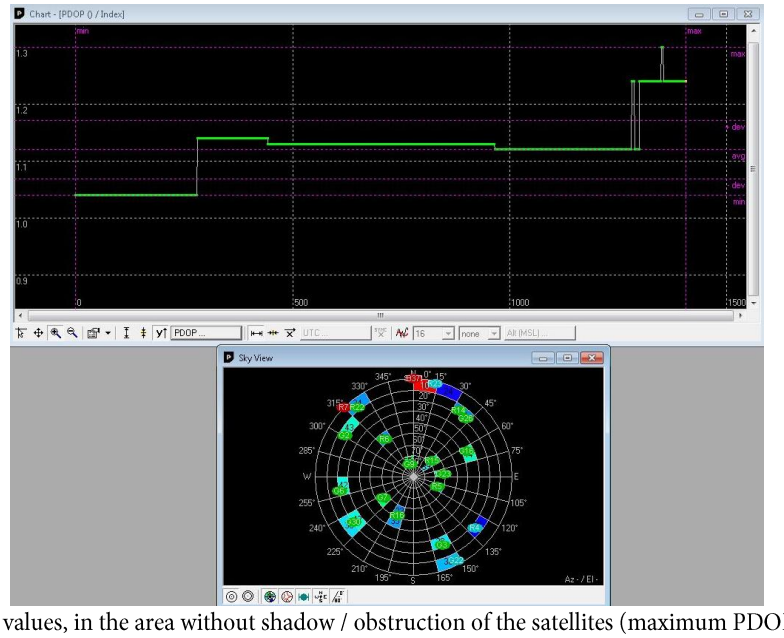

Fig. 3. HDOP values, in the area without shadow / obstruction of the satellites (maximum PDOP value <1.4)

Figures 3 and 4 show the cases of PDOP change in the absence (maximum PDOP less than 1.9) and presence of obstructions (maximum PDOP greater than 20) satellite visibility, respectively. In the experiment for Figure 4, the western area is shaded by a tall building.

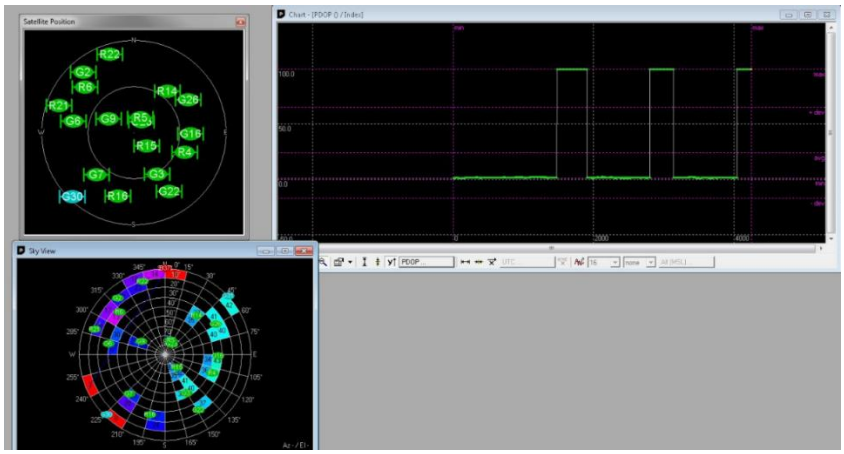

Fig. 4. PDOP values, high shadow / obstruction of satellites (maximum PDOP> 20)

In the case of strong shading (Figure 4), the temporary ability to determine the position of the object with the required accuracy (DOP <2) is rather small and has a random nature.

For accurate measurements, it is recommended in [4] that time periods with DOP values above 6 should not be used for accurate measurements.

DOP values can be estimated based on the current position of the constellation of satellites [2, 3].

During the experiment, the calculated DOP values coincided with the measured ones, which confirms the correctness of the developed technique. In order to actualize the determination of the initial coordinates of the UAV experimentally in conditions of distortion of the navigation field due to re-reflection of the navigation signal from artificial objects and with limited visibility of the horizon, studies were carried out when the location of navigation satellites is shown in Figure 5, where the western side is shaded.

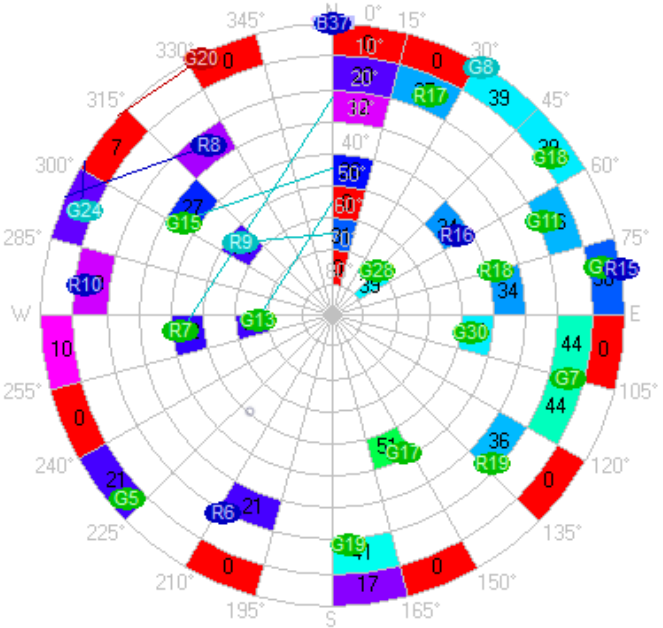

Fig. 5. Location of navigation satellites during the experiment

The figure shows that satellites G15, G13, G5 and R7 are out of line of sight of the antenna of the navigation receiver, nevertheless, the data from these satellites take part in the formation of the navigation solution. Their signals are reflected from the metal roof of a nearby building, thereby introducing an error in determining the coordinates of the location.

The received signal is characterized by a step change in level from 20 to 33 dbHz. The satellites listed above are periodically automatically excluded by the GNSS receiver from the navigation solution.

For comparison, the signal strength of the G17 satellites is 43-50 dbHz,

G1 44–46 dbHz, which are in line of sight.

In the course of the experiment, it was determined that another characteristic sign of the reception of the reflected signal is an abrupt change in the estimate of the decrease in the accuracy of the received GDOP signal from 1.45 to 2.9, which can be observed in the interval in 10-12 minutes.

Under normal conditions, the GDOP parameter changes slowly, the rate of its change is commensurate with the time of change of visible satellites above the horizon.

Based on the analysis and experiment performed, it is possible to conclude that an increase in HDOP of more than 2 is a necessary, but not sufficient condition for the distortion of the navigation field. The analysis should also include the received signal strength of a particular satellite, as well as the rate of change of the GDOP parameter.

Thus, it is necessary to determine the initial position of the UAV, assess the quality of the navigation signal, make a decision on the algorithm for the correction of the onboard SINS during takeoff and landing in conditions of shading and the possible reception of the reflected signal from the SNS.

Possible conditions are:

1. The received signal can be used to initialize the SINS and determine the position of the UAV with high accuracy.

2. It is possible to determine the location of the UAV with reduced accuracy.

3. It is possible to determine the position of the UAV with a large error.

An analysis of a full-scale experiment showed that in order to achieve the maximum accuracy in determining coordinates during the preparation of an UAV for takeoff, it is recommended to carry out a tolerance control of the dispersion of the carrier-to-noise ratio of the navigation radio signal received from the satellites by the GNSS receiver.

If there are at least 7 satellites with normal dispersion indices, and when the HDOP, GDOP parameters are in tolerance, it is necessary to record the navigation parameters into an array containing the fields: longitude, latitude, altitude, HDOP parameter, GDOP parameter. This array will contain navigation parameters with the best indicators of the accuracy of determining the coordinates of the aircraft.

If the HDOP or GDOP indicators do not meet the specified requirements, but the received navigation radio signal from at least 7 satellites meets the requirements for the carrier-to-noise ratio, in this case the navigation parameters recorded in the array will meet the reduced requirements for position determination accuracy UAV.

In the presence of a navigation radio signal satisfying a given carrier-to-noise ratio from less than 7 satellites, the navigation data recorded in the array will determine the position with a low accuracy in determining the position of the ballistic missile. In this case, the following solutions to this problem are possible:

1. Change the launch site of the UAV.

2. Carry out the determination of the initial coordinates using other methods, for example, electronic maps using known landmarks on the ground. Further, it is necessary to load the obtained coordinates into SINS. In this case, it is necessary to estimate the vertical take-off altitude of the SSV in order to leave the zone of the distorted navigation field. During takeoff, the SINS correction from the SNS receiver should not be performed.

In the SNS receiver [4,5], it is possible to use models for calculating navigation parameters depending on the dynamics of objects.

When working with loads <1 g, the model for calculating coordinates assumes a highly dynamic object that can change its speed with an acceleration of up to 1 g, as a result of this the spread of coordinates given by the receiver at rest will be large. When switching to a stationary dynamic platform model, the variance of the generated coordinates will be small.

The dynamic model "Aviation <1 g" is working for UAV. The use of the "stationary" dynamic platform model in determining the coordinates of the initial position will significantly reduce the variance of the initial position coordinates obtained from the SNS receiver.

The operation of the algorithm involves several stages:

1. The stage of configuration of the SNS receiver to work with the model of a stationary object. At this stage, the dynamic model is switched, which is used to estimate the coordinates of the location and check the correctness of the switch.

2. Stage of assessment of the received parameters. The variance is assessed:

– CNO ratio – carrier / noise, for the navigation signal received from satellites;

– HDOP – factor of decrease in the accuracy of determining coordinates in the horizontal plane;

– GDOP – geometrical factor of decrease in coordinate determination accuracy.

3. The stage of dividing the received coordinates depending on the characteristics of HDOP, GDOP and CNO, and writing data to arrays.

4. The stage of determining the accuracy of the navigation data provided for the SINS initialization. At this stage:

– a decision is made on the availability of UAV position data;

– depending on the parameters of the received signals, the accuracy factor of the navigation solution is established;

– a data readiness signal is generated for SINS initialization;

– if it is impossible to determine the coordinates with a given accuracy, a message is issued to the operator to make a decision about another method of initial SINS initialization.

5. The stage of switching the used dynamic platform to "Aviation <1 g" and checking the correct switching.

Conclusions. In this paper, we propose a method for determining the initial coordinates of an SSV under conditions of distortion of the navigation field due to re-reflection of the signal from artificial objects and due to limiting the visibility of the horizon.

The technique, presented in the form of a sequence of actions and equations (5–11), makes it possible to determine the initial location of the ballistic missile system, to assess the quality of the navigation signal, to make a decision on entering the initial coordinates into the SINS under shading conditions and receiving the reflected signal from the SNS. It is based on the use of the HDOP and GDOP parameters, which make it possible to form the initial navigation parameters for loading into the SINS with the best indicators in determining the accuracy of the coordinates of the SSV, in the presence of at least 7 satellites with normal carrier-to-noise ratio.

A feature of this technique is that an onboard GNSS receiver is used as a meter for HDOP and GDOP parameters.

On the basis of the technique, an algorithm has been developed for estimating the parameters of the received navigation signal, which makes it possible to identify the fact of distortion of the navigation field, to minimize the errors that arise when determining the initial coordinates of the ballistic missile.

The estimation of the accuracy of determining the coordinates of a location has three states. The coordinates of the initial location determined by the algorithm can be used to initialize the SINS:

– with high precision;

– with reduced accuracy;

– with a large margin of error.

In the latter case, it is necessary to change the place of the planned take-off of the RBVA. Or estimate the altitude at which the conditions of distortion of the navigation field will be eliminated due to re-reflection of signals or shading of the line of sight of the satellite. After initialization with parameters of low accuracy, take off in the SINS autonomous mode. Turn on the correction after leaving the area of distortion of the navigation field.

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СИСТЕМНЫЙ ПОДХОД К ОЦЕНКЕ ОРГАНИЗАЦИОННОЙ СЛОЖНОСТИ ИНДЕКСА СТОИМОСТИ

SYSTEM APPROACH TO THE ESTIMATION OF THE ORGANIZATIONAL COMPLEXITY OF THE COST INDEX

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Аннотация. *В современных условиях возрастает роль методов и показателей статистики, характеризующих структуру совокупности, как форму организации системы, состоящей из отдельных элементов и связей между ними.*

В статье статистическая совокупность индивидуальных индексов стоимости впервые рассматривается как система, обладающая функциональной и структурной организацией.

Цель. *Показать, что компетентное использование статистической совокупности как системы, проводимое в рамках функционально-структурного подхода, позволяет представить сводный индекс стоимости как пересечение множеств функционального и структурного атрибутов.*

Задачи. *Для достижения поставленной цели были решены следующие задачи: выделены функциональный и структурный элементы совокупности; сводный индекс стоимости представлен в виде структурной формулы; установлен принцип жёсткой детерминированной пропорциональности между функциональным и структурным атрибутами; обоснован выбор расчёта средних значений функционального и структурного атрибута.*

Материалы и методы. *В работе использовались традиционные методы математического анализа множеств, статистические методы, методы исследования операций, обобщения, систематизации статистических данных, методы теории принятия решений.*

Результаты и обсуждения. *Доказано, что без учёта структурной составляющей собственная сущность сводного индекса стоимости познана быть не может. Обоснована возможность комплексной оценки функциональной и структурной организации совокупности индексов стоимости как таковой. Показано, что организация совокупности будет соответствовать состоянию Парето – оптимальности при равенстве оценок функциональной и структурной составляющих.*

Выводы. *Чем ближе фактическая оценка организационной сложности совокупности к состоянию Парето – оптимальности, тем гармоничнее, совершеннее организация совокупности, тем качественно однороднее сама совокупность и возможности её интерпретации в практических целях.*

Ключевые слова: индекс доли, коэффициент изменения структуры, многообразие элементной базы, функциональная и структурная организация, групповые и межгрупповые связи, Парето-оптимальность.

Abstracts. *In modern conditions, the role of statistical methods and indicators that characterize the structure of a summation as a form of organization of a system consisting of individual elements and links between them is increasing.*

In the article, the statistical set of individual cost indices is considered for the first time as a system that has a functional and structural organization.

Goal. *To show that the competent use of the statistical summation as a system, carried out within the framework of the functional-structural approach, allows us to present the composite cost index as the intersection of sets of functional and structural attributes.*

Tasks. *To achieve this goal have been resolved following tasks: identified functional and structural elements together; the composite index value is represented in a structural formula, the principle of strict deterministic relationship between functional and structural attributes; the choice of averaging of functional and structural attribute.*

Methodology. *The paper uses traditional methods of mathematical analysis of sets, statistical methods, methods of operations research, generalization, systematization of statistical data, methods of decision theory.*

Results. *It is proved that without taking into account the structural component, the intrinsic essence of the composite value index cannot be known. The possibility of a comprehensive assessment of the functional and structural organization of a set of cost indices as such is substantiated. It is shown that the organization of the summation will correspond to the state of Pareto – optimality when the estimates of the functional and structural components are equal.*

Conclusions. *The closer the actual assessment of the organizational complexity of the aggregate to a state of Pareto optimality, more harmonious, more perfect organization together, the qualitatively homogeneous itself the totality and the possibility of its interpretation for practical purposes.*

Key words: share index, structure change coefficient, element base diversity, functional and structural organization, group and intergroup relations, Pareto-optimality.

Introduction. A statistical summation is a set of relatively homogeneous elements taken together within specific boundaries of time and space and possessing signs of similarity and difference. A statistical summation has certain properties: indecomposability (a statistical summation is always homogeneous in at least one attribute) and variation (quantitative changes in the value of a statistical attribute when one of its elements passes into another). Between the functional and structural components of the organization of the aggregate, the principle of rigid deterministic proportionality operates, reflecting the consistency of the goals of the functional and structural elements of the aggregate with its main goal - the formation of a composite value index.

Assessing the complexity of organizing a composite cost index based on the Pareto-optimality principle makes it possible to determine the proximity of a set of individual cost indices to the optimal state. One of the relative characteristics that take into account the structural changes that have occurred in the aggregate of values is the ratio of the shares of the elements of the aggregate, represented by the formula:

$$i_d = \frac{d_{11}}{d_{00}} = \frac{q_1p_1}{\sum q_1p_1} \div \frac{q_0p_0}{\sum q_0p_0} = \frac{q_1p_1}{q_0p_0} \div \frac{\sum q_1p_1}{\sum q_0p_0} = \frac{i_v}{I_v} \quad (1)$$

where $d_{11} = \frac{q_1p_1}{\sum q_1p_1}$ – the share of the cost of an individual product (q_1p_1) in the total cost of the summation ($\sum q_1p_1$) of the current («1») period;

$d_{00} = \frac{q_0p_0}{\sum q_0p_0}$ – share of the cost of the same product (q_0p_0) in the total cost summation ($\sum q_0p_0$) on the base («0») period;

$i_v = \frac{q_1p_1}{q_0p_0}$ – individual index of the cost of an individual product;

$I_v = \frac{\sum q_1p_1}{\sum q_0p_0}$ – composite index of the value of the entire summation;

i_d – the index of the share (structural changes), which characterizes the relative change in the share of the value of an individual commodity in the aggregate in period "1" compared to period "0".

Relation (1) has not found wide application either in statistical theory or in practice due to the fact that the analysis of structural changes using such a simple technique does not provide a comprehensive characteristic of structural changes in the studied summation, does not allow describing the phenomenon as a whole [6, p. 76]. Therefore, when studying structural changes, preference is given to indicators of absolute change in the proportion. Stochastic and vector approaches [4], coefficients of structural shifts by L. Kazinets [1], K. Gatev, A. Salai [2], V. Ryabtsev [3] and others [7] are well-known examples of calculating the absolute change in the proportion.

In our opinion, the methodological potential inherent in formula (1) is much greater than one might imagine. Let's take a closer look at this. Composite index I_v, expressed in terms of fractions of elements of aggregates of value "0" of the period (d_{00}) and «1» of the period (d_{11}), is defined as follows:

$$I_v = \frac{\sum V_{1j}}{\sum V_{0j}} = \frac{V_{11} + V_{12} + \ldots + V_{1j} + \ldots + V_{1n}}{\sum V_{0j}}$$

Assuming $\frac{V_{1j}}{V_{0j}} = i_{vj}$, we find $v_{1j} = i_{vj} \cdot v_{0j}$ и $v_{0j} = \frac{V_{1j}}{i_{vj}}$

Then

1) $I_v = \frac{\sum V_{1j}}{\sum V_{0j}} = \frac{i_{v1} \cdot V_{o1} + i_{v2} \cdot V_{o2} + \ldots + i_{vj} \cdot V_{oj} + \ldots + i_{vn} \cdot V_{on}}{\sum V_{0j}}$

But $\frac{V_{oj}}{\sum V_{0j}} = d_{oj}$

So, $I_v = \frac{\sum V_{1j}}{\sum V_{0j}} = \sum i_{vj} \cdot d_{oj}$

2) $I_v = \frac{\sum V_{1j}}{\sum V_{0j}} = \frac{\sum V_{1j}}{\frac{V_{11}}{iv_1} + \frac{V_{12}}{iv_2} + \cdots + \frac{V_{1j}}{iv_j} + \cdots + \frac{V_{1n}}{iv_n}} =$

$$= \frac{1}{\frac{V_{11}}{iv_1 \cdot \sum V_{1j}} + \frac{V_{12}}{iv_2 \cdot \sum V_{1j}} + \cdots + \frac{V_{1j}}{iv_j \cdot \sum V_{1j}} + \cdots + \frac{V_{1n}}{iv_n \cdot \sum V_{1j}}} = \frac{1}{\sum \frac{d_{1j}}{iv_j}}$$

But $\frac{V_{1j}}{\sum V_{1j}} = d_{1j}$

So, $I_v = \frac{\sum V_{1j}}{\sum V_{0j}} = \frac{1}{\sum \frac{d_{1j}}{iv_j}}$

We denote $d_{oj} = d_{00}$, $d_{1j} = d_{11}$ and get:

$$I_v = \frac{\sum q_1 p_1}{\sum q_0 p_0} = \sum i_v \cdot d_{00} = \frac{1}{\sum \frac{d_{11}}{i_v}} \quad (2)$$

Let us transform formula (2) into a structural formula that shows the change in the "contribution" of individual elements and (or) groups of value aggregates to the formation of the composite index I_v.

$$1 = \frac{\sum i_v \cdot d_{00}}{I_v} = \frac{1}{I_v \cdot \sum \frac{d_{11}}{i_v}} \quad (3)$$

Since for the aggregates of the value of period "0" and period "1" the composite index is a constant value, then using formula (1), we can represent formula (3) in the form

$$SI_{v00} = \sum \frac{i_v \cdot d_{00}}{I_v} = \sum i_d \cdot d_{00} = \sum d_{11} = \sum contr\ d_{00} = 1 \quad (4)$$

or

$$SI_{v11} = \sum \frac{I_v \cdot d_{11}}{i_v} = \sum \frac{d_{11}}{i_d} = \sum d_{00} = \sum contr\ d_{11} = 1 \quad (5)$$

Formula (4) shows that the structure of the composite index I_v in estimates "0" of the period (SI_{v00}) is completely determined by the structure of the aggregate of values in the period «1» ($\sum d_{11}$).

Formula (5) shows that the structure of the composite index I_v in estimates "1" of the period (SI_{v11}) absolutely adequate to the structure of the aggregate values in the "0" period ($\sum d_{00}$).

Therefore, between changes to the structure of the composite index I_v and changes in the structure of the aggregate of values, there is a feedback, namely: if the share of any element of the aggregate of values in the "1" period compared to the "0" period changes n times, then the contribution of this element to the formation of the structure of the composite index I_v will change in $1/n$ times.

Based on this, formula (1) can be represented as

$$i_d = \frac{d_{11}}{d_{00}} = \frac{contr\ d_{00}}{contr\ d_{11}} = \frac{i_v}{I_v} \quad (6)$$

From here we find

$$I_v = \frac{i_v}{i_d} = i_v \cdot \frac{contr\ d_{11}}{contr\ d_{00}} = i_v \cdot \alpha_s \quad (7)$$

where $\alpha_s = \frac{contr\ d_{11}}{contr\ d_{00}}$ – structural change ratio of the composite index I_v, showing the level of difference of the structure of the composite index in the estimates of "1" period from the structure of the composite index in the estimates of "0" of the period.

$contr\ d_{11} = \frac{I_v \cdot d_{11}}{i_v} = d_{00}$ - contribution of an element of a set of values to a structure SI_{v11} of a composite cost index.

$contr\ d_{00} = \frac{i_v \cdot d_{00}}{I_v} = d_{11}$ – contribution of an element of a set of values to a structure SI_{v00} of a composite cost index.

As a result, we get

$$I_v = \frac{\sum q_1 p_1}{\sum q_0 p_0} = \frac{i_{vj}}{i_{dj}} = i_{vj} \cdot \alpha_{sj} = c \quad (8)$$

From formula (8) it follows that the composite cost index, represented by modern index theory as a result of dividing the total sums of two sets of values $I_v = \frac{\sum q_1 p_1}{\sum q_0 p_0}$, can be defined for any data item of the aggregates or as the quotient of dividing the individual cost index i_v on the relative change in the share of this element in the aggregate values i_d; or as the product of the individual cost index by the coefficient α_s, characterizing the relative change in the structure of the composite index itself.

Hence, if the share of j-element in the aggregate values "1" of the period (d_{11}) less than its share in the aggregate values "0" of the period (d_{00}), then the significance of this element in the structure of the composite index, expressed in estimates "1" of the period ($contr\ d_{11}$), more than its share in the structure of the composite index, expressed in estimates of "0" period ($contr\ d_{00}$).

For $d_{11} > d_{00}$ we have an inverse relationship $contr\ d_{11} < contr\ d_{00}$.

Thus, formula (8) reflects the principle of rigid deterministic proportionality inherent in any j-element set of cost indices. Principle emphasizing the need to align the goals of the elements of the summation (i_{vj} и i_{dj}) with its main purpose (I_v), as well as the need for a certain ratio between the parts of the whole ($i_{vj}/i_{dj} = i_{vj} \cdot \alpha_{sj} = const$).

The revealed principle of proportionality allows us to consider the composite value index as a set of interrelated elements, united by the unity of goals and functional integrity. That is, as a system that has all the necessary features: the integrity and segmentation of the object, stable connections between the elements of the system (i_{vj} и i_{dj}) and integrative qualities inherent in the system as a whole, but not inherent in its elements separately (average values i_{vj} and i_{dj}) [11, c. 19-21].

Then we can talk about the functional and structural organization (organization) of the aggregate of the composite index. Note that it is the issues related to the difference in the levels of the structural and functional organization of the studied systems, the criteria for their selection, consideration of connections, interactions and mutual transitions that occupy a central place in system analysis [11, p. 15].

By functional organization we mean a set of functions and connections between them. The functional organization of the composite index, represented by many individual indices i_v, reflects the purpose of the system, what it is for. This organization is the most essential characteristic of the system, for the concept of function is closest to the concept of the goal, for the sake of which the system is created.

By structural organization we mean a general idea of the shape, location and number of parts of the system and their interconnections. Structural organization of the composite index, represented by many individual indexes i_d and α_s, characterizes the invariant aspect of the composition of the system and represents the stable ordering of its elements and connections between them.

The functional and structural organization of the system influence each other and are in such a dialectical relationship that it is difficult to establish a one-to-one correspondence between the functions being implemented and the structure of the system. For example, from the standpoint of the structural-functional approach to the creation (analysis) of systems existing in the theory of systems, the primacy of the structural aspect of organization is assumed in the sense that in its absence the system disappears. On the other hand, the functional-structural approach, on the contrary, is based on the assumption that the functional purpose of the system is primary in relation to its structural organization [11, p. 49-51].

The authors adhere to the latter point of view: in the relationship between function and structure, the leading role is assigned to the function (functional organization), and the structure (structural organization) is transformed, modified in accordance with the implemented functions, while remaining unchanged (in terms of the composition of the system) in relation to any internal transformations. In this case, the main emphasis, as it should be in the systemic approach, is made on the integrative properties of the object and its integrity; identifying the variety of connections and relationships between individual elements of the object, their group and intergroup relationships.

At least three fundamental properties of this aggregate follow from the principle of proportionality characteristic of the aggregate of the composite value index of any level of the structural and functional organization:

If the composite value index is more (less) than one, then for all members of a given summation, without exception, the individual functional index (value index) will be more (less) than the corresponding individual structural index (share index), that is, at $I_v > 1$ we always have $i_{vj} > i_{dj}$; at $I_v < 1$, on the contrary, we have $i_{vj} < i_{dj}$;

1. If in a given set at least one individual functional index of value is greater (less) than the corresponding individual structural index of the share, then this inequality will, without exception, be inherent in the rest of the individual indexes of value and the corresponding individual indexes of the share; as well as the fact that the composite index of the summation will be more (less) than one. That is, if $i_{vj} > i_{dj}$, so $i_{v1} > i_{d1}$, $i_{v2} > i_{d2}$, …, $i_{vn} > i_{dn}$ and $I_v > 1$. If $i_{vj} < i_{dj}$, so $i_{v1} < i_{d1}$, $i_{v2} < i_{d2}$ …, $i_{vn} < i_{dn}$ and $I_v < 1$;

2. If one individual functional value index is greater than the corresponding individual structural share index, for example, $i_{vj} > i_{dj}$, and the other individual functional value index is less than the corresponding individual structural share index, for example, $i_{vk} < i_{dk}$, then these indices belong either to different groups of the same summation and we are dealing with group indices, or the indices belong to different collections.

Consequently, the principle of proportionality inherent in formula (8) makes it possible to "philosophically" perceive the set of value indices as a set of unity (in the form of a composite value index) and diversity (in the form of individual functional value indices and structural share indexes), which are internally and inextricably linked between themselves.

Based on formula (8), we represent the variety of the element base of the set of functional cost indices in the form of a system of equations

$$\begin{cases} i_{v1} = I_v \cdot i_{d1} \\ i_{v2} = I_v \cdot i_{d2} \\ \dots\dots\dots\dots\dots\dots \\ i_{vn} = I_v \cdot i_{dn} \end{cases}$$

Then the average functional cost index $\overline{ci_v}$ for a given summation can be determined by the geometric mean simple formula as

$$\overline{ci_v} = \sqrt[n]{i_{v1} \cdot i_{v2} \cdot \dots \cdot i_{vn}} = I_v \cdot \sqrt[n]{i_{d1} \cdot i_{d2} \cdot \dots \cdot i_{dn}} = I_v \cdot \overline{i_d}$$

where $\overline{i_d} = \sqrt[n]{i_{d1} \cdot i_{d2} \cdot \dots \cdot i_{dn}}$ – geometric simple mean of the structural index of the proportion.

Hence we get

$$I_v = \frac{i_{v1}}{i_{d1}} = \frac{i_{v2}}{i_{d2}} = \dots = \frac{i_{vn}}{i_{dn}} = \sqrt[n]{\frac{i_{v1} \cdot i_{v2} \cdot \dots \cdot i_{vn}}{i_{d1} \cdot i_{d2} \cdot \dots \cdot i_{dn}}} = \overline{ci_v} / \overline{i_d} \quad (9)$$

Thus, the diversity of the element base of the set of functional value indices and structural share indices is reflected in the presentation of the composite index in the form of a generalizing formula for the geometric mean.

Selecting a geometric mean formula for calculating values $\overline{ci_v}$, $\overline{i_d}$ and I_v dictated by two fundamental considerations. First, formula (9) can be represented as follows:

$$I_v = \frac{\sum q_1 p_1}{\sum q_0 p_0} = \overline{ci_v} / \overline{i_d} = \overline{ci_v} \cdot \overline{\alpha_d} = const \quad (10)$$

It is well known from the general theory of statistics that "if, when replacing individual indices with an average value, it is necessary to keep the product of individual values unchanged, then the geometric average should be used" [5, p. 77].

Secondly, the calculation methods based on the geometric mean formula reflect a higher stability in relation to errors [4, p. 62].

If we now arbitrarily group the set of functional (individual) cost indices, highlighting in it *k-th* number of groups with *m* elements in each group, then the summary index of the summation I_v can be represented as the geometric mean weighted from the geometric mean group value indices.

For example, we have a set of cost indices, numbering seven elements (n=7). The summation is divided into groups A and B (k=2). Group A consists of two elements ($m_A = 2$). Group B consists of five elements ($m_B = 5$). Then we get

– composite index of the summation equal to

$$I_v = \frac{\sum q_1 p_1}{\sum q_0 p_0} = \sqrt[7]{\left(\frac{i_{v1} \cdot i_{v2} \cdot}{i_{d1} \cdot i_{d2} \cdot}\right) \cdot \left(\frac{i_{v3} \cdot i_{v4} \cdot i_{v5} \cdot i_{v6} \cdot i_{v7}}{i_{d3} \cdot i_{d4} \cdot i_{d5} \cdot i_{d6} \cdot i_{d7}}\right)} = \left[\prod_{j=1}^{7} \frac{i_{vj}}{i_{dj}}\right]^{1/7} = \overline{ci_v} / \overline{i_d}$$

– group indices of the summation equal

$$I_v^A = \frac{\sum q_1^A p_1^A}{\sum q_0^A p_0^A} = \sqrt[2]{\frac{i_{v1} \cdot i_{v2}}{i_{d1} \cdot i_{d2}}} = \left[\prod_{j=1}^{2} \frac{i_{vj}}{i_{dj}}\right]^{1/2} = \overline{ci_{vA}} / \overline{i_{dA}}$$

$$I_v^B = \frac{\sum q_1^B p_1^B}{\sum q_0^B p_0^B} = \sqrt[5]{\frac{i_{v3} \cdot i_{v4} \cdot i_{v5} \cdot i_{v6} \cdot i_{v7}}{i_{d3} \cdot i_{d4} \cdot i_{d5} \cdot i_{d6} \cdot i_{d7}}} = \left[\prod_{j=1}^{5} \frac{i_{vj}}{i_{dj}}\right]^{1/5} = \overline{ci_{vB}} / \overline{i_{dB}}$$

In group indices I_v^A and I_v^B, along with functional changes in value, intra-group structural changes are also reflected ($i_{d\text{вг}} = \frac{q_1 p_1}{\sum q_1^{\text{гр}} p_1^{\text{гр}}} \div \frac{q_0 p_0}{\sum q_0^{\text{гр}} p_0^{\text{гр}}} = \frac{i_v}{I_V^{\text{гр}}}$), occurred in a single group. Intergroup connections and interdependencies naturally arise between groups ($i_{d\text{мг}}$), which should be properly considered when calculating i_d.

Based on the principle of proportionality, it is possible to calculate an individual functional value index, expressed either through a composite index ($i_v = i_d \cdot I_v$), either through the group index ($i_v = i_{d\text{вг}} \cdot I_v^{\text{гр}}$). Then $i_v = i_d \cdot I_v = i_{d\text{вг}} \cdot I_v^{\text{гр}}$. From this identity we obtain

$$i_d / i_{d\text{вг}} = I_v^{\text{гр}} / I_v = i_{d\text{мг}}$$

where $i_{d\text{мг}}$ – the relative change in the share of the group in the total summation, characterizing intergroup structural changes.

Note that the value $I_v^{\text{гр}} = \frac{\sum q_1^{\text{гр}} p_1^{\text{гр}}}{\sum q_0^{\text{гр}} p_0^{\text{гр}}}$ may be less (more) one. Then, for this group, the individual functional cost indices (i_{vj}) there will be fewer (more) individual structural indices (i_{dj}). Simultaneously for the whole summation I_v

may be more (less) one, and then in the volume of the entire summation, individual functional indices (i_{vj}) there will be more (less) individual structural indices (i_{dj}). Such a change in proportions is precisely due to the actions of inter-group connections.

From expression $i_d/i_{d\text{вг}} = i_{d\text{мг}}$ define that

$$i_d = i_{d\text{вг}} \cdot i_{d\text{мг}} = \frac{i_v}{I_v^{\text{гр}}} \cdot \frac{I_v^{\text{гр}}}{I_v} = \frac{i_v}{I_v} \tag{11}$$

Let's represent group indices I_v^A and I_v^B as

$$(I_v^A)^2 = \frac{i_{v1} \cdot i_{v2}}{i_{d1} \cdot i_{d2}} = \left(\frac{\overline{Cl_{vA}}}{\overline{l_{dA}}}\right)^2$$

$$(I_v^B)^5 = \frac{i_{v3} \cdot i_{v4} \cdot i_{v5} \cdot i_{v6} \cdot i_{v7}}{i_{d3} \cdot i_{d4} \cdot i_{d5} \cdot i_{d6} \cdot i_{d7}} = \left(\frac{\overline{Cl_{vB}}}{\overline{l_{dB}}}\right)^5$$

Then we get the final formula of the composite cost index for the considered example

$$I_v = \left[\prod_{i=1}^{7} \frac{i_{vj}}{i_{dj}}\right]^{1/7} = \left[\left(\frac{\overline{Cl_{vA}}}{\overline{l_{dA}}}\right)^2 \cdot \left(\frac{\overline{Cl_{vB}}}{\overline{l_{dB}}}\right)^5\right]^{1/7},$$

that is, the formula for the geometric weighted average of the group average cost indices.

In general:

– for non-grouped summations, the composite value index is calculated as the geometric mean simple from the ratios of individual functional value indexes to individual structural indexes of shares

$$I_{v\Sigma} = \left[\prod_{j=1}^{n} \frac{i_{vj}}{i_{dj}}\right]^{1/n} = \frac{\overline{Cl_{v\Sigma}}}{\overline{l_{d\Sigma}}} \tag{12}$$

– for grouped summations, the composite value index is calculated as the geometric weighted average of the ratios of the average group functional value indexes to the average group structural indexes of shares

$$I_{v\Sigma} = \left[\prod_{i=1}^{k} \frac{\overline{Cl_{vi}}}{\overline{l_{di}}}\right]^{m_i/(n=\sum m_i)} = \prod_{i=1}^{k} \left(\frac{\overline{Cl_{vi}}}{\overline{l_{d\text{вг}i}} \cdot \overline{l_{d\text{мг}i}}}\right)^{m_i/(n=\sum m_i)} \tag{13}$$

From formulas (12) and (13) it follows that

$$\overline{Cl_{v\Sigma}} = \prod_{i=1}^{k} (\overline{Cl_{vi}})^{m_i/(n=\sum m_i)}$$

$$\overline{l_{d\Sigma}} = \prod_{i=1}^{k} (\overline{l_{di}})^{m_i/(n=\sum m_i)} = \prod_{i=1}^{k} (\overline{l_{d\text{вг}i}})^{m_i/(n=\sum m_i)} \cdot \prod_{i=1}^{k} (\overline{l_{d\text{мг}i}})^{\frac{m_i}{n=\sum m_i}} = \overline{l_{d\text{вг}\Sigma}} \cdot \overline{l_{d\text{мг}\Sigma}}$$

Then formula (13) can be represented as

$$I_{v\Sigma} = \frac{\overline{Cl_{v\Sigma}}}{\overline{l_{d\text{вг}\Sigma}} \cdot \overline{l_{d\text{мг}\Sigma}}} = \frac{\overline{I_{v\Sigma}^{\text{гр}}}}{\overline{l_{d\text{мг}\Sigma}}} \tag{14}$$

where $I_{v\Sigma}^{\text{гр}} = \frac{\overline{Cl_{v\Sigma}}}{\overline{l_{d\text{вг}\Sigma}}}$ – the aggregate average group value index.

Like the integral coefficients of Salai and Gatev, formula (13) takes into account the size of the summation (n), the number of selected groups (k), the size of each group (m), the contribution of each group to the formation of the studied trait $\frac{m}{n=\sum m}$.

But unlike the coefficients of Salai, Gatev and others, which do not link structural differences with the final result, the indicator of the average share ($\overline{l_d}$) together with the functional average cost index ($\overline{Cl_v}$) in formula (13) allow us to determine the generalized level of influence of each of these two factors on the change in the final result, represented by the composite cost index (I_v).

According to the authors, formulas (12) and (13) are as important as the formula $I_v = I_q \cdot I_p$, expressing in modern index theory the conceptual principle of factor reversibility, according to which the product of a given index of quantities (I_q) and the original price index (I_p) should be equal to the change in value (I_v) considered unit [8, p.10].

This statement, firstly, is based on the law of classical logic of Aristotle: the own essence (essence) of a phenomenon is inversely proportional to the volume of the concept of this phenomenon [9, p.113-115], that is $H = J \cdot \frac{1}{n}$

where H – the logical essence of a set, which characterizes classes of objects or properties that are homogeneous in a certain respect and is a semantic synthesis of the laws of logic, the rules for the functioning of a set and its elements that form the functional of the existence of a set;

– J is a measure of the element base of the aggregate reflected in the consciousness, characterizing the number of its elements of interest to the researcher from the point of view of the research goal;

– n is the volume of the concept of the summation (the number of elements in the summation).

Hence it follows if $J = m$, $n = \sum m$, so $H = \frac{m}{\sum m} = d$, where d – the share of an element or a group of elements in the total volume of the summation that interests the researcher. This means that without taking into account the structural component, the intrinsic essence of the aggregate of the composite value index cannot be cognized.

Second, the importance of taking structural changes into account in the decomposition of the composite value index lies not only in determining the contribution of the factor i_d in the formation of a consolidated cost index I_v, but also in the possibility of a comprehensive assessment of the functional and structural organization of the aggregate of the composite value index as such.

The point is that for $I_v = const$, according to formula (8) represented by the expression $I_v = i_{vj} \cdot \alpha_{sj}$, the growth of one of the factors as a result of any changes in period "1" in comparison with period "0" is compensated by an equivalent decrease in the other factor. Let's represent the value of the pivot index $I_v = i_{v1} \cdot \alpha_{s1} = i_{v2} \cdot \alpha_{s2} = \cdots = i_{vn} \cdot \alpha_{sn}$ as a set $I_v = \{I_{v1}, I_{v2}, I_{v3} \ldots\}$, consists of dotes $I_{vj}(\alpha_{sj}; i_{vj})$.

This set can be considered as a Pareto set [12, p.120-121], that is, as a set of equally preferred options for achieving a result by various combinations of factors, in which an increase (decrease) in one coordinate, for example, α_{sj} (as abscissas) entails decreasing (increasing) another coordinate i_v (as ordinates) without changing the final result результата I_v.

On the flat $\alpha_s 0 i_v$ a set $I_v = const$, according to [10, p.75], it is visualized as a graph of an isosceles hyperbola. This graph at the point $I_{vj}(\alpha_{sj}; i_{vj})$ of a set $I_v = \{I_{v1}, I_{v2}, I_{v3} \ldots\}$ is intersected by a ray r_j, originating from the origin and representing a given diameter of the hyperbola. The beam is characterized by an attitude $r_j = i_{vj}/\alpha_{sj}$, which sets the angle of inclination of the beam to the axes $0\alpha_s$ and $0i_v$ and is the vector of the gradient of the steepest increase of the function $I_v = f(\alpha_{sj}; i_{vj})$.

Among many rays $r = \{r_1, r_2, r_3 \ldots\}$ there is one single ray in which the value of one of the factors cannot be "improved" without "worsening" the other. The point of intersection of such a ray with the set $I_v = const$ will characterize the state of Pareto optimality.

Obviously, such a state is possible if and only if the straight line $i_v = \alpha_s$ is the direction of the global extremum of the function $I_v = f(\alpha_{sj}; i_{vj})$. The direction in which $I_v = i_v \cdot \alpha_s = {i_v}^2 = {\alpha_s}^2 = max$, or when a ${}^{i_v}/_{\alpha_s} = r = 1$ (fig.1).

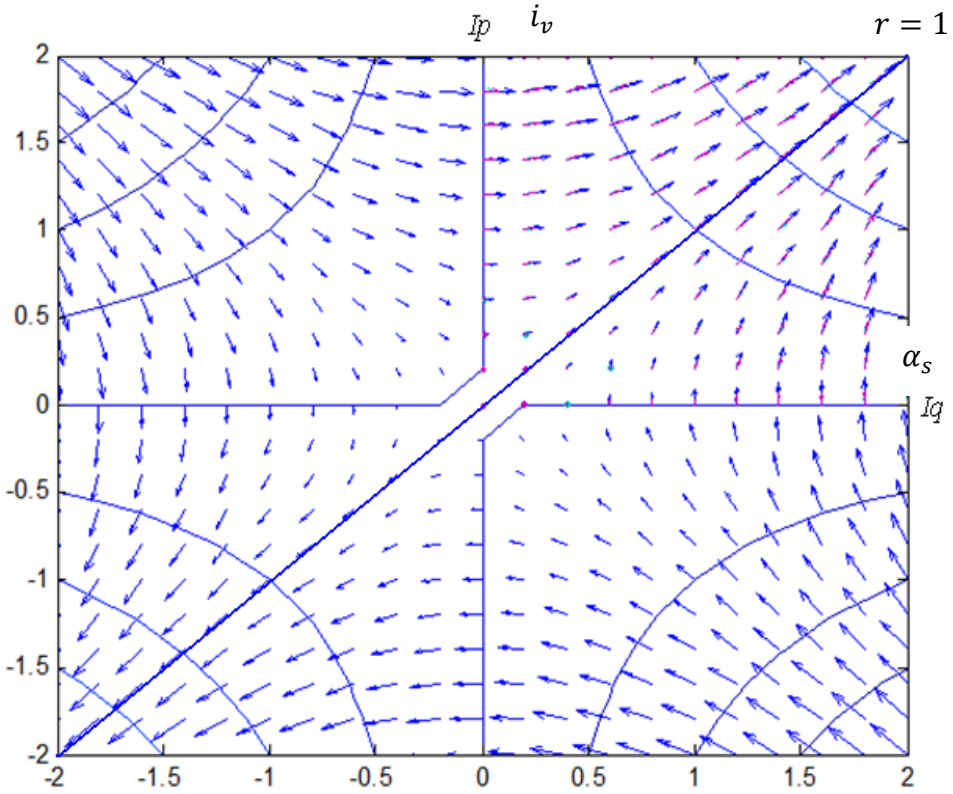

Fig. 1. Field of gradients of the spatial function $I_v = f(\alpha_{sj}; i_{vj})$.

This is indeed so due to the fact that i_v and α_s – the essence of different combinations of the same initial values $\{q_0, q_1, p_0, p_1\}$, and also due to the fact that i_v and α_s - dimensionless relative quantities that have the same scale of calculation.

Any deviation from the ray $r = 1$, for example, right and down leads to growth α_s and decrease i_v. Conversely, the deviation to the left and upward from the ray $r = 1$ causes a decrease in α_s and an increase in i_v.

It happens that the transition from one point of the set $I_v = \{I_{v1}, I_{v2}, I_{v3} \ldots\}$ to the other it allows one to "improve" one factor without "worsening" the other. In this case, the transition leads to an improvement in the Pareto situation (see point I_{v2}^* on fig. 2).

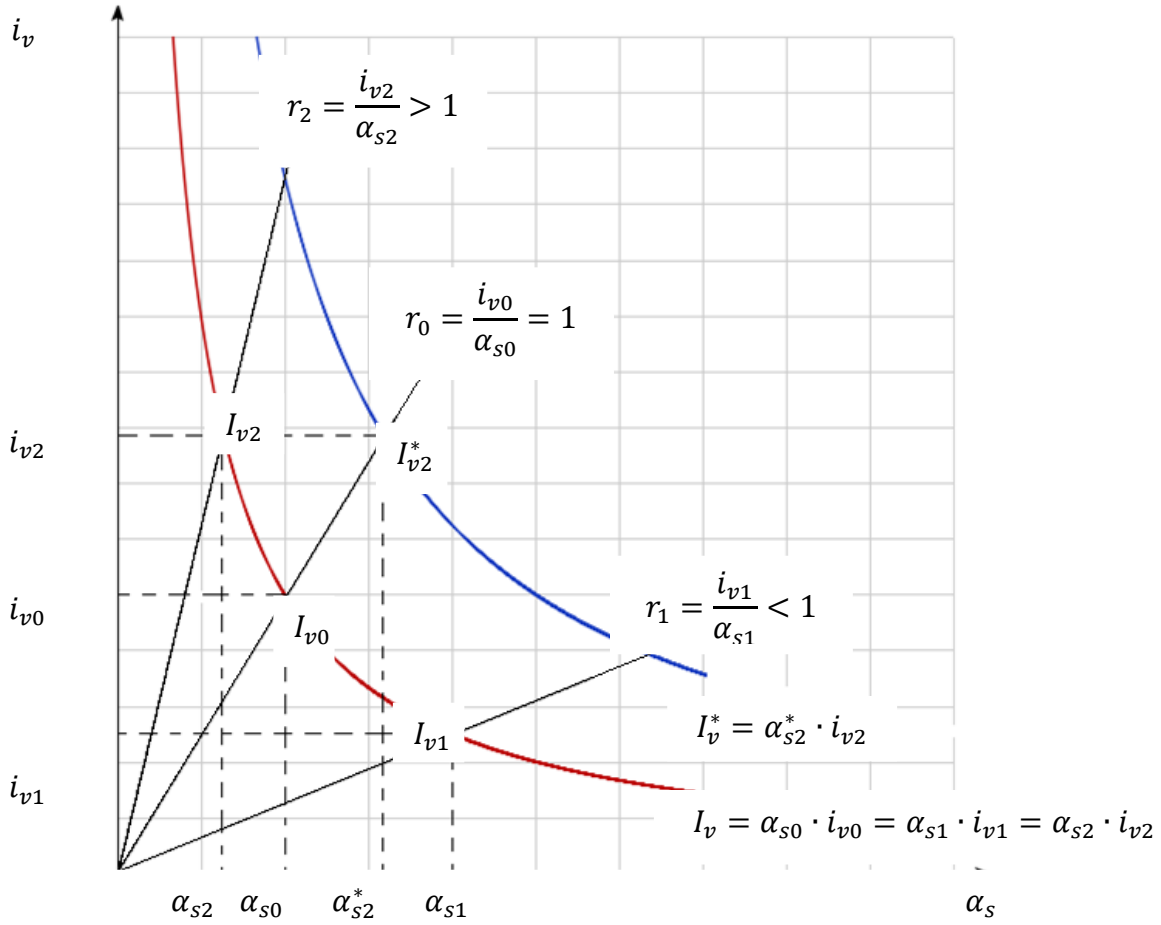

Fig. 2. Change in the state of Pareto optimality

Therefore, if $I_v = \overline{i_v} \cdot \overline{\alpha_s} = \overline{i_v}^2 = \overline{\alpha_s}^2$, then the state of Pareto optimality has been reached for the entire aggregate of the composite cost index. In other words, we can say that a necessary condition for achieving the Pareto optimality situation is the condition according to which $\sqrt{I_v} = \overline{cl_v} = \overline{\alpha_s}$.

A sufficient condition for achieving Pareto optimality is a situation in which $r = \frac{\overline{cl_v}}{\overline{\alpha_s}} = 1$.

From an information and content point of view, the meaning of the indicator r, expressed through the ratio of the means $\bar{r} = \frac{\overline{cl_v}}{\overline{\alpha_s}}$ in accordance with [9, p.120] is as follows. This relationship is represented in the form $r = \frac{\overline{cl_v}}{\overline{\alpha_s}} = \overline{cl_v} \Big/ \frac{1}{i_d} = \overline{cl_v} \cdot \overline{cl_v} \Big/ I_v$, is a pragmatic essence (r) of a summation of composite value indices, defined by the product of the sensuous entity about the means to an end $(\overline{cl_v})$ and the logical entity about the means of achieving the goal per unit of information about the main goal, the result $(\overline{cl_v} \Big/ I_v)$. Then the attitude $r = \frac{\overline{cl_v}}{\overline{\alpha_s}}$ can be interpreted as an integral assessment of the functional $\overline{cl_v}$ and structural $\overline{\alpha_s}$ the complexity of the aggregate of the composite cost index, or as an estimate of the organizational complexity of the aggregate.

If the assessment of the organizational complexity of the composite cost index summation is greater than one, that is $r > 1$, then in the aggregate, the functional organization prevails over the structural organization. I., respectively, if the assessment of organizational complexity is expressed by the inequality $r < 1$, then the structural organization of the aggregate of the composite value index dominates over the functional organization.

It may seem that from the standpoint of the functional and structural approach, it is preferable when $r > 1$, that is, when function dominates structure. However, it is not. As can be clearly seen in Fig. 1, the field of gradients of the spatial function $I_v = f(\alpha_{sj}; i_{vj})$ tends towards the point [11], at which the global extremum of this function is reached.

This implies that if the assessment of the organizational complexity of the summation is equal to one, that is $r = 1$, then the aggregate of the composite value index has Pareto-optimality and cannot be improved in this state.

Thus, it can be argued that the condition $r = 1$ is that normalized-preferable condition with which the actual values of the assessment of the organizational complexity of the summation should be compared. The closer the actual values $r_{\text{факт}}$ to the normalized value $r_{\text{н}} = 1$, the closer the functional and structural organization of the aggregate of the composite value index is to the state of Pareto optimality.

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КРИТЕРИЙ ИДЕНТИФИКАЦИИ ВЕРОЯТНОСТНОЙ МОДЕЛИ СОСТОЯНИЯ СПУТНИКОВЫХ КАНАЛОВ СВЯЗИ

CRITERION FOR IDENTIFICATION OF THE PROBABILITY MODEL OF THE STATE OF SATELLITE COMMUNICATION CHANNELS

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Аннотация. *Для идентификации состояния спутниковых каналов связи используются прогнозные методы и модели. Однако, они оценивают их состояние лишь на качественном уровне, что не позволяет производить тонкую настройку характеристик и параметров спутниковых каналов. Подобные модели и методы не могут обеспечивать достоверную идентификацию состояний спутниковых каналов связи и оперативно определять изменение законов распределения случайных величин, связанных с появлением мелкомасштабных неоднородностей в случае динамичного изменения ионосферного слоя, что характерно для быстрых замираний сигналов GPS/ГЛОНАСС.*

Материалы и методы. *На практике, для прогнозирования и исследования распространения радиоволн, нашли широкое применение вероятностные модели, основанные на законах распределения случайных величин Райса, Релея, Накагами и нормального закона распределения. Оперативное управление и поддержание на требуемом уровне отношения сигнал/шум требует различать состояния спутниковых каналов и идентифицировать их характеристики не только между законами распределения случайных величин, но и внутри каждого закона. Это позволит обеспечить поддержание количественных и качественных характеристик спутниковых каналов на требуемом уровне. Расстояние между эмпирической и теоретической функциями распределения вероятностей является достаточно эффективной статистикой для проверки гипотез о виде закона распределения вероятностей случайной величины. К критериям согласия, использующим различные варианты анализа расстояния между теоретической и эмпирической функциями распределения, относятся: Крамера-фон Мизеса-Смирнова (Омега-квадрат); Колмогорова-Смирнова; Пирсона (Критерий Хи-квадрат); Андерсона-Дарлинга; Купера; Ватсона. В связи с этим, от того, какой критерий будет использован, и насколько адекватно будет проведена оценка и идентификация текущего состояния спутниковых каналов связи, зависит возможность удовлетворения качественных характеристик передаваемых сигналов GPS/ГЛОНАСС. Для каждого из идентифицируемых законов распределений (Накагами, Райса, Релея, нормального закона) были сгенерированы статистические выборки, по 100 выборок с различным количеством измерений (от 1 000 до 1 000 000). Таким образом, суммарное количество выборок различного размера для идентифицируемых законов распределения составляет 1600. Все исследуемые критерии проверялись на одинаковых выборках. Выборки обрабатывались с помощью библиотеки SciPy. Разработан алгоритм, позволяющий осуществить выбор гипотезы по максимальному значению коэффициента правдоподобия. Результатом работы алгоритма является коэффициент правдоподобия, сопоставленный с каждой из статистических гипотез, при этом предпочтение отдается той гипотезе, которая имеет максимальный коэффициент правдоподобия. С помощью библиотеки Timeit проведены измерения времени работы алгоритмов исследуемых критериев в зависимости от размера выборки для исследуемых законов распределений. В статье предложен критерий идентификации состояния спутниковых каналов, обеспечивающий точность не менее 95 %. Его адекватность подтверждена данными, полученными при мониторинге трансионосферных каналов связи с использованием научного оборудования «Аппаратно-программный комплекс пассивного мониторинга ионосферы NovAtel GPStation-6».*

Данные исследования выполнены при поддержке научного проекта «Разработка роботизированного беспилотного летательного аппарата мультироторного типа с использованием бесплатформенной инерциальной навигационной системы» Федеральной Целевой Программы на 2014-2020 годы (уникальный идентификатор RFMEFI57818X0222) при финансовой поддержке Министерства Науки и Высшего Образования России, на базе ЦКП СКФУ.

Ключевые слова: критерий согласия, идентификация закона распределения, трансионосферные каналы связи, GPS, ГЛОНАСС.

Abstracts. *Predictive methods and models are used to identify the state of satellite communication channels. However, they evaluate their condition only at a qualitative level, which does not allow fine-tuning the characteristics and parameters of satellite channels. Such models and methods cannot provide reliable identification of the States of satellite communication channels and quickly de-*

termine changes in the distribution laws of random variables associated with the appearance of small-scale inhomogeneities in the case of dynamic changes in the ionospheric layer, which is typical for rapid fading of GPS/GLONASS signals. In practice, probabilistic models based on the laws of distribution of random variables of rice, Rayleigh, Nakagami and the normal distribution law are widely used for forecasting and studying the propagation of radio waves. Operational management and maintenance of the signal-to-noise ratio at the required level requires distinguishing the States of satellite channels and identifying their characteristics not only between the laws of distribution of random variables, but also within each law. This will ensure that the quantitative and qualitative characteristics of satellite channels are maintained at the required level. The distance between the empirical and theoretical probability distribution functions is a fairly effective statistic for testing hypotheses about the type of probability distribution law of a random variable. The agreement criteria that use different variants of analyzing the distance between the theoretical and empirical distribution functions include: Kramer-von Mises-Smirnov (omega-square); Kolmogorov-Smirnov; Pearson (Chi-square Criterion); Anderson-darling; Cooper; Watson's. In this regard, the ability to meet the quality characteristics of transmitted GPS/GLONASS signals depends on which criteria will be used and how well the current state of satellite communication channels will be assessed and identified. For each of the identified distribution laws (Nakagami, rice, Rayleigh, normal law), statistical samples were generated, 100 samples with a different number of dimensions (from 1,000 to 1,000,000). Thus, the total number of samples of various sizes for the identified distribution laws is 1,600. All the studied criteria were tested on identical samples. Selections were processed using the SciPy library. An algorithm has been developed that allows you to select a hypothesis based on the maximum value of the likelihood coefficient. The result of the algorithm is a likelihood coefficient compared with each of the statistical hypotheses, while preference is given to the hypothesis that has the maximum likelihood coefficient. The Timeit library is used to measure the running time of the algorithms of the studied criteria, depending on the sample size for the studied distribution laws. The article offers a criterion for identifying the state of satellite channels, which provides an accuracy of at least 95 %. Its adequacy is confirmed by data obtained during monitoring of transionospheric communication channels using scientific equipment "NovAtel GPStation-6 passive ionosphere monitoring Hardware and software complex". These studies were carried out with the support of the scientific project "Development of a multirotor type robotic unmanned aerial vehicle using a strapdown inertial navigation system" of the Federal Target Program for 2014-2020 (unique identifier RFMEFI57818X0222) with the financial support of the Ministry of Science and Higher Education of Russia, based on the NCFU Central research center.

Key words: consent criterion, identification of the distribution law, transionospheric communication channels, GPS, GLONASS.

Introduction. One of the important stages in the control and management of transionospheric communication channels is the identification of their states. Based on the results of the analysis of its data, a control action is developed that allows maintaining the signal-to-noise ratio (S / N) within acceptable limits to ensure the required communication quality. For this purpose, various actions can be taken: increasing the power, changing the frequency of signal transmission, using different coding methods, organizing diversity reception, etc. If the S / N ratio is not maintained within acceptable limits, errors in the transmission of GPS / GLONASS signals increase significantly and their quality characteristics do not meet the requirements of practical problems, which is unacceptable.

In practice, for forecasting and studying the propagation of radio waves, probabilistic models based on the distribution laws of Rice, Rayleigh, Nakagami random variables and the normal distribution law have found wide application. These models are basic for the analysis of the qualitative characteristics of satellite channels [1].

The existing practical methods for identifying the state of transionospheric communication channels are based on predictive models [2, 3]. They use parametric forecasting, which cannot fully meet the requirements of practice due to insufficient forecast accuracy with dynamic changes in the ionosphere, which are characteristic when small-scale irregularities appear in the ionosphere [2]. In addition, they do not explicitly indicate the criterion used and do not develop recommendations for its choice. The difference in states belonging to the same distribution law, characteristic of slow fading, has not been studied sufficiently [2].

Thus, the problem of choosing a criterion for identifying the states of transionospheric communication channels, in the case of dynamically changing ionospheric formations, is relevant and significantly affects the efficiency of processing GPS / GLONASS data and the accuracy of determining the location of objects (for example, unmanned aerial vehicles).

It is necessary that the distribution laws of random variables describing the state of satellite communication channels (Nakagami, Rice, Rayleigh, the normal law) are unambiguously estimated by the used criterion with the required accuracy.

Materials and methods. In works [4–7], criteria are given that are used to compare theoretical and empirical probability distribution functions. The distance between the empirical and theoretical probability distribution functions is a fairly effective statistics for testing hypotheses about the form of the probability distribution law of a random varia-

ble. Goodness-of-fit criteria using different versions of the analysis of the distance between the theoretical and empirical distribution functions are presented in [8–12]. These include the following criteria:

- Cramer-von Mises-Smirnov (Omega-square);
- Kolmogorova-Smirnova;
- Pearson (Chi-square test);
- Anderson-Darling;
- Cooper;
- Watson.

The Cramer-von Mises-Smirnov criterion is designed to test simple hypotheses about the belonging of the analyzed sample to a fully known law.

When testing simple hypotheses, the criterion is free of distribution, that is, it does not depend on the type of law with which agreement is checked [11]. The hypothesis being tested is rejected when the statistics are large. In [11,13], it was established that when testing complex hypotheses, where the estimate of a scalar or vector distribution parameter is calculated from the same sample, nonparametric goodness-of-fit tests lose the property of freedom from distribution. In this case, the distributions of statistics of nonparametric goodness-of-fit tests depend on a number of factors: the type of the observed law corresponding to a fair testable hypothesis; the type of parameter being evaluated; the number of estimated parameters. The differences in the limiting distributions of the same statistics when testing simple and complex hypotheses are so significant that it is impossible to neglect it [11, 13].

In the Kolmogorov-Smirnov goodness-of-fit test, it is advisable to use statistics with the Bolshev's correction [14]. The distribution of this statistic, given the validity of the hypothesis being tested, quickly converges to the Kolmogorov distribution, and for n> 25 the dependence on the sample size can be neglected [14]. Statistics like $D_n = \sup|F_n(x) - F(x)|$.

The Anderson-Darling test is acceptable for a sample size n ≥ 25 [15]. The check can be carried out for any type of distribution, if the distribution parameters are assumed to be known. If the statistics are large, the hypothesis being tested is rejected. Statistics of the form [15]

$$S_\Omega = -n - 2\sum_{i=1}^{n}\left(\frac{2i-1}{2n}\ln(F(x_i,\theta)) + \left(1-\frac{2i-1}{2n}\right)\ln(1-F(x_i,\theta))\right)\cdot$$

Cooper's goodness test is a development of the Kolmogorov goodness-of-fit test and was proposed to test simple hypotheses about the fact that the analyzed sample belongs to a fully known law [16]. If the statistics are large, the hypothesis being tested is rejected. Statistics like $D_n^+ = \max\left(\frac{i}{n} - F(x_i,\theta) - \frac{i-1}{n}\right)$, $D_n^- = \max\left(F(x_i,\theta) - \frac{i-1}{n}\right)$.

The Watson goodness test is a development of the Cramer - Mises - Smirnov goodness test [16]. If the statistics are large, the hypothesis being tested is rejected. Statistics like

$$U_n^2 = \sum_{i=1}^{n}\left(F(x_i,\theta) - \frac{i-0.5}{n}\right)^2 - n\left(\frac{1}{n}\sum_{i=1}^{n}F(x_i,\theta) - 0.5\right)^2 + \frac{1}{12n}\cdot$$

Required:

1. Investigate the above criteria for the corresponding statistics on previously known test samples of the laws of distribution of random variables and determine a criterion with an identification accuracy of no worse than 95%.

2. Check the adequacy of the selected criterion on statistical samples obtained using the hardware and software complex for passive monitoring of the ionosphere NovAtel GPStation-6.

Results and discussion. Statistical samples were generated for each of the identified distribution laws (Nakagami, Rice, Rayleigh, normal law). The samples were processed using the SciPy library.

For each of the distribution laws defined above, 100 samples were obtained with a different number of measurements (from 1,000 to 1,000,000). Thus, the total number of samples of different sizes for the identified distribution laws is 1600. All the studied criteria were tested on the same samples.

To solve the identification problem, an algorithm has been developed that provides:

1. Collection of experimental statistics of empirical distribution.
2. Calculation of the mathematical expectation and variance of the sample of the empirical distribution.
3. Construction of the differential function of the empirical distribution.
4. Calculation of the mathematical expectation and variance of the empirical distribution.

5. Construction of differential distribution functions for each of the reference distributions with mathematical expectation and variance of the empirical distribution.

6. Determination of the coefficient of likelihood of the sample under study for each criterion for the assumed distributions.

7. Ranking the results of testing hypotheses according to the maximum likelihood ratio.

8. Selection of a hypothesis based on the maximum value of the likelihood coefficient.

Table 1

Sample sizes for testing identification criteria

Number of measurements in the sample	Distribution law			
	Normal	Rayleigh	Rice	Nakagami
1 000	100	100	100	100
10 000	100	100	100	100
100 000	100	100	100	100
1 000 000	100	100	100	100

The result of the algorithm is the likelihood coefficient compared with each of the statistical hypotheses, with preference given to the hypothesis with the maximum likelihood coefficient. An example of the algorithm for the Anderson-Darling test of the studied sample of 1000 measurements is presented in Table 2. For this test, the maximum likelihood coefficient is 6.485299, which corresponds to the identification of Nakagami's law.

Table 2

An example of the algorithm for the Anderson-Darling test

Criterion	Initial distribution	Estimated distribution	Coefficient of probability
Anderson-Darling	Nakagami	Rice	4,37399
		Nakagami	6,485299
		Normal	4,1812
		Rayleigh	4,2382
Total time			0,653 c.

The greatest interest is the comparison of accuracy criteria and distribution laws of random variables, since It is investigated that the distribution for some values of their arguments has a sufficient form.

Using the algorithm presented above, a study was carried out to select a criterion. Determined on a given plural. The test results are summarized in Table 3.

Obviously, the Omega-square test has the worst result. The standard implementation of the criterion, taken as a basis, is capable of qualitatively determining only the normal distribution. At the same time, the Kolmogorov-Smirnov, Cooper and Watson criteria show a fairly good result. Acceptable for them is the choice of 1000 elements, which allows using the data for the requirements for the laws of distributed random variables in practical application.

Figure 2 shows probability graphs. Similar graphs were obtained for the laws of Rayleigh, Rice, Nakagami.

Using the time library, which measures the running time of the algorithms, the criteria are investigated depending on the size. The results of measuring the average running time of algorithms and empirical selection criteria in accordance with Rice's law are presented in Table 4 and Figure 3.

The analysis showed that the Chi-square test has the longest average running time of the algorithm. The rest of the algorithms have comparable average running time of the algorithms. Taken together, the studied characteristics determine the laws, the best indicators in terms of probability and average time have the Kolmogorov-Smirnov test.

Table 3

Values of probabilities of the correct base of empirical distributions

Normal law				
Criterion	Sample size			
	1000	10 000	100 000	1 000 000
Kolmogorov-Smirnov	96 %	97%	98 %	98 %
Cooper's	95 %	96 %	96 %	96 %
Chi-square	75 %	75 %	78 %	79 %
Omega square	86 %	88 %	90 %	90 %
Anderson-Darling	80 %	85 %	87 %	88 %
Watson	94 %	95 %	95 %	95 %

Nakagami's law				
Kolmogorov-Smirnov	97 %	97%	97 %	97 %
Cooper's	95 %	95 %	95 %	96 %
Chi-square	70 %	72 %	74 %	75 %
Omega square	0 %	0 %	0 %	0 %
Anderson-Darling	80 %	81 %	82 %	84 %
Watson	95 %	95 %	95 %	95 %
Rice's law				
Kolmogorov-Smirnov	95 %	95%	95 %	95 %
Cooper's	94 %	95 %	95 %	95 %
Chi-square	75 %	75 %	78 %	79 %
Omega square	0 %	0 %	0 %	0 %
Anderson-Darling	80 %	85 %	87 %	88 %
Watson	95 %	95 %	95 %	95 %
Rayleigh's law				
Kolmogorov-Smirnov	97 %	97%	98 %	98 %
Cooper's	95 %	95 %	96 %	96 %
Chi-square	72 %	74 %	74 %	75 %
Omega square	0 %	0 %	0 %	0 %
Anderson-Darling	65 %	71 %	72 %	72 %
Watson	95 %	95 %	95 %	95 %

Table 4

Average running time of criteria identification algorithms for distribution of empirical samples according to Rice's law

Criterion	Размер выборки			
	1000	10 000	100 000	1 000 000
Kolmogorov-Smirnov	0,2688 с.	0,688 с.	1,596 с.	1,76 с.
Cooper's	0,328 с.	0,67 с.	1,75 с.	1,83 с.
Chi-square	0,479 с.	0,848 с.	2,72 с.	5,09 с.
Anderson-Darling	0,578 с.	0,823 с.	1,654 с.	1,896 с.
Watson	0,487 с.	0,563 с.	1,647 с.	1,913 с

In order to check the adequacy of the research results, the empirical distributions obtained with the use of the NovAtel GPStation-6 hardware-software complex for passive ionosphere monitoring were tested. For testing, the criteria of Kolmogorov-Smirnov, Cooper and Watson were used. The data received from the GPStation-6 receiver were processed manually. We studied 100 samples with a predetermined distribution of 10,000 elements. The analysis showed the closeness of the results of the studies. The best criterion was the Kolmogorov-Smirnov test, which has an identification accuracy of more than 95%. Cooper and Watson's tests respectively identified the empirical distribution with 90 and 93 percent accuracy.

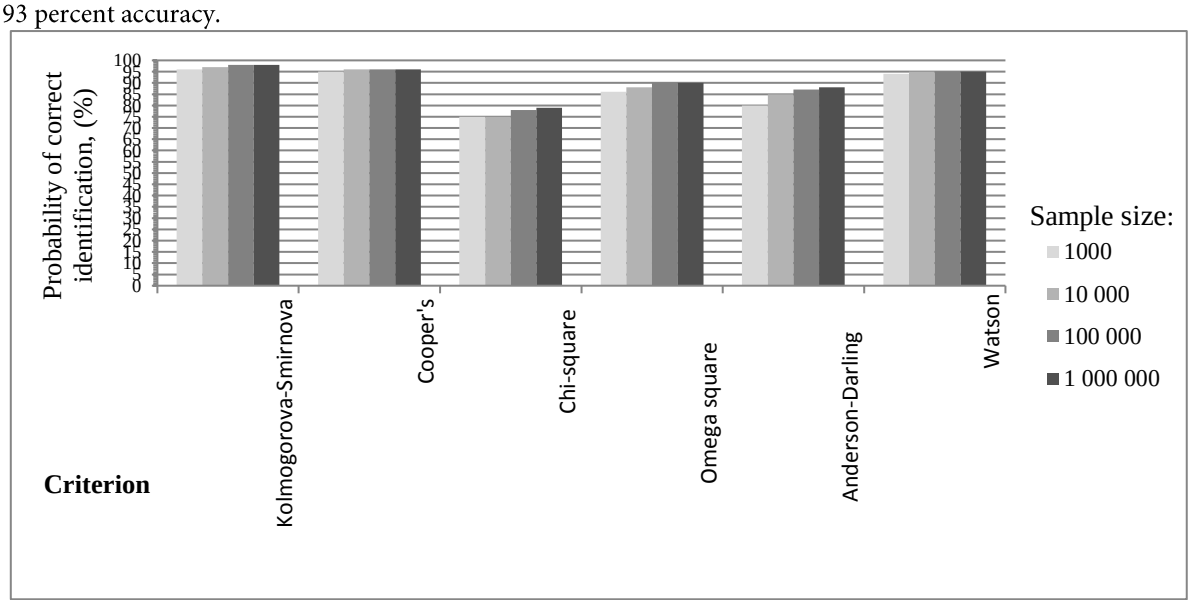

Fig. 2. Graphs of probabilities of correct identification for the normal distribution law

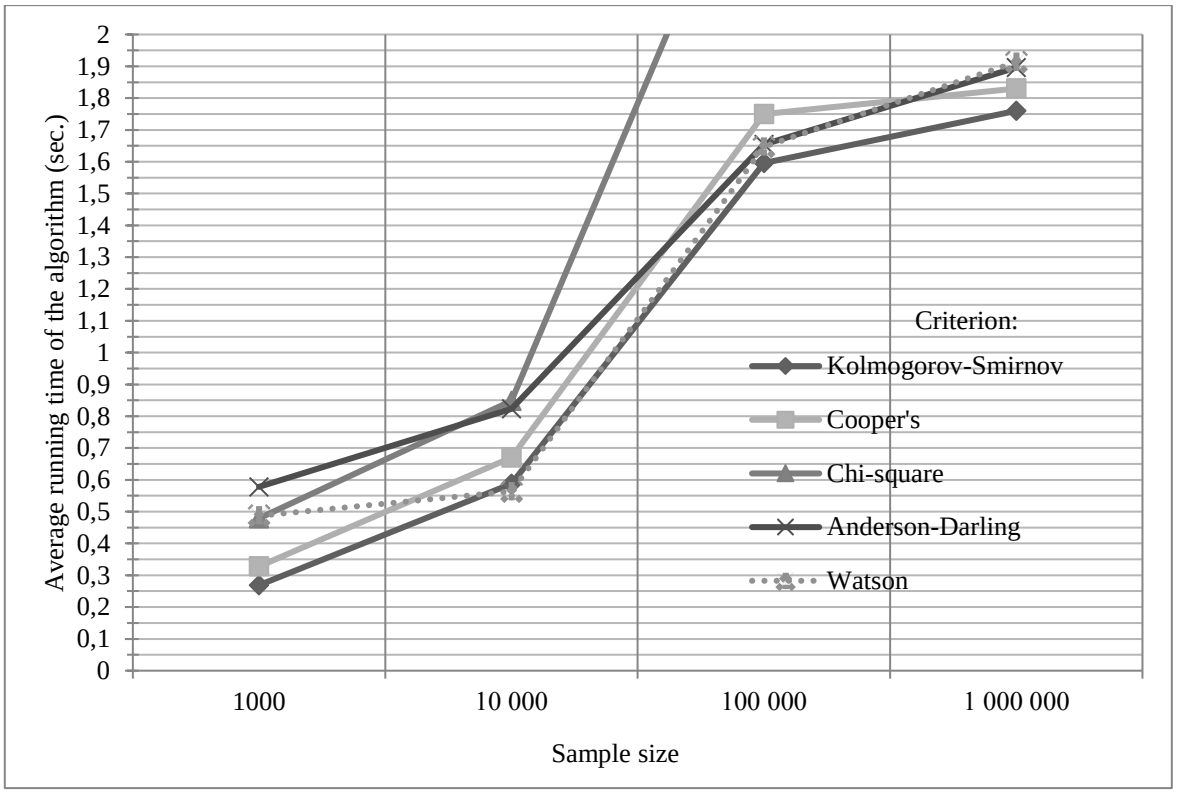

Fig. 3. Graph of the dependence of the average identification time of empirical samples distributed according to Rice's law

Conclusions / Conclusion. In this work, a criterion is chosen for identifying the distribution law describing the disturbances of the ionosphere in transionospheric communication channels. The best criterion is the Kolmogorov-Smirnov criterion, since with relatively close mean values of the identification time of the distribution laws with the Cooper and Watson criteria, it has the best accuracy. The use of this criterion will make it possible to reasonably optimize the classification thresholds for the states of transionospheric communication channels of the laws of distribution of random variables. In the future, it is advisable to conduct additional research using it to identify the following empirical distributions: Beckman, Hoyt, truncated normal law**.**

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РАЗРАБОТКА МЕТОДА НЕЯВНОГО ХРАНЕНИЯ КЛЮЧЕВОЙ ИНФОРМАЦИИ С ПОМОЩЬЮ ФНФ НА ОСНОВЕ СОЗУ В СМАРТ КАРТАХ

DEVELOPMENT OF THE METHOD OF IMPLICIT STORAGE OF KEY INFORMATION USING SRAM PUF IN SMART CARDS

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Аннотация. *В статье приведены результаты исследования и декомпозиция системы смарт-карт, рассмотрена организация подсистем и их взаимосвязи, определены недостатки и угрозы ключевой информации.*

Материалы и методы. *Проведен анализ технологии ФНФ на основе СОЗУ, описана разработанная экспериментальная установка, с помощью которой были получены значения неинициализированной памяти в ячейках, проанализированы и определены закономерности распределения значений, определено количество измерений для определения стабильности значения ячеек памяти. Анализ результатов указывает на необходимость тестирования микросхем СОЗУ при их использовании в качестве ФНФ. Рассмотрена возможность дальнейшего изучения авто-корреляционной функции для исключения коллизии в системах взаимной аутентификации. Дополнительно для всестороннего изучения определенный интерес представляет изучение изменения зависимости количества стабильных и нестабильных ячеек в кристалле СОЗУ в течение жизненного цикла микросхемы, изучение температурных зависимостей значений в ячейках памяти.*

Результаты, обсуждение и вывод. *Разработан метод неявного хранения ключевой информации в смарт картах с использованием ФНФ на основе СОЗУ. Разработан алгоритм взаимной аутентификации с использованием ФНФ на основе СОЗУ для повышения имитостойкости системы. Данная работа заложила основу для определения оптимальной длины вектора инициализации при использовании микросхем СОЗУ в качестве ФНФ в системах со взаимной аутентификацией.*

Ключевые слова: смарт карта, физически неклонируемая функция, статические оперативно запоминающие устройства, микросхема, стабильные и нестабильные ячейки. системный анализ, ключевая информация, алгоритм взаимной аутентификации.

Abstracts. *The article present results of research and decomposition smart cards systems. Subsystems organization and they relationships were reviewed. Weakness and threats of key information were identified. SRAM PUF technology was analyzed. Paper describes experimental setup for getting values of initialization memory, analyzed and detected system properties, determined numbers of measurements to detect stable memory cells. An analysis of the results indicates the need for testing the circuits of the RAM when using them as PUF. The possibility of further study of the auto-correlation function to eliminate collisions in mutual authentication systems is considered. Additionally, for a comprehensive study, it is of certain interest to study the change in the dependence of the number of stable and unstable cells in the RAM chip during the life cycle of the microcircuit, and study the temperature dependences of the values in the memory cells.*

A method has been developed for implicit storage of key information in smart cards using SRAM PUF. An algorithm for mutual authentication using PUF based on the SRAM is developed to increase the system imitability. This work laid the foundation for determining the optimal length of the initialization vector when using the RAM chip as an PUF in systems with mutual authentication.

Key words: system analysis, smart card, physical unclonable function, static random access memory, microcircuit, stable and unstable cells, key information, mutual authentication algorithm.

Introduction. Smart cards were chosen as the object of research, since they are currently widely used in various fields, such as: cellular communications, industry, transport and warehouse logistics, access control systems, medicine, libraries, transport payments, remote control, agriculture, human implants, baggage and cargo management systems in

transport companies, real-time object localization systems, car immobilizers, bank cards. They became widespread due to the low cost, simplicity of the technical production process, and the development of the "Internet banking" technology.

Smart cards are plastic cards with a built-in microcircuit. In most cases, smart cards contain a microprocessor and an operating system that controls the device and controls access to objects in its memory. There are smart cards with the ability to perform cryptographic calculations.

According to the principle of data exchange, smart cards are divided into 3 types:

1. Contact
2. Contactless
3. Hybrid

By the presence of a battery, smart cards are divided into active and passive. Active batteries have a built-in battery, and passive ones, respectively, lack it.

According to the method of exchange with a reader, contact smart cards are divided into 2 categories: cards of the ISO / IEC 7816 standard (cellular sim cards, bank cards) and cards with a USB interface (tokens). Such cards do not contain a battery; the energy is supplied to them by the reader. Cards with a USB interface are more convenient for computer authentication, since they do not require additional devices, they are often used to carry out cryptographic calculations.

Contactless smart cards use RFID (radio channel) technology to transfer data between the card and the reader without physically contacting the transponder and the reader. An oscillatory circuit is used to transmit data and supply power to the card, which consists of a capacitor and an inductor. Proximity cards are subdivided according to their operating frequency characteristics into low frequency (LF - 125-134 kHz), high frequency (HF - 13.56 MHz) and ultra-high frequency (UHF - 860-960 MHz). The reader emits an alternating electromagnetic field of a given frequency, which excites an alternating electric current in the inductance coil and in the oscillatory circuit of the card, the current is converted into direct current and charges a sufficiently capacious capacitor that feeds the microcontroller of the card. The exchange of information between the card and the reader is carried out through the same coil by modulating the oscillations of the transponder's electromagnetic field. In the simplest systems, the card transmits only its unique number (identifier). In more complex systems, a two-way exchange of information takes place on the basis of a request-response principle; in such systems, cards have memory and can memorize a certain amount of information, for example, the state of the counter, store an arbitrary number, a unique identifier, and key information.

System decomposition. Based on the methods of systems theory and system analysis, decomposition was performed, evaluation criteria, analysis of smart cards and evaluation of the storage subsystem were determined for its subsequent improvement.

Decomposition is a scientific method that uses the structure of a problem and allows you to replace the solution of one large problem with the solution of a series of smaller problems, albeit interrelated, but simpler. Decomposition, as a process of dismemberment, allows to consider any investigated system as complex, consisting of separate interconnected subsystems, which, in turn, can also be dismembered into parts. Not only material objects, but also processes, phenomena and concepts can act as systems.

The main goal of this study is to improve the efficiency and reliability of information exchange between smart cards and the reader in the process of performing the function of mutual authentication using FNF. Achieving the goal of the research involves solving the following tasks and subtasks:

1. decomposition of the hardware and software part of modern smart cards and authentication systems;
2. analysis of existing methods of mutual authentication;
3. analysis of hardware components that implement a physically non-clonable function;
4. increasing the efficiency and reliability of smart cards functioning as a means of mutual authentication in various systems;
5. synthesis of hardware and software solutions for the implementation of the proposed method.

As a sign of decomposition in this study we used:

1. The functional purpose of the parts,
2. Constructive device.

Modeling of the structure of the object was carried out for visualization, study of properties, identification of significant connections, verification of the compatibility of components, study of the stability of the object in various modes.

Under the behavior of an object in this study, we will take the changes that occur with it over time. In other words, the reaction of the object to the impact, the information response to the impact. Modeling of behavior is necessary for: predicting the behavior of an object under various influences, establishing connections with other objects, developing control functions, designing technical devices, etc.

In this study, the decomposition of the smart card system by functional purpose and structural elements was carried out. Regardless of the type of power source, the system will look like:

1. the control subsystem consists of a microcontroller;

2. the data storage subsystem consists of microcircuits or individual crystals that implement random access memory (RAM) and read-only memory (PROM);

3. The communication subsystem consists of a transmit-receive interface and batteries.

The subsystem connection diagram is shown in Figure 1:

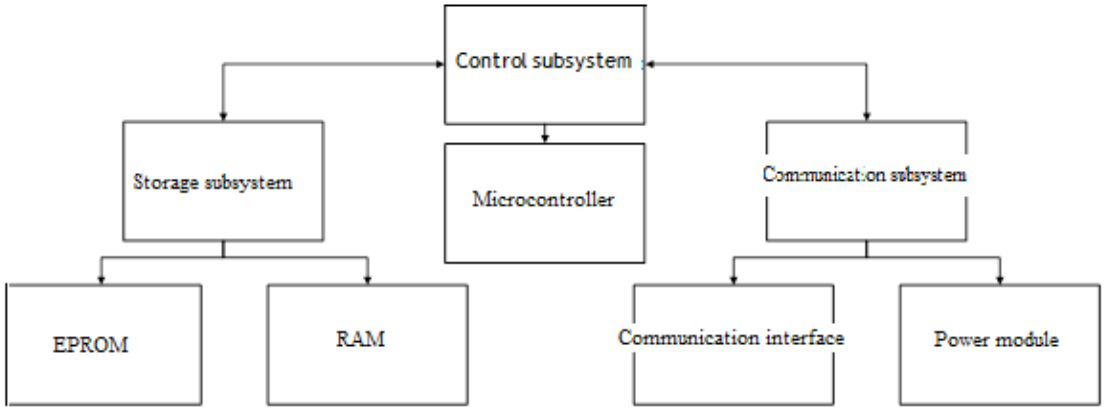

Fig. 1. Decomposition of the smart card system

Figure 1 shows that the control subsystem has feedback from the storage and communication subsystems. Depending on the type of card, the communication interface can be contact or wireless. The overwhelming majority of modern smart cards do not contain autonomous energy sources; for this reason, the power module is part of the communication subsystem. The power supply of the electronic components of the smart card is carried out through data lines with a contact method of transmitting information, or inductively using antennas or communication coils.

Smart card storage subsystem organization. The decomposition diagram shown in Figure 1 shows that the smart card memory consists of RAM and EPROM modules. RAM is the non-volatile and most expensive memory in a smart card. It is used by the processor to store fragments of executable code and intermediate data during operations, since it is the fastest type of memory. The access time to RAM is several tens of nanoseconds. A feature of the RAM is the loss of all data stored in it in case of loss (disconnection) of power supply. This is quite an important feature in the case when the device does not have its own power source.

EPROM is designed for long-term storage without power supply of identifier, key information and program code, which consists of non-volatile Flash cells, erasable programmable read-only memory (EPROM) or electrically erasable programmable read-only memory (EEPROM). The stored data can be any information required for the operation of certain applications, for example: card issuer, card serial number, or other user information. Key information and identifier can be stored explicitly or encrypted. EPROM data can only be written once and is used with prepaid cards such as telephone or disposable transit cards. Electrically Erasable Programmable EEPROM has up to 500,000 rewrite cycles and built-in logic to update the rewrite counter, as well as another limitation on operation - this is speed, it usually takes from 2 to 10 ms to erase and rewrite data into EEPROM memory. Memory card security can be ensured by symmetric cryptographic algorithms with a key length of up to 128 bits, which are used to encrypt data transferred from the card.

Figure 2 shows the relative sizes of a multiply enlarged memory cell of various types.

Fig. 2. Comparative sizes of memory boards of different types with a size of 1 bit per chip

Figure 2 shows that the largest size is in the RAM memory cells, which are used for RAM, and the smallest - in the memory cells used to store the identifier and key information. The analysis should also note the economic component of the production of smart cards with different memory sizes. Thus, a unit of EPROM memory is 4 times more expensive than a unit of ROM and 4 times cheaper than a unit of RAM.

Smart card network subsystem organization. According to the performed decomposition of the smart card system (Fig. 1), the communication subsystem consists of a communication interface and a power supply module. To provide power to the electronic components located in the smart card frame, the reader constantly maintains the required potential on the wired contacts or emits the carrier frequency in the case of using a wireless interface. The interaction of the reader and the smart card occurs after the formation of the required electrical potential on the electronic components and the loading of the controller microcode. Interaction protocols implement both one-way and two-way data exchange; both the reader and the smart card can act as initiators of the connection, depending on the used communication protocol.

The structure of the communication interface depends on the type of card, contact cards are of the ISO / IEC 7816 or USB standard, and contactless ones use RFID technology based on the ISO 14443, ISO 15693 standards, etc. In contact cards, the I / O channel of the chip for a smart card is a unidirectional serial interface, so at each moment only 1 bit of information can be transmitted over it and transmitted only in one direction (half duplex). To organize data transfer between the reader and the card in a contact way, two lines of the card interface are used. The I / O line (I / O line) carries data bits. The second line is the clock (CLK line) indicates when to sample in the I / O line to receive a data bit, so each exchange participant monitors whether it is in a transmit or receive state. The USB interface uses two additional lines to form a second I / O channel or full duplex connection, which can increase the speed up to 1.5 Mbps.

In contactless cards, communication with the reader takes place via radio signals. To carry out the procedure of reading information, it is necessary to place the card in the area of action of the electromagnetic field of the reader coil. For different frequency ranges and types of readers, the maximum distance varies from 12 to 50 cm. The contactless method of information transmission is often used in those areas where it is necessary to perform the operation of information transfer quickly, for example, in public transport, in access control and management systems.

The wireless data transfer protocol between the reader and the smart card generally contains the following operations:

1. The reader is waiting for the connection or appearance of the card in the access zone when using the contactless system

2. The card, connecting or appearing in the zone of a sufficient level of the reader's radio signal, receives power supply by contact or induction.

3. The reader receives the card's identifier and can optionally send a request to read the memory storing information for verification (key information, initialization vector).

4. The card generates a data packet containing key information and card identifier, and transmits to the reader

5. The reader compares the received data with the reference one, if the card identifier matches the password, identification is successful. If the key information does not match, the access control subsystem reader denies service.

The research carried out on the principles of construction and algorithms for the operation of smart cards made it possible to classify it as a complex system. Like any complex system, a smart card has a number of disadvantages, such as:

1. Key information is stored explicitly,

2. Access to key information can be obtained by any reader,

3. Low imitation resistance of the system,

4. In contactless cards, communication takes place via an open communication channel.

Implementation of these vulnerabilities will allow an attacker to:

1. Having obtained physical access to the smart card, extract key information and use it for subsequent verification and access,

2. After intercepting the key information of the wireless card for the reader, reuse it,

3. After gaining access to the smart card, change the secret information so that a trusted user will not gain access to the system.

These vulnerabilities can lead to threats of loss, theft or modification of key information and personal data, disruption of the correct and efficient operation of the system. Studies have shown that the information storage subsystem has the largest number of vulnerabilities. This is due to the peculiarities of operation and the hardware architecture of the cards. To increase the imitation resistance of the system, it is proposed to use the technology of physically non-cloning functions as a method of implicit storage of key information and an algorithm for mutual authentication of the reader and smart card.

Development of a method for implicit storage of key information using PUF based on SRAM

A physically unclonable function (PUF) is a function applied using a physical system that has the following properties:

1. on a request to a function (impact on a physical system), it is easy to get an answer - the result of a function's work (a reaction of a physical system);

2. the given function is practically difficult to reproduce, it is computationally difficult to mathematically simulate or copy in some other way (non-cloning property);

3. for a unique request, the function must return a unique response.

A mathematically physically non-clonable function can be described by the values of pairs of input and output values, which are respectively the values of the CH (Challenge) request signals and the values of the R (Response) output signals [1]. Thus, any FNF can be represented by a set of possible request-response values and can be described by the following function:

$$R_i = PUF(CH_i) \quad (1)$$

In other words, it is a function embodied in a physical structure that is easy to assess but difficult to characterize, simulate, or reproduce. The physical structure containing the PUF consists of many random components that are formed during the manufacturing process of the PUF carrier and are uncontrollable. The output crypto-material is exactly the "request-response" pair. The mathematical analogue of a physically non-clonable function is a hash function. In this case, the physical system itself acts as the key of the hash function. Physically non-cloning functions are unidirectional - it is almost impossible to recover the request from the response. PUF has two important properties:

1. the practical impossibility of creating a physical copy of the PUF;

2. the impossibility of creating an accurate mathematical model of the PUF,

The response cannot be computed if the exact request parameters and other request-response pairs are known. These properties together and define the concept of "non-cloning".

The variability of the PUF implementation on a chip of integrated circuits allows us to determine the main directions of PUF application [2]: digital watermarks and fingerprints [3], generation of random number sequences [4], identification and authentication [5], implementation of hardware hash functions [6], detection of hardware bugs [7], generation of encryption keys [8], radio frequency identifiers [9], etc.

Since the smart card contains a RAM microcircuit, it is of the greatest interest to study the possibility of using SRAM-based PUF as a method of implicit storage of key information to improve imitation resistance.

Static random access memory (SRAM) is a semiconductor random access memory in which each binary or ternary bit is stored in a positive feedback circuit that maintains state without the regeneration required in heap memory. This type of memory has features that will allow you to use it as FNF:

1. Stores data only while there is power,

2. Has unpredictable (random) memory contents after power-on.

The memory cell of the RAM consists of four transistors that implement two inverters with cross-feedback, which are always in one of two states, which allows it to be used to store one bit of information. When the supply

voltage is applied, all SRAM cells are set to one of two possible states; moreover, due to the circuitry symmetry of the RS-flip-flop, it is not known beforehand which final state the cell will take - "0" or "1". This state is random and is determined by many factors, such as: features of the technology of manufacturing microcircuits and many asymmetric elements in each cell of the RAM (length of connecting conductors, their geometric dimensions, inhomogeneity of the physical and chemical properties of silicon, deviation of signal delays, etc.). These features allow obtaining a unique PUF each time power is applied to the memory card.

In [10], during memory initialization, two types of values in memory cells were identified: stable and unstable. In stable cells, the same values appeared every time during initialization. they can be used as a method for storing key information of smart cards, physical key based authentication. In unstable cells, random values appeared every time. They can be used as a built-in hash function for a mutual authentication algorithm, a random sequence generator for encryption, or as additional blocks of pseudo-random data when transmitting useful information.

Identifying static properties of the values in SRAM cells. To conduct research on uninitialized memory, an experimental setup was assembled, shown in Figure 3, which is based on a universal Arduino Mega board based on an Atmel 2560 processor, static RAM chips, a quick-detachable panel for memory chips, and a transistor switch for controlling the device's power supply. The microcontroller in this setup is used to read uninitialized memory, control interruption and power supply between readings, primary processing and transfer of data to a personal computer. Ten HM62256 static random access memory chips from different manufacturers (Hynix, Toshiba, Hundai) were used as the samples under study. The main goal of this stage is to determine the statistical properties of values in the cells of static RAM microcircuits when they are used as physically non-clonable functions. The main tasks of this stage are: determining the number of stable and unstable memory cells, the number of stable and unstable bits, identifying periodic patterns in the formation of initialization values of static RAM microcircuits.

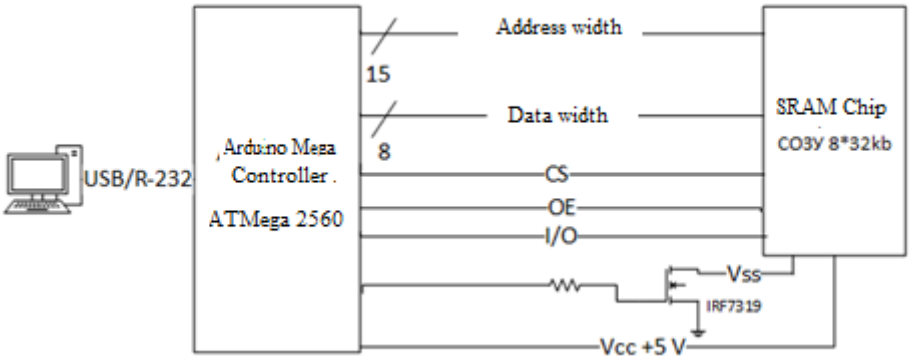

Fig. 3. Scheme of the experimental setup

To solve the set tasks, it is necessary to use data from the technical documentation of RAM memory cards to determine the delays between readings of cell values. The timeline for the selected memory cards is shown in Figure 4.

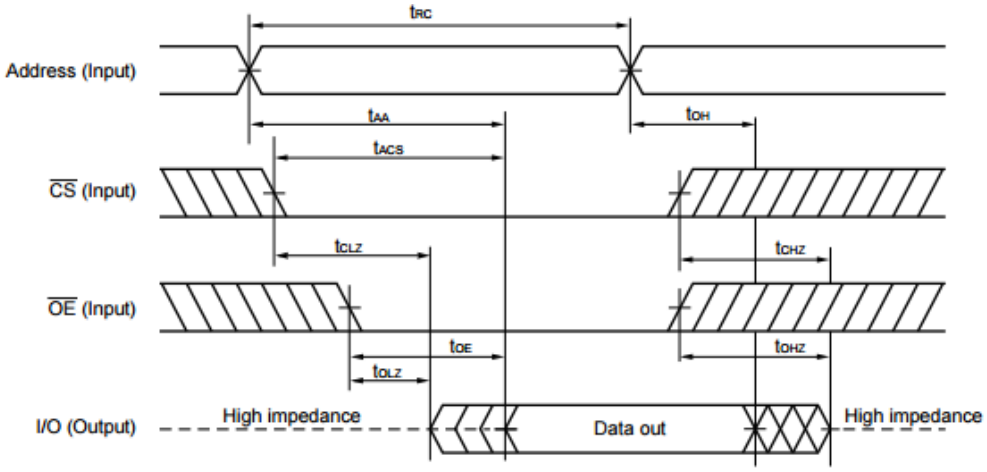

Fig. 4. Timeline of access to the static RAM cell

The timeline determines the sequence of signals for each stage of interaction with the RAM microcircuit and the delay times of the control signals for the memory microcircuit.

The algorithm for reading data reading in general is shown in Figure 5. It uses the following variables: i is the counter of the experiment number, N is the specified number of measurements for the experiment, Adr is the address of the memory cell for reading, S is the memory length, V Is the value of the initialized memory cell, t is the delay for changing the address, T is the delay with turning off the power for a repeat experiment.

At the initial stage, to solve the problem in order to improve the accuracy of the study, 100 measurements were used for each investigated sample of RAM.

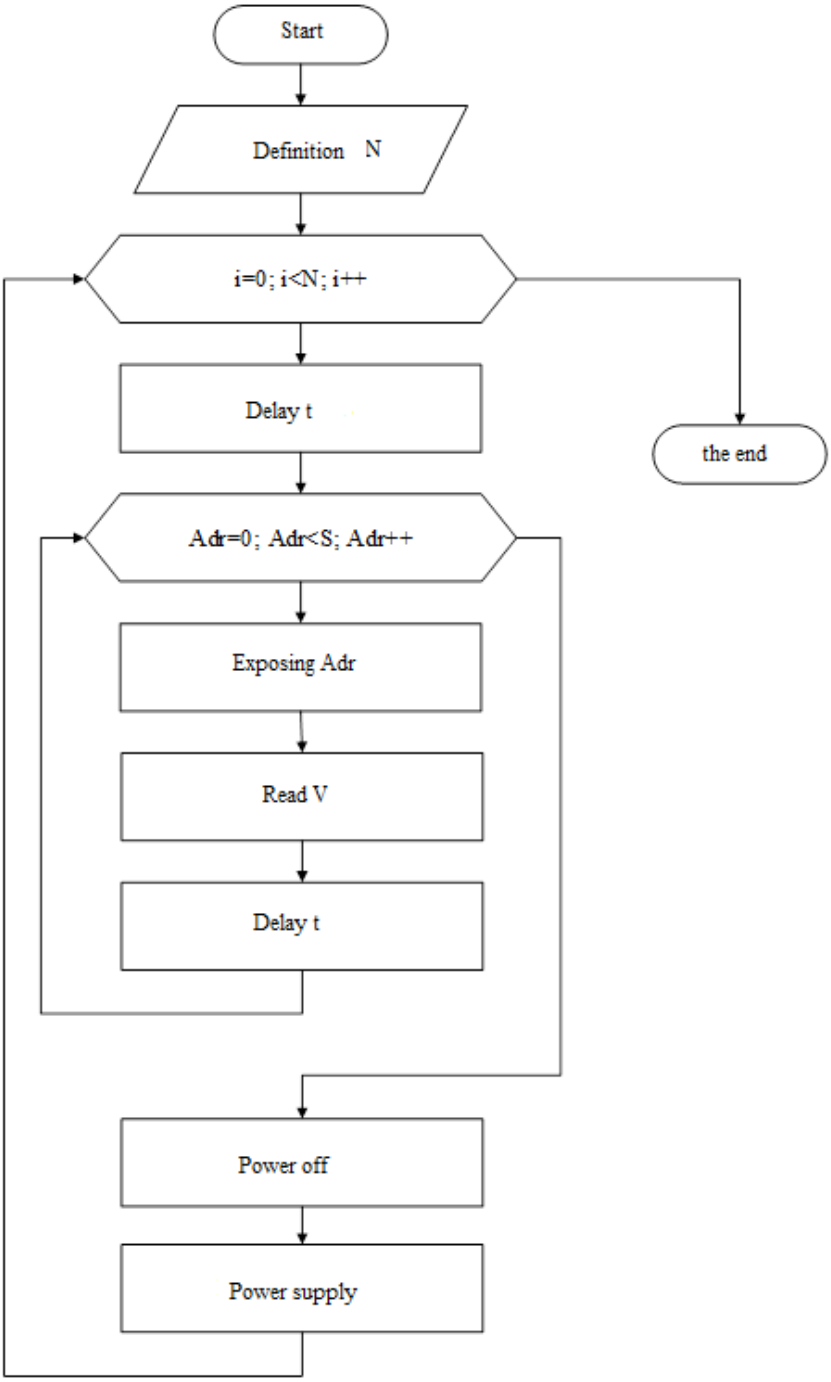

Fig. 5. Algorithm for reading the values of the initialized memory

To determine stable and unstable cells and their addresses, the results obtained in the algorithm (Fig. 5), it is necessary to compare the values of the corresponding cells in all measurements.

Additionally, the data analysis showed that for all the samples under study the condition

$$N_{стаб} * 8 < n_{стаб} \quad (2)$$

where $N_{стаб}$ – number of stable bytes, $n_{стаб}$ – number of stable bits.

This confirms the original assumption that in unstable bytes, some of the bits remain stable. This fact limits the range of random values generated in memory cells during initialization. Thus, the studies carried out make it clear that when used as an identifier or an initialization vector, a sequence of 8 bytes (64 bits) length, subject to a uniform distribution of the probability of occurrence of values "0" and "1" in each position of each byte, gives under the condition of "brute force "264 = 18446744073709551616 values, while if each byte changes not 8, but 4 bits, and the rest remain stable, then under the condition of" brute force "the number of unique combinations is reduced to 232 = 4294967296 values.

Thus, an optimization problem arises on the one hand, to reduce the predictability of the initialization vector, and on the other hand, to increase the reliability of detecting the displacement of the initialization vector in the memory "snapshot" with the general task of reducing the length of the transmitted data sequence.

Figures 6-8 show the distribution maps of values for memory cards.

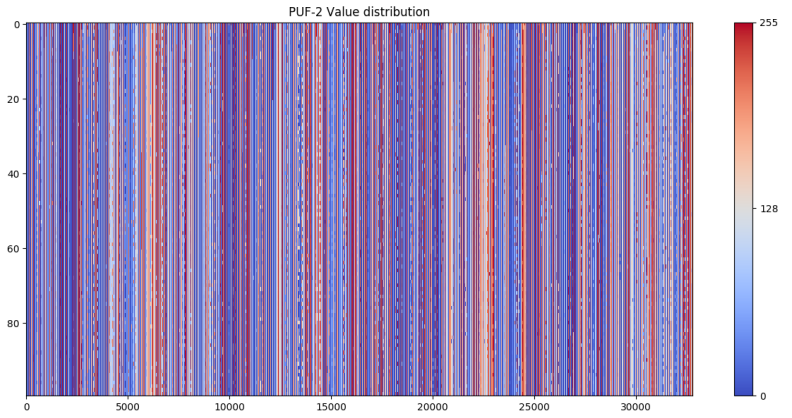

Fig. 6. Map of the distribution of values in the memory cells of the sample SRAM No. 2 for 100 measurements

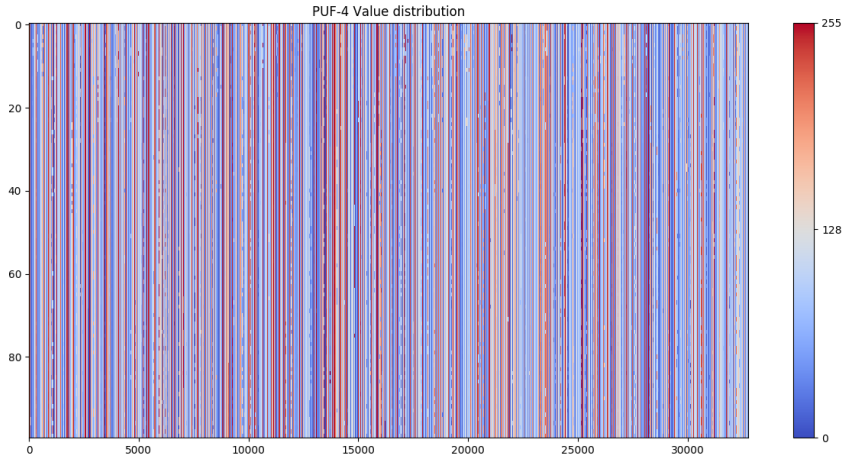

Fig. 7. Map of the distribution of values in the memory cells of the sample SRAM No. 4 for 100 measurements

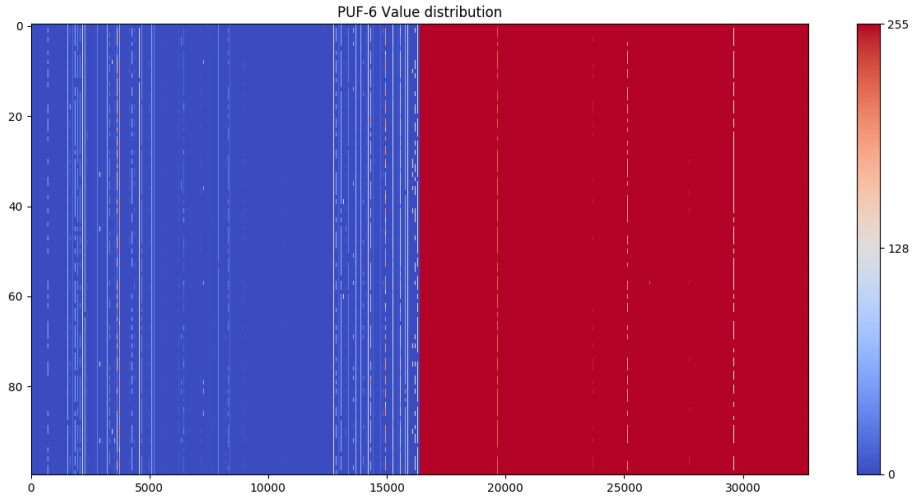

Fig. 8. Map of distribution of values in memory cells of sample SRAM No. 6 for 100 measurements

The results of the studies carried out for the most characteristic samples No. 2, No. 4 and No. 6 for 100 measurements are presented in Figures 6-8. The addresses of the cells are plotted along the horizontal axis, along the vertical axis of the measurement numbers. The color on each card shows the value in the memory cell in the range from 0 to 255.

The measurements performed and the initial analysis of the data show that a significant number of cells are unstable, while in sample No. 2 there are periodically repeating regions with a predominance of zero and one values in all bit positions (numbers 0 and 255). Sample No. 6 (and in the general case, samples 6 to 10) have two pronounced areas of prevalence of values "0" and "1", which means that there are 2 "banks" of memory in the board. Solid vertical lines on maps indicate stable values, color indicates the value in a given cell. Broken vertical lines represent unstable cells. The alternation of solid and dashed lines, as well as different colors of solid lines is an important characteristic of an ideal physically non-cloning function proposed for use in a smart card for storing key information in an implicit form.

Studies have shown that FNFs in the cells of the RAM have a chaotic distribution, using stable values, you can modify the smart card storage subsystem in such a way that it will not permanently store key information, and the initialization vector will appear in memory only at the moment of authentication, and its random distribution only a trusted system will know, in which a snapshot of values in stable cells and their addresses will be stored, so the purpose of the study in increasing imitation resistance and imposing an intercepted signal (key information) is implemented by modifying the storage subsystem. To increase the speed of the initial calculation of the FNF in the cells of the RAM and register the impression in the system, it is necessary to reduce the initial number of measurements, so, using the theorem of the product of probabilities for independent events carried out under normal conditions, we obtain formula 3:

$$P_{ош} = 2^{-N} \tag{3}$$

where $P_{ош}$ – the probability of an error, N – is the number of studies performed.

Thus, increasing the number of experiments reduces the likelihood of errors, but complicates the process of initial registration of the card. Using 25 measurements, we will reduce the initial registration time by 4 times compared to 100 measurements, and we get expression 3:

$$P_{ош} = 2^{-25} = 0.00000003 \tag{4}$$

Thus, the analysis of 25 measurements will reduce the error probability to 1 error in 33 million.

To increase the accuracy of the study and to compensate for possible errors, it is of interest to analyze the possibility of using an auto-correlation function, which will allow a signal that has an error to be accepted as reliable with a certain probability of less than one.

The studies carried out make it possible to increase imitation resistance and reduce the likelihood of selection by enumerating key information.

Thus, the analysis and decomposition of the system, the study of the properties of PUF based on SRAM, makes it possible to develop a model of a smart card, replacing the traditional storage scheme for key information on PUF based on stable values in the cells of the SRAM, imitation resistance of the system. To improve the communication sub-

system, it is necessary to develop a mutual authentication algorithm. To exclude the possibility of using the intercepted message.

Algorithm of mutual authentication using SRAM PUF as method of implicit storage of key information

The main disadvantage of the communication subsystem is the use of an open communication channel for the transmission of password-key information. So, by gaining access to a contact card or by intercepting a contactless radio signal, you can get unauthorized access to key information. The analysis of the existing vulnerabilities of smart cards and existing solutions excludes the possibility of protecting the communication channel, therefore we have proposed a new approach and the use of a mutual authentication system.

For the initial registration of the card, a modified algorithm will be used (Fig. 5), in which there will be 25 consecutive reads of uninitialized memory and further comparison of the values of each cell of all measurements, after which an array of stable values and their addresses is formed, which will be further used as a key ...

To increase the imitation resistance, namely the imposition of the intercepted signal, we propose to use the mutual authentication algorithm, which is shown in Figure 9:

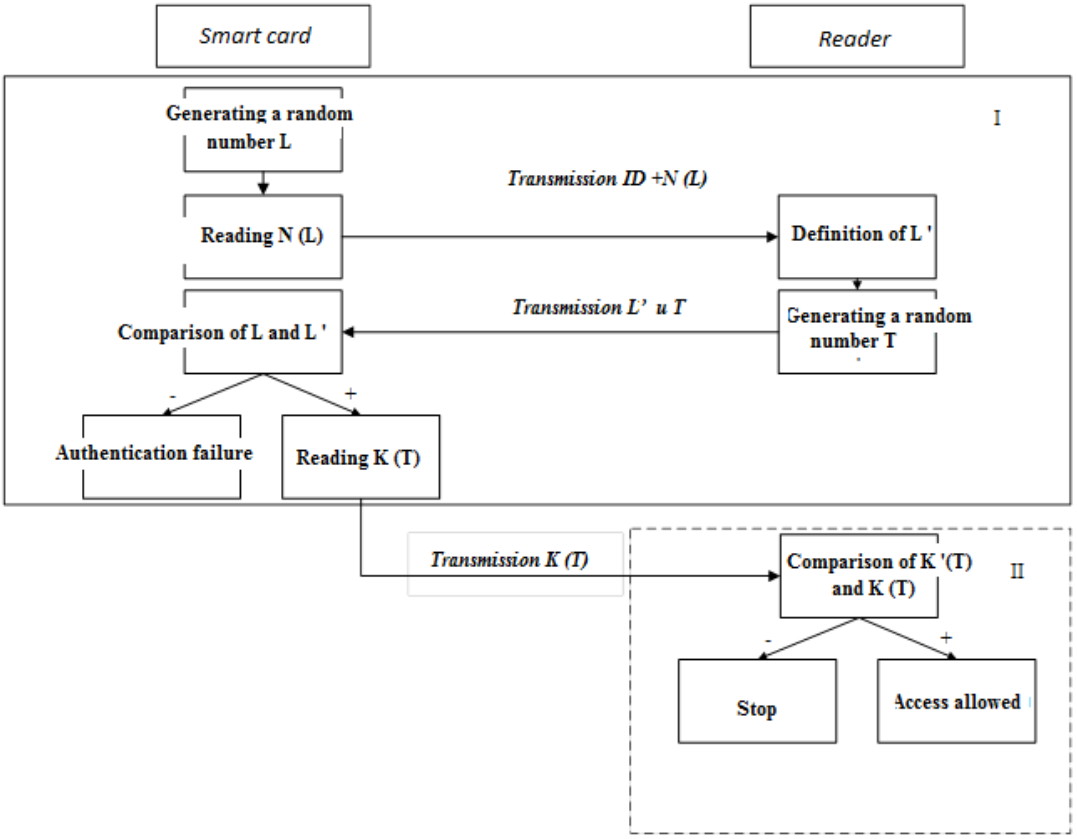

Fig. 9. Mutual authentication algorithm

The algorithm consists of two main stages. The task of the first stage is to check the reliability of the reader. The smart card microcontroller generates a random number L, reads N bytes from the uninitialized RAM starting at offset L, and then sends N (L) and a unique card ID (CardID). The reader calculates an offset L' based on a pre-existing snapshot of a specific RAM. If the offset is calculated correctly, then the map goes to stage 2. The task of the second stage is to check if the card is trying to gain access, so the reader calculates a random offset T and sends it to the card, the smart card receives T and reads successive K bytes with offset T, after which the card sends K (T) if K '(T) match the system snapshot, the card and reader are mutually authenticated. So each time using random values K and N, you can endlessly use the same RAM board, an attacker cannot get a full snapshot of the system by intercepting a secret message and even receiving it - it will be a random set of bytes with a random offset. Thus, with each authentication procedure, the initialization vector N (L) and the key K (T) are changed.

For the impossibility of creating a snapshot of the system in further studies, it is necessary to consider the possibility of using encryption to protect the stages of information exchange, for which unstable PUF values can be used as an analogue of the hash function.

Conclusions. The analysis of the results of our research shows an increase in the imitation resistance of smart cards by using PUF based on SRAM as a method for storing key information in an implicit form. Using a mutual authentication algorithm eliminates the possibility of imposing an intercepted signal. For a comprehensive study, it is of interest to use the autocorrelation function to eliminate errors and interference in the signal, and to use the encryption of some stages in the authentication algorithm using unstable PUF values as an analog of the hash function.

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ЛИНГВИСТИЧЕСКОЕ ОПИСАНИЕ МНОГОЭТАПНЫХ НЕСТАЦИОНАРНЫХ ПРОЦЕССОВ

THE LINGUISTIC DESCRIPTION OF MULTI-STAGE NON-STATIONARY PROCESSES

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Аннотация. *Рассмотрена проблема формализации лингвистического описания социально-экономических и организационно-технологических процессов на основе построения периодизации, дающей возможность разбить их на этапы для более детального изучения.*

Материалы и методы, результаты и обсуждения. *Методологической основой исследования является понятийный аппарат теории лингвистической переменной Л. Заде в сочетании с экспертными технологиями оценивания.*

С учетом специфики описания нестационарных социально-экономических и организационно-технологических процессов разработана лингвистическая переменная, значения которой (темпоральные термы) соответствуют этапам процесса. Предложен новый тип темпоральных термов, семантически описываемых битрапециевидными функциями принадлежности, и указана экспертная процедура построения этих термов. Предложена и обоснована (утверждениями о свойствах) система алгебраических операций над темпоральными термами, позволяющая формулировать синтаксические и семантические правила преобразования термов. Для описания зависимости характеристик многоэтапных процессов от времени предложено использовать пары лингвистических переменных, первая из которых соответствует исследуемой характеристике, а вторая – этапу процесса.

Заключение. *Предложенное формальное лингвистическое описание многоэтапных процессов позволяет проводить анализ и прогнозирование функционирования социально-экономических и организационно-технологических систем с использованием инструментальных средств интеллектуальной поддержки научных исследований (в частности применяя процедуры нечеткого логического вывода на основе нечеткой продукционной модели знаний о предметной области), что может способствовать повышению научной обоснованности управленческих решений.*

Ключевые слова: многоэтапный процесс, лингвистическая переменная, темпоральный терм.

Abstact. *The problem of formalizing the linguistic description of socio-economic and organizational-technological processes based on the construction of periodization, which makes it possible to break them into stages for a more detailed study, is considered.*

Materials and methods, results and discussions. *The methodological basis of the study is the conceptual apparatus of the theory of the linguistic variable L. Zadeh in combination with expert assessment technologies.*

Taking into account the specifics of the description of unsteady socio-economic and organizational-technological processes, a linguistic variable has been developed, the values of which (temporal terms) correspond to the stages of the process. A new type of temporal terms that are semantically described by bitrapezoid membership functions is proposed, and an expert procedure for constructing these terms is indicated. A system of algebraic operations on temporal terms is proposed and justified (by assertions about properties), which makes it possible to formulate syntactic and semantic rules for the transformation of terms. To describe the dependence of the characteristics of multi-stage processes on time, it is proposed to use pairs of linguistic variables, the first of which corresponds to the studied characteristic, and the second to the stage of the process.

Conclusion*. The proposed formal linguistic description of multi-stage processes allows us to analyze and predict the functioning of socio-economic and organizational-technological systems using tools for the intellectual support of scientific research (in particular, using fuzzy inference procedures based on a fuzzy production model of knowledge about the subject area), which can contribute to increase the scientific validity of management decisions.*

Key words: multi-stage process, linguistic variable, temporal term.

Introduction. One of the general methodological approaches in the analysis of complex non-stationary processes of a very different nature is the division of the time interval of consideration (the lifetime of the process) into subintervals (stages, periods), each of which is determined by its own set of indicators, its own limitations and its own evaluation criteria [1]. At the same time, the process conditions characteristic of the considered temporal (temporal) subinterval can be inherent at specific points in time to varying degrees, which causes the application of the formal apparatus of fuzzy logic ([2]) to the temporal description of processes. The aim of this work is to formalize the linguistic description of non-stationary processes based on fuzzy temporal modeling of stages.

Materials and methods, results and discussions. The methodological basis of the research is the conceptual apparatus of the theory of linguistic variable L. Zadeh ([3]) in combination with expert assessment technologies (for example, [4]). To formalize operations on temporal terms, the apparatus of context-free grammars was used ([5]).

Temporal description of multistage processes

By the lifetime of the process TL we mean its projection onto the time continuum. If the lifetime of the process is limited, then it is a length of time

$$TL = [t_{start}, t_{stop}],$$

where t_{start} corresponds to the start of the process, and t_{stop} the moment it ends. In this case, it is convenient to consider the lifetime as a pair $< \tau, \delta >$, where $\tau = t_{start}$, and $\delta = t_{stop} - t_{start}$ - the duration of the lifetime.

The lifetime of a process (as a set of stages and the relationship between them) can be formalized using a linguistic variable

$$< Stage, T, TT_{Base}, GT, MT >,$$

where *Stage* the name of the linguistic variable "Stage of the life of the process"; T - time continuum; TT_{base} – is the base vector of temporal terms; GT - is a syntactic rule allowing to generate the names of temporal terms from the names of elements TT_{Base}; MT - a semantic rule establishing a correspondence between temporal terms and fuzzy subsets of T.

We will assume that the semantics of the temporal term tt (corresponding to the stage of the process) is determined by a fuzzy interval having a bit-trapezoidal membership function (Fig. 1). The proposed type of semantics of temporal terms makes it possible to describe the stages of the process more accurately (in comparison with terms, the semantics of which is determined by the usual trapezoidal membership function), taking into account the transition processes between the stages.

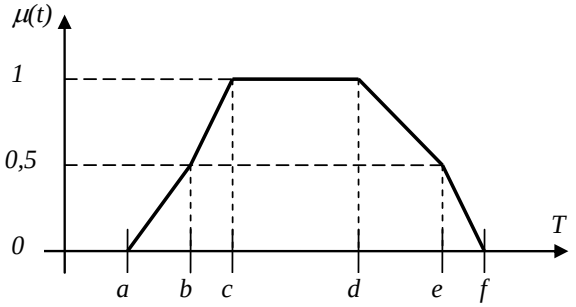

Fig. 1. Bi-trapezoidal membership function of a temporal term

Formally, the bi-trapezoidal membership function is a 6-parameter piecewise linear function $\mu_{a,b,c,d,e,f} : T \to [0,1]$, where T - is a continuum; $a,b,c,d,e,f \in T$ - are parameters ($a < b < c < d < e < f$) определяется формулой:

$$\mu_{a,b,c,d,e,f}(t)=\begin{cases}0, if\ t<a\\ \frac{0,5}{b-a}\cdot t+\frac{-0,5\cdot a}{b-a}, if\ a\le t<b\\ \frac{0,5}{c-b}\cdot t+\frac{0,5\cdot c-b}{c-b}, if\ b\le t<c\\ 1, if\ c\le t<d\\ \frac{-0,5}{e-d}\cdot t+\frac{e-0,5\cdot d}{e-d}, if\ d\le t<e\\ \frac{-0,5}{f-e}\cdot t+\frac{0,5\cdot f}{f-e}, if\ e\le t<f\\ 0, if\ f\le t\end{cases}$$

It is important to note that the parameters $a,b,c,d,e,f\in T$ have a natural interpretation and can be obtained as a result of a survey of experts:

- the parameters *a, f* correspond to the moments in time - the boundaries of the temporal region, which in no way can be attributed to the considered stage of the process (the segment *[a, f]* is the carrier of a fuzzy interval);

- the parameters c, d correspond to the moments of time - the boundaries of the temporal region, which can be fully attributed to the stage of the process under consideration (the segment *[c, d]* is the core of the fuzzy interval);

parameters *b* and *e* correspond to points in time - the boundaries between the considered and adjacent (previous and next) stages (transition points of the membership function).

At the same time, the issues of organizing team examinations and analysis to assess the stability of the results to possible changes in expert judgments (for example, [6]) require additional research.

For further formalization, it is convenient to use the characteristics of the duration of the temporal term tt (process stage):

- optimistic duration: $\delta_{opt}=d-c$;
- standard duration: $\delta_{norm}=e-b$;
- pesimistic duration: $\delta_{pes}=f-a$.

The durations of transient processes correspond to the lengths of the segments [*a*, *b*], [*b*, *c*], [*d*, *e*] and [*e*, *f*], which we denote as δ_{e_pre}, δ_{i_pre}, δ_{i_post}, δ_{e_post}. These values will be called the durations of the external pre-stage, internal pre-stage, internal post-stage, and external post-stage, respectively. Fig. 2 illustrates the concepts introduced

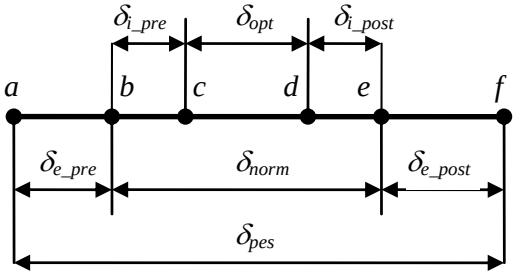

Fig. 2. The relationship of durations and parameters of the bi-trapezoidal membership function of the temporal term *tt*

Thus, the membership function for a temporal term tt_N can be redefined in terms of durations as a 6-component vector

$$\mu_N=<\tau^{(N)},\delta_{e\_pre}^{(N)},\delta_{i\_pre}^{(N)},\delta_{norm}^{(N)},\delta_{i\_post}^{(N)},\delta_{e\_post}^{(N)}>$$

Here N - the name of the temporal term, τ the initial moment of time coinciding with the parameter a. The base vector of temporal terms is a finite linearly ordered set $\{tt_b,\ldots,tt_i,\ldots,tt_e\}$, in which tt_b - an initial stage, tt_i - some intermediate stage, and tt_e - a final stage. The membership functions of these temporal terms must satisfy the requirements clearly shown in Fig. 3.

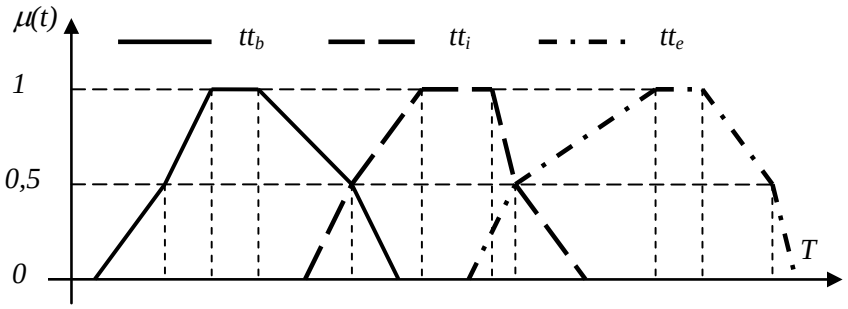

Fig. 3. Membership functions of elements of the base vector of temporal terms TT_{Base}

The syntactic rule *GT* and the semantic rule *MT*, which make it possible to pass from the basic vector of temporal terms TT_{BASE} to the set of all terms *TT*, will be built on the basis of the introduced operations on temporal terms *O1 ÷ O10*.

The entered operations have a general syntax:

1. The alphabet (set of terminal metacharacters) includes the following subsets:

– N_{Base} - names of elements of the base vector of temporal terms;

– R_+ - a set of rational numbers greater than 0, written in the 10th number system;

– Z_+ - a set of integers greater than 0, written in the 10th number system;

– $\{*, e\_pre*, i\_pre*, e\_post*, i\_post*, >>, +, /, :, .1, .2, (,)\}$ - a set of special characters.

2. The grammar of the syntactic rule, presented in the Backus-Naur form:

$prop := n:m.1 \mid n:m.2$, where $n, m \in Z_+$;

$term := N$, where $N \in N_{Base}$;

$$term := (term)*\alpha \mid (trem)e\_pre*\alpha \mid (term)i\_pre*\alpha \mid (term)e\_post*\alpha \mid (term)i\_post*\alpha \mid$$
$$(term) >> \alpha \mid (term + term) \mid (term)/prop$$

where $\alpha \in R_+$.

Semantically introduced operations are determined by setting / changing the values of the parameters of the bit-trapezoidal membership function of the temporal term: *O1*.

The operation of initiating a basic temporal term:

$$\mu_N = < \tau^{(N)}, \delta_{e\_pre}^{(N)}, \delta_{i\_pre}^{(N)}, \delta_{norm}^{(N)}, \delta_{i\_post}^{(N)}, \delta_{e\_post}^{(N)} >$$

where the values $\tau^{(N)}$, $\delta_{e\_pre}^{(N)}$, $\delta_{i\_pre}^{(N)}$, $\delta_{norm}^{(N)}$, $\delta_{i\_post}^{(N)}$, $\delta_{e\_post}^{(N)}$ for the base temporal term and name N are set in a dialogue with the expert.

O2. Time shift operation of a temporal term:

$$\mu_{(N)>>\alpha} = < \tau^{(N)} + \alpha, \delta_{e\_pre}^{(N)}, \delta_{i\_pre}^{(N)}, \delta_{norm}^{(N)}, \delta_{i\_post}^{(N)}, \delta_{e\_post}^{(N)} >$$

O3. The operation of multiplying (increasing / decreasing the standard duration) of a temporal term:

$$\mu_{(N)*\alpha} = < \tau^{(N)}, \delta_{e\_pre}^{(N)}, \delta_{i\_pre}^{(N)}, \delta_{norm}^{(N)} \cdot \alpha, \delta_{i\_post}^{(N)}, \delta_{e\_post}^{(N)} >,$$

when $\alpha \geq \dfrac{\delta_{i\_pre}^{(N)} + \delta_{i\_post}^{(N)}}{\delta_{norm}^{(N)}}$.

O4. Operation of changing the duration of the external pre-stage of a temporal term:

$$\mu_{(N)e\_pre*\alpha} = < \tau^{(N)} + \delta_{e\_pre}^{(N)} \cdot (1-\alpha), \delta_{e\_pre}^{(N)} \cdot \alpha, \delta_{i\_pre}^{(N)}, \delta_{norm}^{(N)}, \delta_{i\_post}^{(N)}, \delta_{e\_post}^{(N)} >$$

O5. Operation of changing the duration of the internal pre-stage of a temporal term:

$$\mu_{(N)i\_pre*\alpha} = < \tau^{(N)}, \delta_{e\_pre}^{(N)}, \delta_{i\_pre}^{(N)} \cdot \alpha, \delta_{norm}^{(N)}, \delta_{i\_post}^{(N)}, \delta_{e\_post}^{(N)} >,$$

when $\alpha \leq \dfrac{\delta_{norm}^{(N)} - \delta_{i\_post}^{(N)}}{\delta_{i\_pre}^{(N)}}$

O6. Operation of changing the duration of the internal post-stage of a temporal term:

$$\mu_{(N)i\_post*\alpha} =< \tau^{(N)}, \delta_{e\_pre}^{(N)}, \delta_{i\_pre}^{(N)}, \delta_{norm}^{(N)}, \delta_{i\_post}^{(N)} \cdot \alpha, \delta_{e\_post}^{(N)} >$$

when $\alpha \le \dfrac{\delta_{norm}^{(N)} - \delta_{i\_pre}^{(N)}}{\delta_{i\_post}^{(N)}}$

O7. Operation of changing the duration of the external post-stage of a temporal term:

$$\mu_{(N)e\_post*\alpha} =< \tau^{(N)}, \delta_{e\_pre}^{(N)}, \delta_{i\_pre}^{(N)}, \delta_{norm}^{(N)}, \delta_{i\_post}^{(N)}, \delta_{e\_post}^{(N)} \cdot \alpha >$$

O8. The operation of allocating the initial substage of a temporal term in the proportion $n:m$:

$$\mu_{(N)/n:m.1} =< \tau^{(N)}, \delta_{e\_pre}^{(N)}, \delta_{i\_pre}^{(N)}, \delta_{norm}^{(N)} \cdot \frac{n}{n+m}, \delta_{i\_post}^{(N)}, \delta_{e\_post}^{(N)} >,$$

when $\dfrac{n}{n+m} \ge \dfrac{\delta_{i\_pre}^{(N)} + \delta_{i\_post}^{(N)}}{\delta_{norm}^{(N)}}$

O9. The operation of allocating the final sub-stage of a temporal term in the proportion $n:m$:

$$\mu_{(N)/n:m.2} =< \tau^{(N)} + \frac{\delta_{norm}^{(N)} \cdot n}{n+m}, \delta_{e\_pre}^{(N)}, \delta_{i\_pre}^{(N)}, \delta_{norm}^{(N)} \cdot \frac{m}{n+m}, \delta_{i\_post}^{(N)}, \delta_{e\_post}^{(N)} >,$$

when $\dfrac{m}{n+m} \ge \dfrac{\delta_{i\_pre}^{(N)} + \delta_{i\_post}^{(N)}}{\delta_{norm}^{(N)}}$

O10. The operation of combining temporal terms:

$$\mu_{(N1+N2)} =< \tau^{(N)}, \delta_{e\_pre}^{(N1)}, \delta_{i\_pre}^{(N1)}, \delta_{norm}^{(N1)} + \delta_{norm}^{(N2)}, \delta_{i\_post}^{(N2)}, \delta_{e\_post}^{(N2)} >$$

when $\tau^{(N1)} + \delta_{e\_pre}^{(N1)} + \delta_{norm}^{(N1)} = \tau^{(N2)} + \delta_{e\_pre}^{(N2)}$

For the operations introduced, the following statements are true:

Statement 1. Any temporal term $tt \in TT$ can be generated using the unary operations *O2* ÷ *O7* from an arbitrary basic temporal term $tt^* \in TT_{BASE}$, initiated by the operation *O1*. Exclusion of any operation from the *O2* ÷ *O7* list will result in the loss of this property.

Statement 2. The order of performing unary operations *O2* ÷ *O7* irrelevant.

Statement 3. Application of the operation of combining temporal terms *O10* to the terms obtained by applying the operations *O8* (selection of the initial substage) and *O9* (selection of the final substage) to the same term $tt \in TT$ with the same parameters of the operations will lead to the same term.

Obvious statements presented without proof can serve as a justification for the type of operations introduced.

Linguistic description of the temporal dependence of the characteristics of multistage processes.

Consider a set of characteristics of the considered non-stationary process:

$$CHR = < Chr_1, Chr_2, \dots, Chr_s >,$$

taking (after reduction to dimensionless form) values in the segment [0, 1].

We will assume that the characteristics under consideration are functions of time, determined over the entire interval of the process lifetime *TL*:

$$Chr_i = Chr_i(t),\ t \in TL,\ i=1,2,\dots,s.$$

and for the values of $Chr_i(t)$ fuzzification can be carried out with the traditional trapezoidal type of membership functions of the terms "low", "medium", "high" corresponding to the linguistic description of the levels of values of these characteristics at times *t*. Thus, to characterize Chr_i a linguistic variable is constructed

$$< Characteristic_i, C, TC_{Base}, GC, MC >,$$

Where $Characteristic_i$ - the name of the linguistic variable "characteristic"; $C = [0, 1]$ – universal set; TC_{base} = {"low", "medium", "high"} base set of terms common for all characteristics of Chri Chr_i ($i=1,2,\dots,s$); *GC* - GC is a syntactic rule that allows generating the names of the Chr_i haracteristic terms from the names of TC_{base}; *MC* - is a semantic rule establishing a correspondence between terms and fuzzy subsets.

The proposed temporal fuzzification allows us to describe the functional dependence of the characteristics of the process Chr_i ($i=1,2,\dots,s$) on time in the form of a pair of linguistic variables:

$$< Characteristic_i, Stage >$$

For linguistic variable $Characteristic_i$ syntactic and semantic rules are defined in the usual way (eg [3]) (*GC* и *MC*) extending the base term-set TC_{base} to the set of all terms of this variable. In this case, strengthening / weakening of the terms "low", "medium", "high" to represent the value $Characteristic_i$ does not change the second element of the pair $< Characteristic_i , Stage >$.

However, the use of logical connectives $\wedge$ ("and") and $\vee$ ("or") as rules requires (to ensure adequacy) a change in the value of the linguistic variable included in the pair *Stage*.

The type of such change is determined by the specifics of the subject area. For example, one option is to use the T-norm / S-conorm: min / max. In this case:

$$< (Characteristic - tc_1, \alpha_1), (Stage - tt, \beta_1) > \wedge$$
$$\wedge < (Characteristic - tc_2, \alpha_2), (Stage - tt, \beta_2) > =$$
$$= < ((Characteristic - tc_1 \wedge tc_2), \min(\alpha_1, \alpha_2)) , (Stage - tt_1, \min(\beta_1, \beta_2) >$$

where $tc_1, tc_2 \in TC_{base}$, α_1, α_2 – the degree of correspondence of the values of the characteristic *Chr* to the terms tc_1, tc_2, *tt* – is the temporal term (the stage of the process at which the characteristic *Chr* was estimated), β_1, β_2 – are the degrees of correspondence of the moments of time at which the characteristic *Chr* was measured to the term *tt* (the stage of the process under consideration). Depending on the subject area, it is possible to use other T-norms / S-conorms (intersection / union of Gamacher, product / sum of Einstein and Werner functions, etc.). In this case, it is possible to use different T-norms / S-conorms for different elements of the linguistic pair

Conclusion. Thus, in the work, taking into account the specifics of the description of non-stationary socio-economic and organizational-technological processes, a linguistic variable has been developed, the values of which (temporal terms) correspond to the stages of the process. A new type of temporal terms is proposed, semantically described by bit-trapezoidal membership functions, and an expert procedure for constructing these terms is indicated. A system of algebraic operations on temporal terms, which allows formulating syntactic and semantic rules for transforming terms, is proposed and substantiated (with statements about properties). To describe the multistage processes under consideration, it is proposed to use pairs of linguistic variables, the first of which corresponds to the studied characteristic, and the second to the stage of the process. Further development of the developed toolkit can be associated with its use in solving problems of analysis of interrelated non-stationary processes ([7]) using expert technologies ([7]).

The proposed formal linguistic description of multi-stage processes makes it possible to analyze and predict the functioning of socio-economic and organizational-technological systems using tools for intellectual support of scientific research (in particular, using fuzzy inference procedures based on a fuzzy production model of knowledge about the subject area), which can contribute to increasing the scientific validity of management decisions.

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МОДЕРНИЗИРОВАННЫЙ МЕТОД КОНТРОЛЯ ГРУПП КВАДРОКОПТЕРОВ

THE UPDATED METHOD OF CONTROL OF GROUP OF QUADROCOPTERS

ФГАОУ ВО «Северо-Кавказский федеральный университет» г. Ставрополь /
FSAEI HE "North-Caucasus Federal University"

Аннотация: *в статье представлен метод управления роем квадрокоптеров. Для координации группы необходимо формировать пространственную программную траекторию БПЛА с помощью соответствующего закона управления. Вводится понятие координированного разворота, который позволяет получить аналитические уравнения пространственных движений, выраженных через определение вектора скоростей и угла рыскания. Метод был протестирован в симуляторе Gazebo. Результаты используются для пространственных перемещений групп квадрокоптеров.*

Ключевые слова: групповое управление, контроль формаций, роевое движение, квадрокоптер, БПЛА.

Abstract. *In this article, the method of swarm control was presented. To coordinate the group, the spatial trajectory of UAV has to be implemented by applying efficient control law. The principle of coordinated rotation has been introduced. The coordinated rotation allows receiving analytical equations of spatial motion which are represented within defining of the vector of velocity and yaw angle. The method was evaluated in Gazebo simulator. All results were utilized to move the group within the environment.*

Key words: group control, the control of formation, swarm motion, quadrocopter, UAV.

Введение. За последние 10 лет наблюдается широкое и массовое использование БПЛА для решения практических задач [4]. В настоящее время, рынок беспилотных технологий предлагает огромный выбор доступных по цене и простых в сборке моделей БПЛА с мощными бортовыми вычислителями и возможностью установки дополнительных устройств. Наиболее популярным типом является квадрокоптер, используемый как в коммерческой индустрии, так и в академической среде. Квадрокоптеры оборудованы бортовыми сенсорами и популярны из-за своего размера и наличием возможности “зависать” над объектами и свободно перемещаться в пространстве. Квадрокоптеры могут быть использованы в различных областях, начиная от мониторинга, задействования их в поисковых мероприятиях до применения в спасательных операциях [4]. Квадрокоптеры объединенные в группы могут покрыть большее пространство, собрать большее количество информации и менее восприимчивы к потерям участников группы.

Материалы и методы. Обзор известных методов решения групповой задачи. Групповой контроль может быть выполнен с помощью использования нескольких различных стратегий [9]. Каждая из них имеет преимущества и недостатки, в зависимости от выполняемой задачи. На сегодняшний день в мире существует ряд примеров демонстрирующих работоспособность алгоритмов группового управления.

Все используемые алгоритмы группового контроля можно разделить на три типа: лидер-следователь [1], виртуальную структуру [2] и поведенческий подход [3]. В первом типе один из участников выбирается как лидер группы, остальные корректируют свое движение согласно лидеру. Преимущество такого метода заключается в том, что упрощается контроль группы, поскольку управление осуществляется только лидером. Однако в случае выхода из строя лидера, контроль всей группой будет потерян. Виртуальная структура рассматривает всю группу как фиксированную структуру, представленную как одна контрольная точка. Поведенческий подход представляет запрограммированное движение группы для выполнения определенных действий, уход от коллизий, движение группы с сохранением максимально возможного малого расстояния между участниками и т.д. В большинстве случаев этот тип групповой стратегии основан на реальных природных феноменах. Для движения группы, в данной статье предлагается использовать метод, базирующийся на стратегии виртуального лидера.

Результаты и обсуждения

1. Математическая модель движения квадрокоптера

Для начала опишем систему квадрокоптера, которая имеет 6 степеней свободы и представлена 12-ю параметрами, такими как углы Эйлера φ Ψ Θ [2]. Применение углов Эйлера в системе координат, связанной с землей обозначается как p, q, r. Остальные параметры являются позициями в наземной системе координат x, y, z. Скорости представлены в локальной системе координат U, ω υ.

Далее опишем Матрицу поворота [6] вокруг трех осей.

Поворот вокруг оси OX описывается матрицей:

$$R_x=\begin{pmatrix}1 & 0 & 0\\ 0 & cos\vartheta & sin\vartheta\\ 0 & -sin\vartheta & cos\vartheta\end{pmatrix}, \quad (1)$$

вокруг оси OY:

$$R_y=\begin{pmatrix}cos\Theta & 0 & -sin\Theta\\ 0 & 1 & 0\\ sin\Theta & 0 & cos\Theta\end{pmatrix}, \quad (2)$$

вокруг оси OZ:

$$R_z=\begin{pmatrix}cos\Psi & sin\Psi & 0\\ -sin\Psi & cos\Psi & 0\\ 0 & 0 & 1\end{pmatrix}. \quad (3)$$

Матрица $D=R_x * R_y * R_z$ описывает перевод из глобальной системы координат в локальную [5]. Это матрица представлена как:

$$D=\begin{pmatrix}cos\Theta cos\Psi & cos\Theta sin\Psi & -sin\Theta\\ sin\vartheta sin\Theta cos\Psi - cos\varphi sin\Psi & sin\vartheta sin\Theta sin\Psi + cos\vartheta cos\Psi & sin\vartheta cos\Theta\\ cos\varphi sin\Theta cos\Psi + sin\vartheta sin\vartheta & cos\vartheta sin\Theta sin\Psi - sin\vartheta cos\vartheta & cos\vartheta cos\Theta\end{pmatrix}. \quad (4)$$

Трансформация от скоростей в глобальной системе координат к скоростям в локальной системе координат определяется выражениями:

$$\begin{pmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{pmatrix}=D^{-1}\begin{pmatrix}u\\ v\\ \omega\end{pmatrix}. \quad (5)$$

Трансформация угловых скоростей для перевода из одной системы координат в другую определяется как:

$$\begin{pmatrix}p\\ q\\ r\end{pmatrix}=E\begin{pmatrix}\dot{\varphi}\\ \dot{\Theta}\\ \dot{\Psi}\end{pmatrix}, \quad (6)$$

где E-матрица представлена:

$$E=\begin{pmatrix}1 & 0 & -sin\Theta\\ 0 & cos\vartheta & sin\vartheta cos\Theta\\ 0 & -sin\vartheta & cos\vartheta cos\Theta\end{pmatrix}. \quad (7)$$

Далее опишем уравнение движения, представляющее второй закон Ньютона в глобальной системе координат [7]:

$$F=m\dot{V}, \quad (8)$$

где m – масса квадрокоптера, V – скорость квадрокоптера в глобальной системе координат. Записывая полную производную скорости по времени, перепишем закон в виде:

$$F=m\dot{V}+m\,(\vec{\omega} * \vec{V}), \quad (9)$$

или

$$\begin{pmatrix}F_x\\ F_y\\ F_z\end{pmatrix}=m\begin{pmatrix}\dot{u}\\ \dot{v}\\ \dot{\omega}\end{pmatrix}+m\begin{pmatrix}p\\ q\\ r\end{pmatrix}*\begin{pmatrix}u\\ v\\ \omega\end{pmatrix}. \quad (10)$$

После выполнения векторного произведения, уравнение второго закона Ньютона будет записано как:

$$\begin{pmatrix}F_x\\ F_y\\ F_z\end{pmatrix}=m\begin{pmatrix}\dot{u}+q\omega-rv\\ \dot{v}+ru-p\omega\\ \omega+p\dot{v}-qu\end{pmatrix}. \quad (11)$$

Пренебрегая всеми силами, кроме тяги и гравитации уравнение выше перепишем как:

$$\begin{pmatrix}0\\ 0\\ mg-T\end{pmatrix}=m\begin{pmatrix}\dot{u}+q\omega-rv\\ \dot{v}+ru-p\omega\\ \omega+p\dot{v}-qu\end{pmatrix}. \quad (12)$$

Далее осуществляется переход к локальной системе координат с помощью трансферной матрицы D, получаем систему уравнений:

$$\begin{aligned} \dot{u} &= rv - q\omega - g sin\Theta \\ \dot{v} &= p\omega - ru + g sin\Theta sin\varphi \\ \dot{\omega} &= qu - pv + g cos\varphi cos\Theta - \frac{I}{m}. \end{aligned} \quad (13)$$

Затем представим уравнение тяги всех двигателей как:

$$T = b(\Omega_1^2\Omega_2^2\Omega_3^2\Omega_4^2), \quad (14)$$

где b – коэффициент тяги, Ω – угловая скорость каждого двигателя (i=1, 2, 3, 4).

В этом случае уравнение 14 перепишется в следующем виде:

$$\begin{aligned} \dot{u} &= rv - q\omega - g sin\Theta \\ \dot{v} &= p\omega - ru + g cos\Theta * sin\varphi \\ \dot{\omega} &= qr - pv + g cos\varphi cos\Theta - \frac{b}{m}(\Omega_1^2+\Omega_2^2 + \Omega_3^2 + \Omega_4^2). \end{aligned} \quad (15)$$

Для представления полной математической модели движения квадрокоптера опишем вращательное движение [8].

Представим моменты вращения в виде следующего равенства:

$$M = \dot{H}. \quad (16)$$

Полную производную вектора H запишем в виде:

$$M = \dot{H} + \omega * H. \quad (17)$$

Определим:

$$H=I^*\omega, \quad (18)$$

где I – момент инерции, ω = (p, q, r) – вектор.

Следующим этапом запишем тензор момента инерции как:

$$I = \begin{pmatrix} I_x & 0 & 0 \\ 0 & I_y & 0 \\ 0 & 0 & I_y \end{pmatrix}. \quad (19)$$

Тогда уравнение 17 перепишем в следующую систему:

$$\begin{aligned} M &= I\dot{\omega} + \omega * I\omega \\ M_x &= \dot{p}I_x + qr(I_zI_y) \\ M_y &= \dot{q}I_y + pr(I_xI_z) \\ M_z &= \dot{z}I_z + pq(I_yI_x). \end{aligned} \quad (20)$$

Согласно симметрии, относительно плоскости XZ и YZ получим:

$$I_x = I_y. \quad (21)$$

Упрощаем уравнение 20:

$$\begin{aligned} M_x &= \dot{p}I_x + qr(I_z - I_x) \\ M_y &= \dot{q}I_y + pr(I_x - I_z) \\ M_z &= \dot{r}I_z. \end{aligned} \quad (22)$$

Учитывая силу тяги и сопротивление, моменты будут переписаны как:

$$\begin{aligned} M_x &= lb(\Omega_2^2\Omega_4^2) \\ M_y &= lb(\Omega_1^2\Omega_3^2) \\ M_z &= d(\Omega_2^2\Omega_4^2\Omega_1^2\Omega_3^2), \end{aligned} \quad (23)$$

где d – коэффициент сопротивления, l – длина винта.

Преобразования системы 22 в уравнения движения представляем, как:

$$\begin{aligned} \dot{p} &= \frac{lb}{I_x}(\Omega_2^2\Omega_4^2) - qr\left(\frac{I_z - I_x}{I_x}\right) \\ \dot{q} &= \frac{lb}{I_y}(\Omega_1^2\Omega_3^2) - pr\left(\frac{I_x - I_z}{I_y}\right) \\ \dot{r} &= \frac{d}{I_z}(\Omega_2^2 + \Omega_4^2 - \Omega_1^2 - \Omega_3^2). \end{aligned} \quad (24)$$

Следующим этапом введем описание динамики двигателя [6].

Уравнения Кирхгоффа и второй закон Ньютона представляют собой уравнения двигателей квадрокоптера:

$$\begin{cases} J_r\ddot{\omega}_m + b\dot{\omega}_m = K_t i \\ L\frac{d_i}{d_t} + R_i = U - K_e\dot{\omega}_m \end{cases}, \quad (25)$$

где J_r – момент инерции вала

b – коэффициент вязкого трения

K_e – коэффициент ЭДС

$\dot{K}_t$ – момент вращения двигателя

R – электрическое сопротивление

L – индуктивность.

2. Описание конфигурации квадрокоптеров

Для проведения практических экспериментов были выбраны два квадрокоптера Клевер, которые были произведены компанией Copter Express. Базовая конфигурация квадрокоптеров включала 2300 Kv моторы, 30A контроллеры оборотов скоростей (ESCs), четыре 5046 винта и 8 канальную станцию ручного управления на 2.4 Ггц. В качестве полетного контроллера использовался Pixracer r14 [10].

Данный полетный контроллер имеет следующие характеристики: процессор 180 Мгц ARM Cortex M4, память 256 Кб, ICM-20608 Акселерометр / Гироскоп (4 Ггц) / MPU9250 Акселерометр / Гиро / Магнитометр (4 Ггц), магнитометр с температурной компенсацией HMC5983, барометр MS5611, карта памяти типа microSD для логгирования полетов.

Полетный контроллер с установленным автопилотом PX4 обеспечивает отправку сигналов широкоимпульсной модуляции на 4 контроллера оборотов, контролирующих скорости вращения двигателя, а также его тягу. Сенсоры на борту включают гироскоп и акселерометр для определения скоростей и углового положения в пространстве. Отдельный GPS модуль используется для определения положения квадрокоптера относительно земли. Управление квадрокоптера осуществляется через **LoRa 2.4 Ггц модуль, осуществляющий дуплексную передачу как управляющих сигналов от наземной станции на квадрокоптер, так и телеметрии от квадрокоптера на наземную станцию.**

Наземная станция представлена ноутбуком с установленной Linux ориентированной операционной системой с набором необходимых библиотек.

3. Программное обеспечение

Приложение разработано под семейство систем Linux на языке программирования C++ 17 стандарта. Процесс проектирования происходил под Ubuntu 19.10, тестирование осуществлялось как на реальных БПЛА, так и в системе симуляции, состоящей из среды Gazebo, программной симуляции прошивки PX4 и модуля MAVROS. Система симуляции запускается в docker-контейнере, чем обеспечивает переносимость и развёртываемость на других операционных системах, отличных от указанной.

ПО является модульным, что предполагает подгрузку каких-либо сериализованных команд, параметрических функций и моделей поведения роя. Управление централизованное, на данном этапе дроны не производят коммуникацию между собой и являются простыми исполнителями команд и отправляют телеметрию на наземную станцию. Для коммуникации с реальными квадрокоптерами используется библиотека MavSDK. Помимо подключения к дронам, использующим Mavlink, возможно создание простых виртуальных объектов в симуляции, обладающих инерцией, для докомплектования оригинального роя виртуальными участниками.

В качестве точки отсчёта для определения позиции группы используется геодезическая координата первого подключённого к приложению квадрокоптера.

В основе алгоритма лежит стратегия виртуального лидера. Каждый агент группы сохраняет фиксированное расстояние относительно лидера.

Управление роем осуществляется путём задания компонентов системы: метода построения роя и стратегии перемещения всего роя. Метод построения роя может также содержать набор команд для ввода, например, перемещение отдельного элемента роя. Стратегия перемещения представляет собой набор вводимых команд, которые так или иначе воздействуют на текущее местонахождение роя, т.е. одна стратегия может перемещать весь рой по прямой линии, получить набор точек и перемещать также рой к каждой по прямым, другая же может манипулировать роем путём создания траекторий на основе сплайнов. Также существует третья стратегия, выраженная как параметрическая функция построения винтовой линии.

4. Симуляционные тесты

Предложенный алгоритм группового контроля был протестирован в программной симуляции Gazebo (рис. 1) позволяющей моделировать среду, модели роботов и сенсоры. Основным преимуществом данного про-

граммного симулятора является возможность интеграции различных платформ. Симуляция работы полетного контроллера и создание точной виртуальной копии реальных квадрокоптеров с идентичными характеристиками позволяет апробировать результаты в условиях, приближенных к реальности.

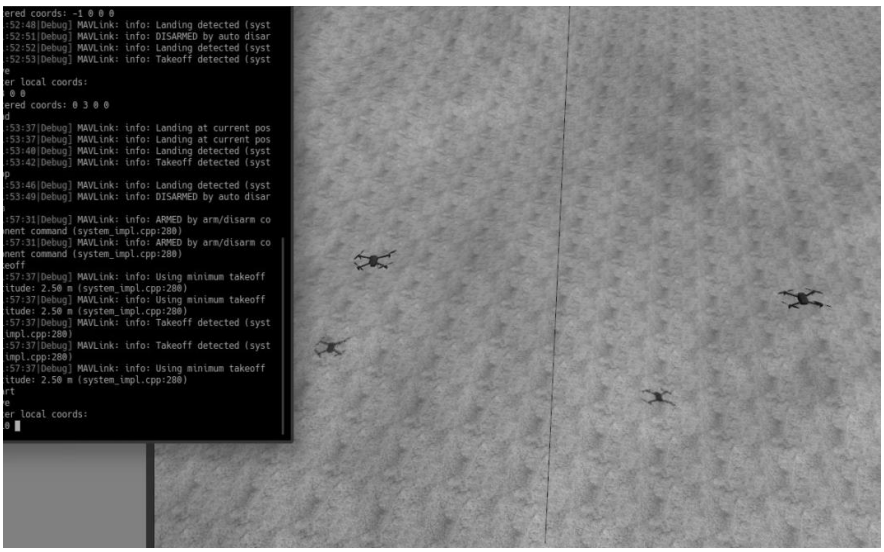

Рис. 1. Тестовый полет в Gazebo симуляции

Выводы/Заключение. В данной статье было представлено программное обеспечение, позволяющее контролировать группу квадрокоптеров с установленными полетными контроллерами Pixhawk.

В основе алгоритма лежит стратегия виртуального лидера. Программное обеспечение было разработано в программной среде C++. Для запуска использовалась операционная система Ubuntu 19.10.

Было выполнено 10 симуляционных полетов. Каждый из тестов выполнялся с разной стартовой позицией GPS. Был определен сценарий согласно которому квадрокоптеры выполняли взлет на высоту 2,5 метров, занимали целевые позиции в воздухе путем построения в линию и далее двигались к задаваемым для них точкам с жестким сохранением строя (рис. 1).

В ближайшем будущем планируется модернизация программного обеспечения путем добавления дополнительных сенсоров на квадрокоптеры и реализация возможности обхода препятствий в не моделированных средах.

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ИННОВАЦИОННЫЕ РЕШЕНИЯ ДЛЯ СОВЕРШЕНСТВОВАНИЯ КОНСТРУКЦИИ РАСПЫЛИТЕЛЬНОЙ СУШИЛЬНОЙ УСТАНОВКИ

THE INNOVATIVE SOLUTIONS FOR IMPROVING THE DESIGN OF SPRAY DRYING PLANTS

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Аннотация. *Статья посвящена исследованиям по разработке рациональной конструкции распылительной сушильной установки. Предложенная конструкция позволяет увеличить интенсивность процесса сушки при производстве сухих дисперсных материалов в пищевой и химической отраслях промышленности.*

Материалы и методы. *В статье приведены принципиальная схема и описан принцип действия разработанной установки распылительной сушки.*

Результаты, обсуждения, вывод. *Результаты исследований и конструкторские решения позволяют усовершенствовать установки распылительной сушки и использовать распылительную технологию сушки для получения сухих дисперсных материалов высокого качества.*

Ключевые слова: сушка, распылительная сушка, сушильная установка.

Abstract. *The article is devoted to research on the development of a rational design of the spray dryer. The proposed design allows to increase the intensity of the drying process in the production of dry dispersed materials in the food and chemical industries.*

The article presents a schematic diagram and describes the principle of operation of the developed spray drying unit.

The results *of research and design solutions allow to improve the installation of spray drying and use spray drying technology to produce dry dispersed materials of high quality.*

Key words: drying, spray drying, drying installation.

Introduction. Traditionally, for the implementation of the drying process in the production of dispersed materials, convective spray drying installations and dryers with a dense, fluidized, aerial and actually suspended product bed are used. These types of equipment have a high technical level, based on a developed powerful machine-building and scientific and technical base. Spray drying installations are limitedly used for liquid thermolabile materials (extracts, purees, juices, etc.), since they do not provide reliable, efficient and high-quality drying [1, 2, 8, 10].

Of practical interest are the results of research and development work on the development and implementation of rational designs of dryers [3, 4, 11], which make it possible to implement non-stationary aerodynamic modes of phase contact during drying, including with combined methods of energy supply. The use of combined methods with microwave and IR energy supply is promising [5, 6, 12, 13], which allows for higher quality indicators of dried products, but inevitably leads to an increase in production costs. In addition, research on the development of practical recommendations for the modernization of existing drying plants to increase their productivity and thermal efficiency is relevant.

Characteristics of the research object. Based on the analysis of scientific, technical and patent literature, it was concluded that a promising direction is the development of a design solution for organizing the process of spray drying of liquid and pasty materials, which allows you to create a stable directional spiral aerodynamic contact with a large number of turns between the product and the drying agent in the working chamber.

The object of research is the structural elements of spray drying plants.

Research results and their discussion. A promising design solution for dewatering liquid and pasty materials is a spray drying installation (Figure 1), developed by a group of authors under the leadership of Professor I.Yu. Aleksanyan [14].

As a result of continued research, the design was improved and a patent for a utility model was obtained [15], which additionally confirms its industrial applicability. There is no conflict of interest. The authors have proven that the intensification of the heat and mass transfer process in this design when the particles of the dried material interact with the drying agent is achieved by replacing vertical rectangular partitions with vertical curved partitions (Figure 2).

The proposed device (Figures 1 and 2) has a cylindrical drying chamber 1, made in the form of two series-connected cylinders, small 2 and large 3, of different diameters, a sprayer 4 installed along the axis of the chamber 1, a suction system 5 installed under a large cylinder 3 and unloading unit 6 in the form of a hollow cone installed under the large cylinder 3 along the axis of the chamber 1.

Small cylinder 2 has a drying agent 7 inlet. Large cylinder 3 has a drying agent 8 inlet located tangentially to the surface of a large cylinder 3.

In the cavity of a large cylinder 3, vertical curved partitions 9 are installed and rigidly fixed in a circular array around the axis of the drying chamber 1 with gaps between themselves, forming curvilinear slot channels and between partitions is $\alpha = 360/n$, where n – the number of partitions (Figure 2). The partitions 9 are rigidly fixed on the inner surface of the large cylinder 3 with the help of fasteners 10 and rod fasteners 11 to stiffen the structure (Figure 2), and the large cylinder 3 and vertical curved partitions 9 are made the same in height.

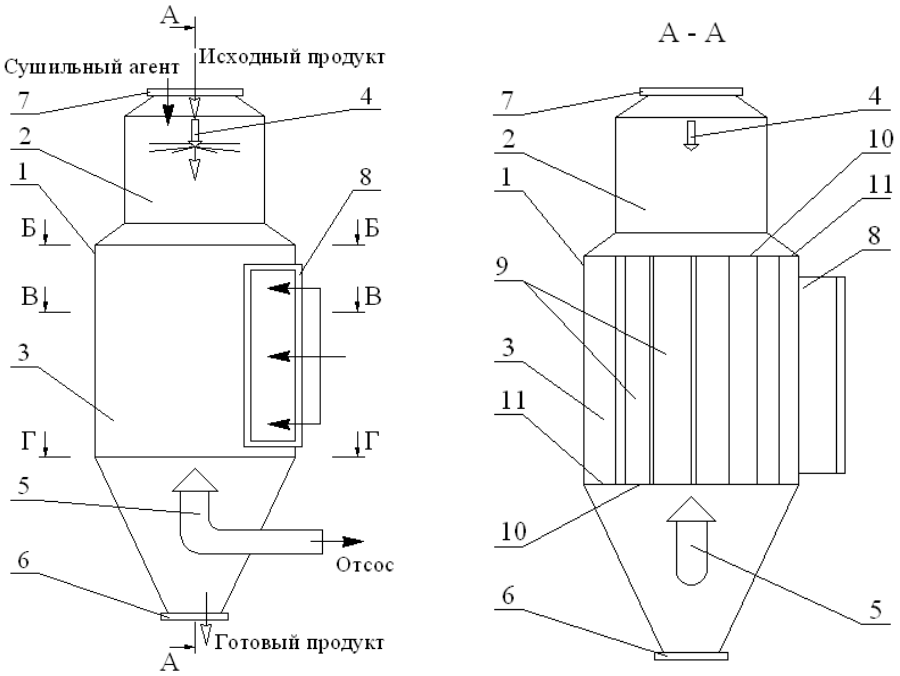

Fig. 1. Spray dryer
1 - drying chamber; 2, 3 - cylinders; 4 - sprayer; 5 - suction system; 6 - unloading unit; 7, 8 - branch pipes; 9 - vertical rectangular partitions; 10 - fasteners; 11 – fasteners

The initial product to be dried is fed by a spray gun 4 into the volume of a small cylinder 2. The drying agent is injected through the nozzles 7 and 8. The sprayed particles of the product, upon contact with the drying agent, dry up and are taken through the unloading unit 6, the spent drying agent is removed through the suction system 5.

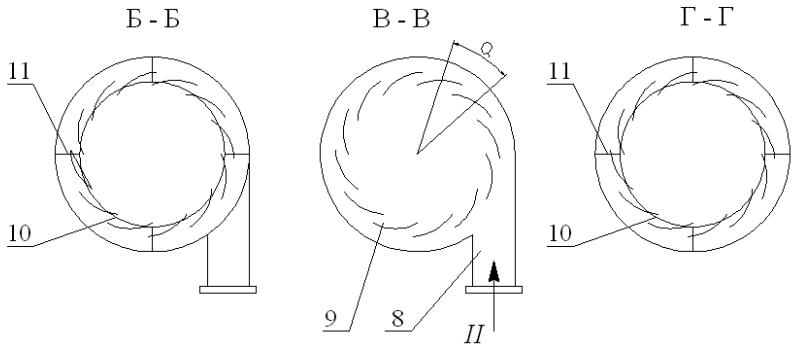

Fig. 2. Spray dryer (sections)
8 - branch pipe; 9 - vertical curved partitions; 10 - fasteners; 11 - fasteners

Due to the introduction of the drying agent through the branch pipe in the large cylinder tangentially to the circumference of the large cylinder and the presence of vertical curvilinear partitions in it, an additional uniform supply of the drying agent is carried out into the curved slotted channels between the partitions, while the sprayed product particles, entrained by the coolant flows, begin to rotate about the axis drying chambers and make a directed motion along a downward spiral trajectory.

Thus, an increase in the number of turns of the active spiral aerodynamic contact of the product and the drying agent in the drying chamber is achieved, which makes it possible to increase the residence time of the sprayed particles of the product in the drying chamber and provides an intensive flow of the drying agent around the particles and increases the intensity of the drying process. The spiral trajectory of the particles movement determines the longer contact time of the product with the drying agent in the chamber compared to the traditional straight-line downward movement, which makes it possible either to reduce the height of the drying chamber at a given productivity, or to increase the process intensity and plant productivity.

The ratio of the consumption of the drying agent supplied through the nozzles and the number of baffles depend on a number of factors: the productivity of the installation, the parameters of the spray pattern, the drying time, the geometric characteristics of the drying chamber, etc.

The positive effect of the proposed device is provided by improving the design of the dryer.

Further development is being carried out by conducting research on taking into account the kinetic laws and a set of properties of drying objects, including thermodynamic, structural-mechanical and thermophysical properties, when designing drying equipment. In addition, it is necessary to develop mathematical models [4] for operational control of the process and product quality, as well as automation of the drying plant [7, 12].

Conclusions. The results of the analysis confirm that an urgent direction is the development of methods for intensive drying of raw materials in a dispersed state, as well as design solutions to minimize or eliminate the disadvantages inherent in traditional drying plants. Further development is received by spray drying with active vortex aerodynamic contact of the product and the drying agent. The developed recommendations allow using the spray drying technology to obtain high quality dry dispersed materials. A utility model patent was obtained for the design of the facility [15], which confirms the competitiveness and industrial applicability of the development.

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О ВОЗМОЖНОСТИ МОДИФИКАЦИИ РЕЦЕПТУРЫ ХЛЕБА «ФИТНЕС» ГРЕЧНЕВЫЙ ПУТЕМ ПРИМЕНЕНИЯ МУКИ ИЗ ОРЕХА ГРЕЦКОГО

ABOUT THE POSSIBILITY OF MODIFYING THE RECIPE OF “FITNESS” BUCKWHEAT BREAD BY USING WALNUT FLOUR

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Аннотация. *Мука из грецкого ореха в настоящее время рассматривается специалистами пищевых технологий как источник полноценного белка, липидов, углеводов, минеральных веществ, витаминов и др. Исследовано качество и химический состав муки пшеничной, муки из ореха грецкого и смеси хлебопекарной гречневой. Выявлено превосходство муки из ореха грецкого над пшеничным сырьем по количеству ряда нутриентов. Определена приоритетная роль пшеничной муки в образовании пористости и формировании удельного объема хлеба. Проведена модификация рецептуры хлеба «Фитнес» гречневый.*

Ключевые слова: мука пшеничная, мука из ореха грецкого, смесь хлебопекарная, хлеб «Фитнес».

Abstracts. *Walnut flour is currently considered by food technology experts as a source of high-grade protein, lipids, carbohydrates, minerals, vitamins, etc. The quality and chemical composition of wheat flour, walnut flour and buckwheat mixture have been studied. The superiority of walnut flour over wheat raw material in the number of nutrients was revealed. The priority role of wheat flour in the formation of porosity and the formation of the specific volume of bread is determined. Buckwheat fitness recipe was modified.*

Key words: wheat flour, walnut flour, baking mix, "Fitness" bread.

Walnut flour is considered by food technology specialists as a source of complete protein, lipids (mono-, di-, triglycerides, free fatty acids, phosphatides), carbohydrates (sugars, starch, fiber), minerals, vitamins, antioxidants (ascorbic acid, tocopherol, carotene), phenolic compounds (tannins, flavonols, catechins), organic acids, etc. [1-4]. In this regard, technologies are known for the use of walnut flour in the production of acidophilic fermented milk product with improved organoleptic and functional properties; experience in using walnut kernel concentrate in wafer fillings with a high content of essential amino acids, polysaccharides, polyunsaturated fatty acids; developed a recipe for lingering biscuits containing walnut flour, rich in protein, iron, magnesium, potassium, copper, phosphorus [4-7]. The technologies for obtaining flour confectionery and bakery products (wheat, rye and rye-wheat) with the addition of walnut flour are described [8]. Foods containing walnut shell powder have a low glycemic index [9].

The purpose of this study is to study the possibility of using walnut flour in the "Fitness" buckwheat bread technology in order to expand the range and increase the food density of bakery products.

The objects of research were samples of raw materials and model bread samples:

- baking wheat flour of the first grade (GOST 26574-2017) produced by IP A.A. Mikhailyuta (Russia, Omsk region, Kormilovsky district, Pobeditel village);

- Walnut flour (STO 33974444-011-2016) produced by OOO "Specialist" (Russia, Altai Territory, Biysk);

- bakery mix "Fitness Mix" buckwheat (TU 9295-040-18256266-2014) produced by LLC "IREKS" (Russia, Moscow region, Lyubertsy). Ingredients: buckwheat flour, wheat bran, dextrose, bakery wheat flour of the highest grade, malt wheat flour, malt barley extract, emulsifier E472e, wheat gluten, roasted wheat malt flour, stabilizers E341iii, E170, acidity regulator E263, antioxidant microbial origin.

- control samples of "Fitness" buckwheat bread (TU 9110-006-18256266-2005 with additions dated 04.16.2008) were produced according to a regulated recipe (table 1);

- prototypes No. 1 - with the replacement of 15% wheat bakery flour of the first grade for an identical amount of walnut flour. The dosage of unconventional raw materials was established empirically in a series of preliminary studies.

- prototypes No. 2 - with the replacement of 15% of the first grade wheat bakery flour with walnut flour and the replacement of 2% of the “Fitness Mix” bakery mixture with buckwheat for the same amount of wheat gluten;

- prototypes No. 3 - with the replacement of 15% of wheat bakery flour of the first grade for walnut flour and replacement of 4% of the bakery mix "Fitness Mix" with buckwheat for wheat gluten;

- prototypes No. 4 - with the replacement of 15% of the first grade wheat bakery flour with walnut flour and the replacement of 6% of the “Fitness Mix” bakery mixture with buckwheat for wheat gluten.

An accelerated dough preparation method was used; the products were baked with a molded mass of 0.5 kg net.

Table 1

Recipe for "Fitness" buckwheat bread

Raw material composition and technological parameters	Raw material consumption and dough preparation parameters, kg
Wheat flour of the first grade	80,00
Bakery mix "Fitness mix" buckwheat	20.00
Pressed bakery yeast	3.00
Table salt	2.00
Drinking water	by calculation
Dough fermentation time, min	15-20
Initial dough temperature, ° C	26-28

The organoleptic evaluation of raw materials was carried out in accordance with GOST 27558-87, finished products - in accordance with GOST 5667-65. The quantity and quality of gluten was determined according to GOST 27839-2013, mass fractions of substances: moisture - according to GOST 9404-88, protein - according to GOST 10846-81, fat and ash - according to MU 4237-86. The content of dietary fiber was determined by the classical method [10], the content of calcium and magnesium - according to R 4.1.1672-03, iron, copper, zinc - according to GOST 30178-96, phosphorus - according to GOST 30615-99, selenium - according to M 04-33 -2004. The microstructure was determined using a scanning electron microscope [11]. The specific volume of bread was determined according to GOST 27669-88, acidity - according to GOST 5670-96, porosity - according to GOST 5669-96. The content of thiamine was determined according to GOST 29138-91, riboflavin - according to GOST 29139-91.

The study of organoleptic characteristics and compatibility of the raw materials used will prevent the formation of undesirable changes in the consumer properties of the finished bread. It was found that wheat flour has no visible deviations in the sensor quality indicators (Figure 1) from the standards regulated by the requirements of GOST 26574-2017. For the rest of the raw materials, specific characteristics were determined, due to both the botanical characteristics of the culture and the ingredient composition. So, walnut flour is a homogeneous finely ground powder, gray with a cream shade, a characteristic odor, a characteristic sweetish taste with a slight astringent aftertaste. Mixture "Fitness Mix" buckwheat is a free-flowing powder with the inclusion of small bran particles, which are especially noticeable when chewing. The color is light brown with a reddish tinge, uniform throughout the mass, the smell is characteristic, without extraneous tones, the taste is characteristic of buckwheat, sweeter, without extraneous tastes. An acceptable sensory compatibility of the studied raw material was revealed, which makes it possible to use it as part of a complex food system.

flour wheat | flour from walnuts | baking mix

Fig. 1. Appearance of raw materials

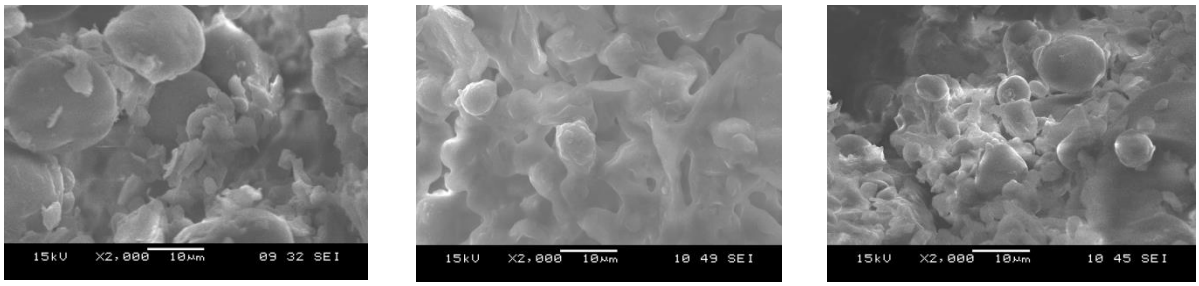
The study of physical and chemical indicators and chemical composition of raw materials contributes to understanding the formation of crumb structure, rise and nutritional value of bread. It was determined that the basic physical and chemical quality indicators of the studied samples of raw materials are characteristic of the quantitative ranges of each of them. The moisture content of the baking mixture is somewhat different from that of the studied flour samples (Table 2), which must be taken into account when calculating the amount of water required for the preparation of the dough. Despite the content of glutelin in the composition of the walnut [8], and in the composition of the bakery buckwheat mixture - wheat flour of the highest grade and wheat gluten, it was not possible to determine the quality and quantity of gluten proteins in these samples of raw materials using the traditional method. Thus, in this case, only wheat flour objectively participates in the formation of porosity and specific volume of bread. This assumption was also confirmed when studying the microstructure of raw materials using scanning electron microscopy, where gluten proteins were found in large quantities in wheat flour and in the form of single inclusions in buckwheat mixture (Figure 2).

No significant difference in the amounts of the protein fraction of the tested samples of raw materials, which could globally reduce the protein deficiency in the new modification of bakery products, was not revealed. However, it is generally known that the amino acid composition of the walnut protein balance significantly prevails over the usefulness of wheat protein [4].

Table 2

Physical and chemical indicators and nutritional value of raw materials

Defined indicator	Results		
	flour wheat	flour from walnuts	baking mix
Moisture content, %	11,3 ± 0,3	10,7 ± 0,3	7,3 ± 0,2
Protein mass fraction,%	10,2 ± 0,4	14,7 ± 0,5	11,5 ± 0,4
The amount of gluten,%	32,3 ± 0,9	-	-
Gluten quality, units IDK	68 ± 1,1		
Mass fraction of fat in terms of dry matter,%	1,10 ± 0,02	23,5 ± 0,5	3,03 ± 0,03
Dietary fiber content, g / 100 g, including: - soluble, - insoluble	3,71 ± 0,03 0,90 ± 0,02 2,81 ± 0,03	8,63 ± 0,04 2,81 ± 0,03 5,82 ± 0,05	4,92 ± 0,03 1,12 ± 0,02 3,80 ± 0,05
Ash content in terms of dry matter,%	0,57 ± 0,02	4,17 ± 0,07	2,62 ± 0,06
Mineral elements, mg / kg, including:			
P	1040,2 ± 53,4	6110,4 ± 79,6	4210,3 ± 49,2
Ca	237,1 ± 19,2	3007,2 ± 64,7	3100,0 ± 55,2
Cu	2,0 ± 0,3	15,9 ± 1,8	4,5 ± 0,7
Fe	53,1 ± 4,2	113,2 ± 6,1	46,4 ± 2,4
Mg	300,1 ± 21,7	3328,3 ± 58,9	1887,3 ± 33,1
Zn	19,8 ± 2,2	40,5 ± 3,3	24,9 ± 2,3
Se	0,26 ± 0,10	1,6 ± 0,6	1,1 ± 0,4



flour wheat flour from walnuts baking mix

Fig. 2. Microstructure of raw materials (increase in 2000 times)

In further studies, the emphasis is placed on a comparative assessment of the nutritional value of first grade wheat bakery flour and walnut flour in order to establish the effectiveness of replacing traditional raw materials with original plant material.

A relatively high oil content of raw materials from walnuts has been established. Thus, the content of lipids in unconventional material exceeds their content in wheat flour by 21 times. It is known that essential polyunsaturated fatty acids of the following families predominate in nut oil: ω-3, ω-6, ω-9 [12]. High content in oil δ- and γ- tocopherols (natural antioxidants) protects its lipid complex from oxidation [1, 2]. It should be noted the superiority of nut flour both in terms of the total dietary fiber content and the amount of insoluble fiber. An increase in the content of dietary

fiber in bread due to the substitution of raw materials can change the rheological properties of the dough and the finished product.

The high ash content of unconventional raw materials is reflected in its mineral composition. Thus, in comparison with wheat raw materials, walnut flour contains more of the following mineral elements: calcium (12.7 times), magnesium (11.1 times), copper (7.9 times), selenium (6, 1 time), phosphorus (5.8 times), iron and zinc (2 times). This circumstance will increase the nutritional density of modified bread and reduce the deficiency of certain minerals in the diet of Russians. It is also obvious that the use of a complex of food additives in the formulation of a buckwheat mixture, namely, orthophosphate, carbonate and calcium acetate, in total to the content of phosphorus and calcium in buckwheat flour, contributed to an increase in the content of these macronutrients in it by 4 and 13.1 times, respectively. The relatively high level of selenium in the baking mixture is apparently associated with the inclusion of wheat bran in its composition, since it is known that it is more selenium contained in wheat bran than in wheat grain, wheat or buckwheat flour [13].

The next step was testing the quality of model samples of "Fitness" buckwheat bread, obtained from the studied raw materials. It was revealed (Figure 3) that the control and experimental (experiment No. 1 with replacing 15% of wheat flour with raw materials from walnuts) samples have differences visible with the naked eye only in the color of the crumb (the control has light brown, uniform throughout the mass, experiment - there is a slight dark brown tint) and the height of the loaves (in the control - the height of the bread in the cross section is 13.0 ± 0.2 cm, in the experiment - 10.2 ± 0.3 cm, which gives the experimental samples some squat) ... The taste and smell of both samples of bread contains tones typical of buckwheat culture, without foreign tastes and smells.

control experiment No. 1

Fig. 3. Appearance of model bread samples

The use of measuring research methods made it possible to study in more detail the difference in the quality of the tested bread samples. It was determined that replacing wheat flour with raw materials from walnuts in the recommended dosage reduced the specific volume (by 11.1%) and porosity (by 10.9%) of bread, but increased the acidity (by 19.4%) of products in excess of the regulated norm (table 3).

Table 3

Physicochemical indicators of model bread samples

Defined indicator	Norm according to TU 9110-006-18256266-2005	Test results	
		control	experiment No. 1
Specific volume, cm3 / g	not regulated	3,79 ± 0,03	3,37 ±0,02
Porosity,%		73,5 ± 0,9	65,5 ± 1,1
Acidity, deg.	no more than 4.0	3,6 ± 0,3	4,3 ± 0,2

To date, there is a positive experience of using dry wheat gluten in the composition of a bakery mixture in the production of bread from wheat flour of the first grade with the additional inclusion of gluten-free raw materials to increase the porosity and specific volume of finished products to standard levels [14]. In the production of "Fitness" bread in accordance with the requirements of TU 9110-006-18256266-2005, a quantitative variation of the buckwheat mixture in the range of up to 20% is possible without setting the lower limit. Considering the above, we considered several options for modifying the recipe of experimental samples No. 1 by replacing 2, 4 and 6% of the bakery mix "Fitness Mix"

with buckwheat for wheat gluten (GOST 31934-2012, brand "A", manufactured by LLC "First Diet", Russia, Moscow) with the following results (table 4):

Table 4

Physicochemical indicators of model bread samples after modification

Defined indicator	Test results		
	experiment No. 2	experiment No. 3	experiment No. 4
Specific volume, cm3 / g	3,53 ± 0,02	3,82 ± 0,03	3,71 ± 0,02
Porosity,%	69,2 ± 0,8	73,4 ± 0,9	72,2 ± 0,7
Acidity, deg.	4,0 ± 0,2	3,7 ± 0,3	3,4 ± 0,2

It was found that modified bread samples with the replacement of 4% buckwheat mixture for an identical amount of wheat gluten according to the studied parameters were as close as possible to the control sample against the background of the formation of a new taste feature, namely, a pleasant nutty flavor, and a lighter crumb tone. In this regard, control and experiment No. 3 were used in further tests.

It was determined that the moisture content of control and modified samples of bread corresponds to the established norm - no more than 46.0% (table 5). The bread of the modified recipe composition is characterized by a high content of: vegetable fat (3.9 times), rich in polyunsaturated fatty acids; protein (by 46.1%); soluble (by 47.5%) and coarse (by 23.6%) fiber that stimulates the work of the gastrointestinal tract; mineral elements (table 5). The new products showed a relatively high content of magnesium (2.1 times), calcium (1.8 times), selenium (1.7 times), phosphorus (1.6 times), copper (1.4 times), iron (by 25.1%), zinc (by 22.5%).

Table 5

Physical and chemical indicators and nutritional value of bread

Defined indicator	Test results	
	control	experiment No. 3
Moisture content, %	42,6 ± 1,2	44,3 ± 1,3
Protein mass fraction,%	6,5 ± 0,4	9,5 ± 0,5
Mass fraction of fat in terms of dry matter,%	1,1 ± 0,2	4,3 ± 0,4
Dietary fiber content, g / 100 g, including: - soluble, - insoluble	2,45 ± 0,04 0,59 ± 0,02 1,86 ± 0,04	3,17 ± 0,05 0,87 ± 0,03 2,30 ± 0,05
Ash content in terms of dry matter,%	0,62 ± 0,05	1,15 ± 0,06
Content of mineral elements, mg / kg, including:		
P	1110,1 ± 44,7	1825,8 ± 51,3
Ca	502,2 ± 15,3	920,9 ± 21,8
Cu	1,5 ± 0,3	2,1 ± 0,5
Fe	32,3 ± 2,4	40,4 ± 3,3
Mg	384,4 ± 13,6	825,8 ± 19,8
Zn	12,9 ± 1,9	15,8 ± 1,7
Se	0,267 ± 0,010	0,465 ± 0,025
Vitamins content, mg / 100 g, including:		
B1 (thiamine)	0,078 ± 0,023	0,120 ± 0,040
B2 (riboflavin)	0,14 ± 0,03	0,23 ± 0,06

The vitamin value of the experimental samples of “Fitness” buckwheat bread also increased, in particular, due to an increase in the content of thiamine and riboflavin by 1.5-1.6 times. The elimination of vitamin and mineral deficiencies in the diet of the working-age population is the most important factor in maintaining their health and performance [15]. The role of each of these micronutrients in the metabolism of the human body is undeniable.

The efficiency has been proven and the practical possibility of modifying the formulation of "Fitness" buckwheat bread has been established by replacing 15% of first grade wheat flour with walnut flour and replacing 4% of the "Fitness Mix" bakery mixture with a similar amount of dry wheat gluten. The bread of the modified recipe composition has good consumer properties, is distinguished by a high content of vegetable fat, protein, dietary fiber, rich in mineral and vitamin composition.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССА ПЕРЕМЕШИВАНИЯ МНОГОКОМПОНЕНТНЫХ ПИЩЕВЫХ СМЕСЕЙ В ПРОГРАММЕ VISIMIX

MATHEMATICAL MODELING OF THE MIXING PROCESS OF MULTI-COMPONENT FOOD MIXTURES IN THE VISIMIX PROGRAM

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Аннотация. *Процесс перемешивания применяется во многих сферах промышленности, таких как пищевая, химическая и нефтеперерабатывающая, и его изучение является одной из важнейших задач, при моделировании новых перемешивающих устройств, а также при усовершенствовании уже существующих технологий и техники.*

Материалы и методы. *Рассмотрено разложение ускорения по сопутствующему базису, также наглядно представлен процесс перемешивания, при котором происходит полное взаимное распределение компонентов. Представлен обзор математических программ по моделированию процесса перемешивания. Подробно описана программа VisiMix, в которой произведено моделирование процесса перемешивания жидкой фазы, широко распространённой в технологии производства пищевых продуктов.*

Результаты и обсуждения. *Проведена визуализация гидродинамического моделирования. По заданным значениям параметров ёмкости, рабочего органа и жидкой фазы математически рассчитан показатель числа Рейнольдса. Смоделирован график зависимости тангенциальной скорости от радиуса мешалки и представлены значения параметров тангенциальной скорости. Представлен график зависимости рассеиваемой энергии W/kg от радиуса мешалки.*

Заключение. *В связи с ростом технологического прогресса, пакеты программ, способные моделировать разнообразные процессы играют ключевую роль в создании инновационных технических решений в различных сферах промышленности. В результате анализа возможностей программы VisiMix представляется перспективным дальнейшее её использование при усовершенствовании оборудования и создании новых технологических схем.*

Ключевые слова: перемешивание, моделирование, пищевые смеси, VisiMix.

Abstract. *The mixing process is used in many areas of industry, such as food, chemical and oil refining, and its study is one of the most important tasks when modeling new mixing devices, as well as improving existing technologies.*

Materials and methods. *The decomposition of the acceleration of the ends of the mixer is considered, the mixing process is also clearly presented, under the action of which the complete mutual distribution of the components occurs. A review of mathematical programs for modeling the mixing process is presented. The VisiMix program was studied in detail, in which the simulation of the mixing process of the liquid phase, widely used in food production technology, was performed.*

Results and discussions. *The hydrodynamic modeling was visualized. Based on the given values of the parameters of the capacity, working body and liquid phase, the Reynolds number indicator is mathematically calculated. A graph of the dependence of the tangential velocity on the radius of the mixer is simulated and the values of the tangential velocity parameters are presented. A plot of the dissipated energy W / kg versus the radius of the mixer is presented.*

Conclusion. *In connection with the growth of technological progress, programs capable of simulating a variety of processes play a key role in creating innovative technical solutions in various industries. As a result of the analysis of the capabilities of the VisiMix program, it seems promising to further use it in the production of new technological schemes for production.*

Key words: mixing, modeling, food mixes, VisiMix.

Introduction. Recently, in the food industry, the most common mixing method is mechanical, used for dry fine mixtures and viscous liquids. The presented type of mixing is used in the manufacture of high quality gels and food products. The demand for installations using this type of mixing in the production of consumer products is also growing. With the growing demand for these installations, the requirements for the equipment in question also grow, due to their widespread use.

It should be noted that hydrodynamic technologies in mixing machines occupy a special place, since they combine simplicity, reliability and high efficiency. An important role is also played by the design of the impellers used for intensive and high-speed mixing, which is also a necessary condition for the creation of high-tech equipment. To solve

these problems, when designing new or modernizing existing equipment, high-precision methods of calculating and modeling physical processes are used using CFD libraries and CAE programs [1].

With all its wide industrial distribution, mixing technology has not been fully studied, due to the complex physical processes that occur during mixing. Thus, the creation of new, as well as the improvement of existing devices is relevant. For this reason, much attention is paid to the search for existing and the creation of completely new methods for analyzing complex physical processes that occur during mixing, which determine the technological process of the mixing device.

Materials and methods. Mixing is used to create emulsions, bulk products and in the implementation of processes such as mass transfer and heat transfer. In this regard, there are several types of mixing process. The equipment is also divided into types, used depending on the state of aggregation of the mixing components. Depending on the environment in which the process takes place, mixing is isolated in a liquid, in a solid, in a granular, and also in a homogeneous medium [2].

It should be noted that in many industries mixing of components is used, which are in different states of aggregation. This mixing process is carried out to obtain homogeneous and heterogeneous emulsions, as well as suspensions and bulk materials.

It is in the complex movement of particles and their movement relative to each other that the mixing process lies. The presented motion of the particles is formed by the addition of three directions that arise due to the rotation of the mixer. Figure 1 shows the rotation curve of the agitator ends, which characterizes centripetal and tangential acceleration [3].

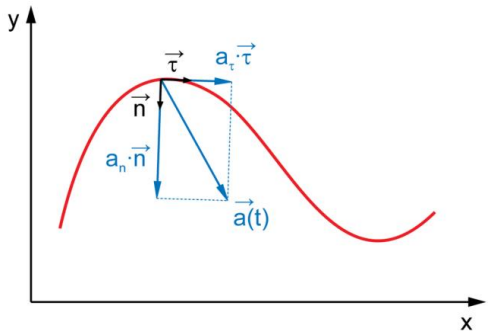


Fig. 1. Decomposition of acceleration $a(t)$ to tangential α_τ and normal α_n

Tangential acceleration in vector form can be represented as:

$$\alpha_\tau = \frac{dv}{dt} = \frac{d|\vec{v}|}{dt} \quad (1)$$

The centripetal acceleration modulus is:

$$|\alpha_n| = \omega^2 \cdot r = \frac{v^2}{r} \quad (2)$$

The third direction of rotation of the mixer is axial u_o, which has a direction along the axis of the shaft.

However, when mixing the two components, we get a mixture in which these components are evenly distributed throughout the entire volume of the resulting mixture. At the same time, at the beginning of mixing, the components are slightly distributed over each other's volume, and pronounced areas of mixing components are observed. In turn, the result of a long mixing process is a complete mutual distribution of components. Figure 2 illustrates the mixing process of the two components [4].

As a result of mixing, a variety of mixtures are obtained, which can be divided into two groups, these are homogeneous and heterogeneous mixtures. A characteristic feature of homogeneous mixtures is the complete decomposition of components into elementary particles, such as atoms and molecules of miscible substances, which in turn are completely distributed in each other. Homogeneous mixtures include saline solutions, mixtures of gaseous compounds, and true solutions [5].

A characteristic main feature for heterogeneous mixtures is the presence of chemical-integral components, which are evenly distributed in each other in the form of drops or powder. The mixtures under consideration include powders, emulsions, suspensions, and aerosols.

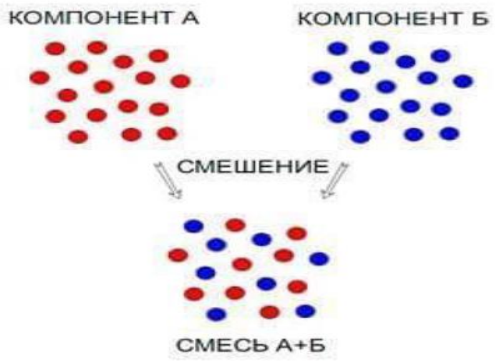


Fig. 2. Mixing process

Thus, it is possible to single out the main goals of mixing, which include the acceleration or deceleration of chemical reactions, ensuring the full distribution of both solid particles in a liquid and a liquid in a liquid, and one of the goals is to intensify the heating and cooling processes.

When choosing a mixing device, as well as the mixing method itself, the following categories should be followed:

- the degree of mixing or the indicator of homogeneity, characterized by the distribution of the components as a result of the end of mixing. This indicator is determined empirically to determine the quality of mixing

- the intensity of mixing, an indicator expressed in the frequency of rotation of the working body of the mixing device. In industrial applications, the intensity of mixing is characterized by the time it takes to obtain a certain technological result.

- mixing efficiency, characterized by the ability to obtain the required mixing quality for a certain period of time with the lowest energy costs.

Having considered the above indicators, it should be noted that at the moment there is no specific method or criterion by determining which you can choose the necessary mixer for the process under consideration. Since each mixing device has both positive and negative aspects of its use. Thus, for a more rational choice of a mixer, it is required to be guided by existing experiments and results that were carried out in laboratory conditions [6].

Computer-aided design methods for a variety of processes are being developed and implemented, thus, the traditional methods of modeling are gradually being replaced by newer ones using CAD / CAM / CAE packages on personal computers. One of the programs under consideration is ANSYS, which, according to many experts, is the most powerful tool, the main task of which is the calculation and simulation of programmed processes. This program allows to accelerate the development technology, as well as the efficiency of the designed machines and devices.

Another program under consideration is VisiMix Turbulent, which is a unique tool for mathematical modeling. This program allows you to simulate mixing processes in which one of the components is a liquid. The program under consideration contains the parameters of the mixing process, which are required for the analysis and optimization of mixing plants with various types of working bodies. This program provides the ability to use Newtonian and non-Newtonian media, it also has a wide range of used sizes, both tanks and working bodies. One of the main features of VisiMix is the modeling of emulsions, determination of the achievement of the final stage of emulsification. Also, the program has the ability to calculate the drop size, mixing time of components and many other indicators of processes that play an important role in the mixing process. The main area of application of the program is to simulate the mixing process in cylindrical tanks using mixing devices [7].

Within the framework of this work, we will simulate the mixing process in a tank with a conventional heat jacket and an elliptical bottom. The total volume of the designed tank should be 5000 liters with a diameter of 1600 mm. Also, the projected tank must have a reflector, the upper part of which does not protrude beyond the upper level of the mixing mixture. The thermal jacket should be designed in such a way that it covers the entire surface area of the tank. It is also necessary to place a turbine mixer in the tank, the rotation speed of which will be 125 rpm.

A tank with these characteristics is necessary for mixing both liquid mixtures and mixtures with the addition of a solid phase. A simulated reservoir will also allow studying the formation of stagnant zones, which will give an idea of the required degree of mixing. The simulated impeller will allow you to study the change in tangential velocity over the entire volume of the considered vessel. This will allow evaluating the effectiveness of the decisions made.

Creating a project in VisiMix begins by opening Project, which is on the home page in the menu bar. Figure 3 clearly demonstrates the above menu.

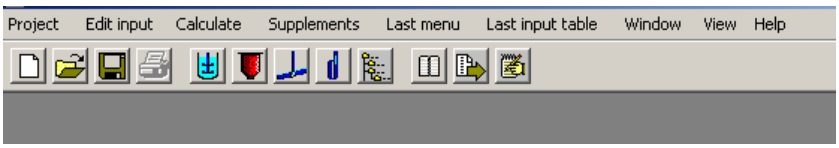


Fig. 3. Main menu of the program

After selecting Project, a menu appears, which is shown in Figure 4. In this window, select New ...

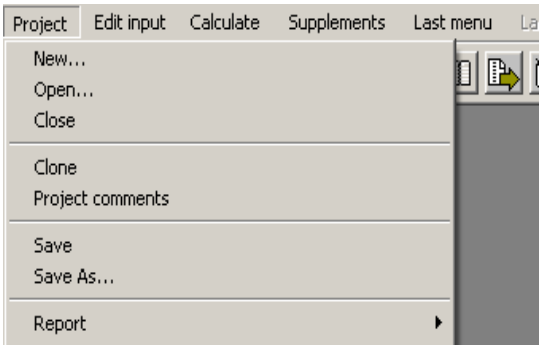


Fig. 4. Project Submenu

After selecting the New ... menu, a window for saving a new project opens, in which we specify the name of the Project-1 file and save it. This window is shown in Figure 5.

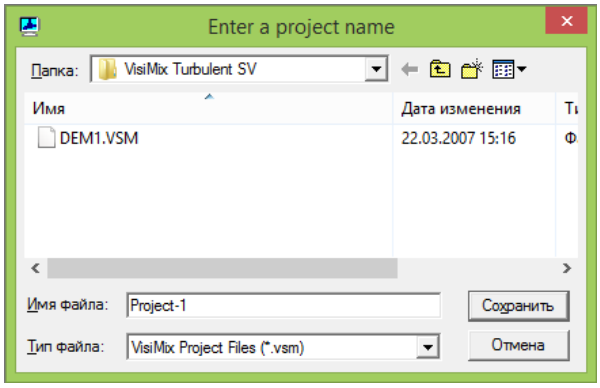


Fig. 5. Dialog box for saving a new project

After saving the project, the program provides a window for selecting different types of tankers, shown in Figure 6. All tankers are divided into four groups, namely, an insulated tank without a jacket, a tank with a conventional thermal jacket, a tank with a half-tube thermal jacket and tanks with embossed / dimpled thermal shirt. Also in each group are tanks with different types of bottom, such as flat bottom, elliptical and conical.

In the corresponding window, select a tank with a conventional heat jacket and an elliptical bottom. When you select this tank, it will be displayed in a small window on the right, in which you should confirm your choice by clicking on the Ok button.

When the required tank is selected, a window for entering its dimensions will open. This window is shown in Figure 7.

In this window, you must enter the inner diameter, enter 1600 mm, the volume of the tank, which is 5000 liters, while the program will calculate the height of the tank, the value found is 2620 mm. Also in this window, the volume of liquid is entered, in this case 4000 liters, the height of the column is 2123 mm. After entering the necessary data, the entered data will be reflected in the right area of this window. To confirm them, click OK, after which the window will change.

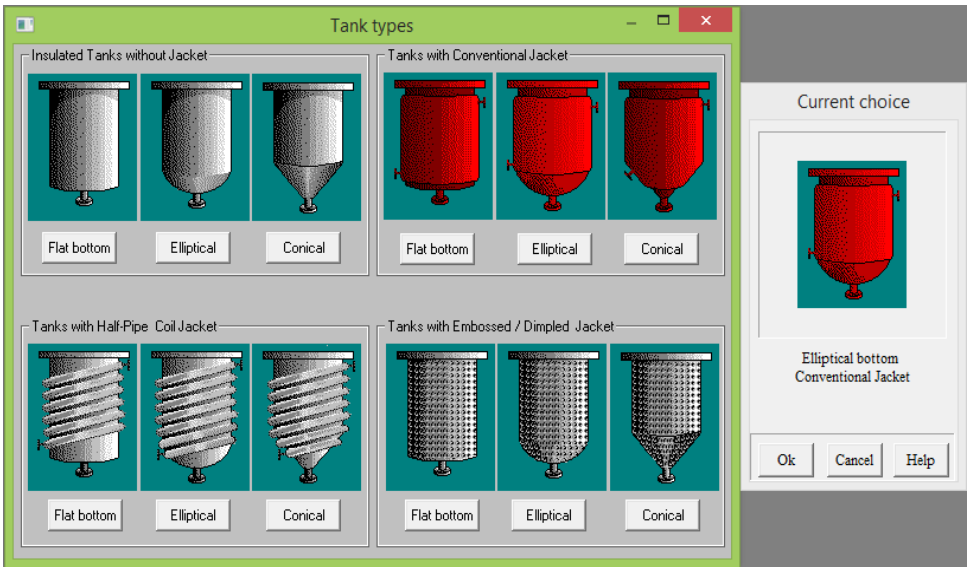


Fig. 6. Window for selecting the type of tank

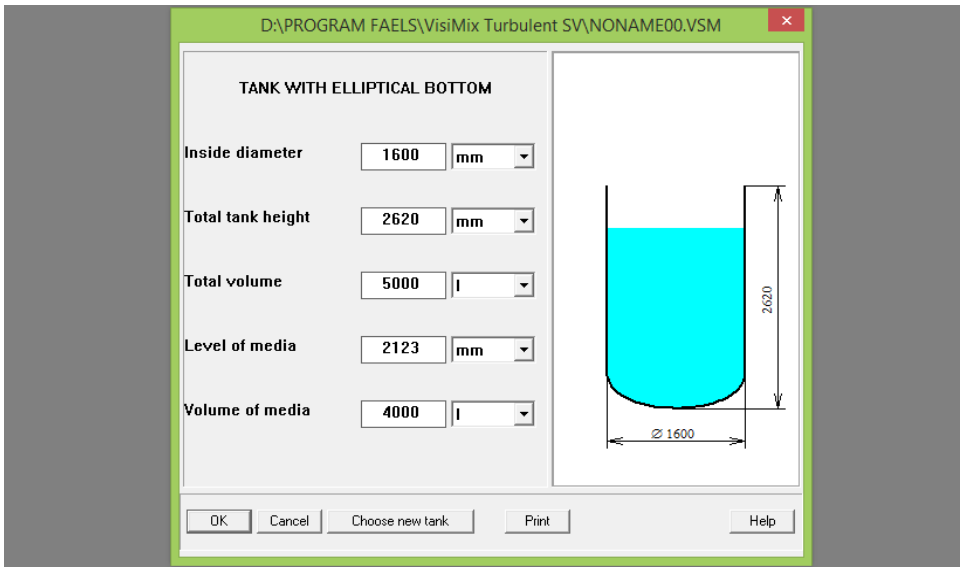


Fig. 7. Window for entering tank dimensions

Next, a window for selecting the type of reflectors appears. This window is shown in Figure 8. There are two types of flat reflectors, namely flat reflector 1 (placed on the wall) and flat reflector 2 (located at a distance from the wall). There are also two types of tubular reflectors of different designs. In this window, you can also select a defocused reflector and a container in which there will be no reflective partition.

Select the flat reflector 2 (located at a distance from the wall) and confirm the selection in the secondary window on the right. Next, the window for entering the dimensions of the reflective partition will be presented. Let's enter the number of partitions located along the perimeter of the container equal to 4. We also enter the width and height of the partitions, which are equal to 160 mm and 1700 mm, respectively. Next, you should enter the distance at which the partition will be from the bottom of the tank, which is 450 mm. The distance from the wall is 50 mm. The tilt angle of the partition is 0^{o}. All entered data will be reflected in the right part of the selection window, which is shown in Figure 9.

After entering all the values for the dimensions of the partition, you should confirm your choice by clicking on the OK button. Then a window for selecting a working body will appear. The non-commercial version of this program provides only two types of mixing body to choose from, such as turbine and propeller. Choosing a turbine mixer. The mixer selection window is shown in Figure 10.

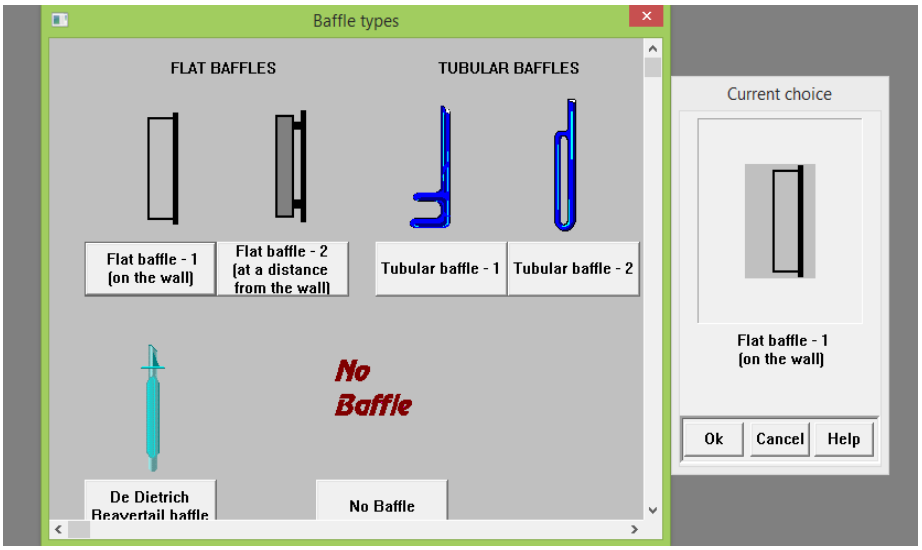


Fig. 8. Selection of the type of baffle plate

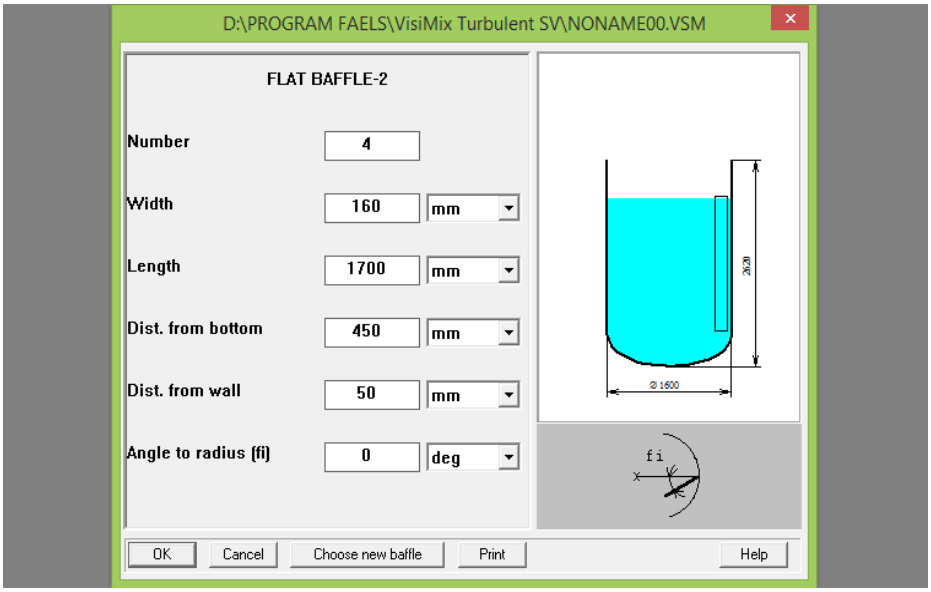


Fig. 9. Window for entering the dimensions of the reflector

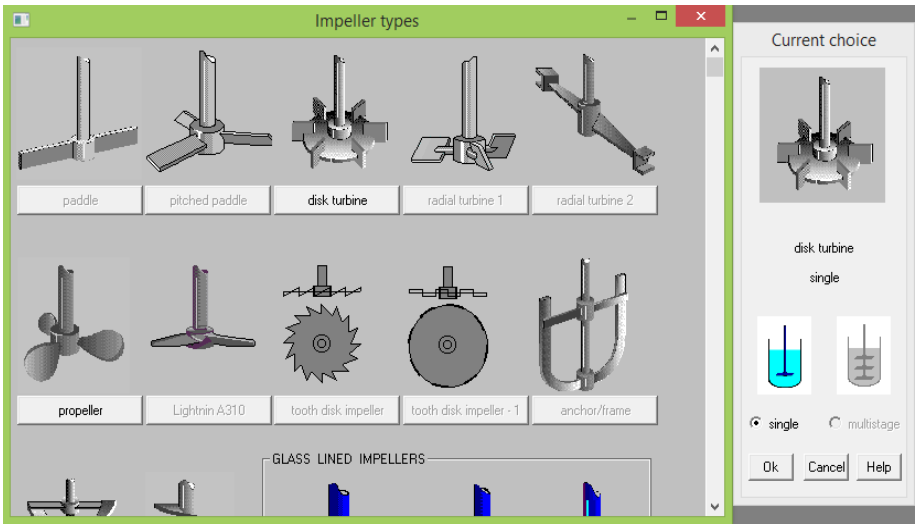


Fig. 10. Impeller selection window

After confirming the selection by pressing the OK button, the following window for entering the mixer dimensions will appear. This window is shown in Figure 11.

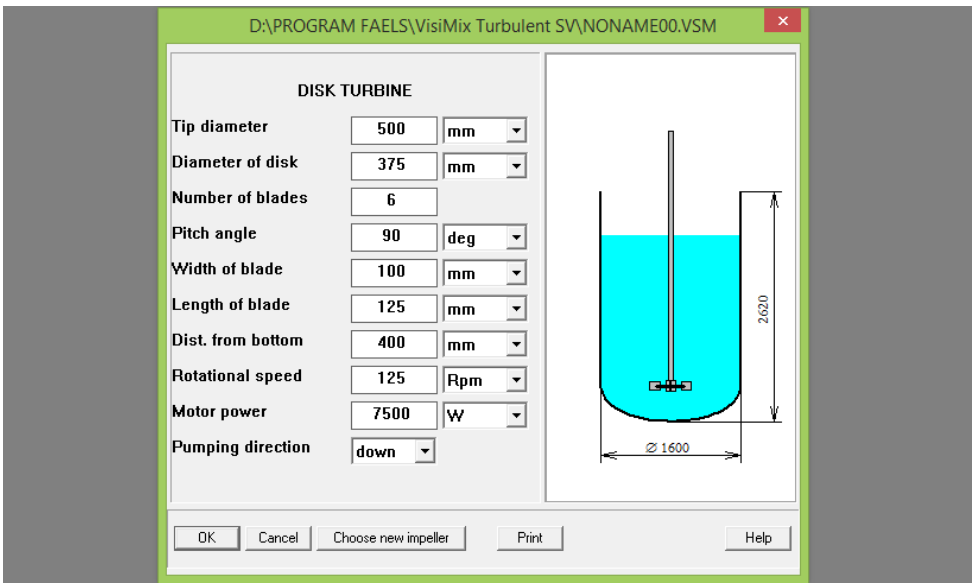


Fig. 11. Window for entering mixer parameters

In this window, enter the following values:
- blade diameter T_d = 500 mm;
- disc diameter D_d = 375 mm;
- the number of blades N_b = 6;
- the angle of inclination of the blades P_a = 90;
- blade width W_b = 100;
- blade length L_b = 125;
- distance from the bottom D_b = 400 mm;
- rotation speed R_s = 125 rpm;
- motor power M_p = 7500 Watts.

After entering the data, click on the OK button, as a result of which the following window appears. Figure 12 shows the window for entering the characteristics of the casing.

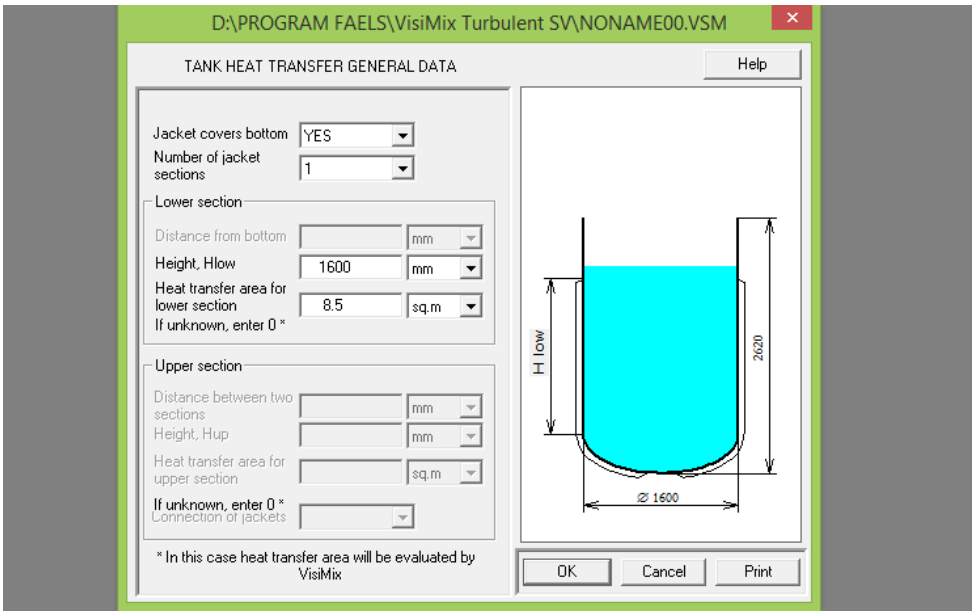


Fig. 12. Window for input of casing values

In this window, select the YES value, which means that the casing will cover the bottom of the container. Next, let's choose 1, the value of the number of sections. The section height is 1600 mm. The heat transfer area of the lower section is 8.5 m2.

Further, after confirming the entered values, you must enter the average properties of the environment. The main indicators are the average density, the value of which is equal to 1050 kg / m3. This data entry window is shown in Figure 13.

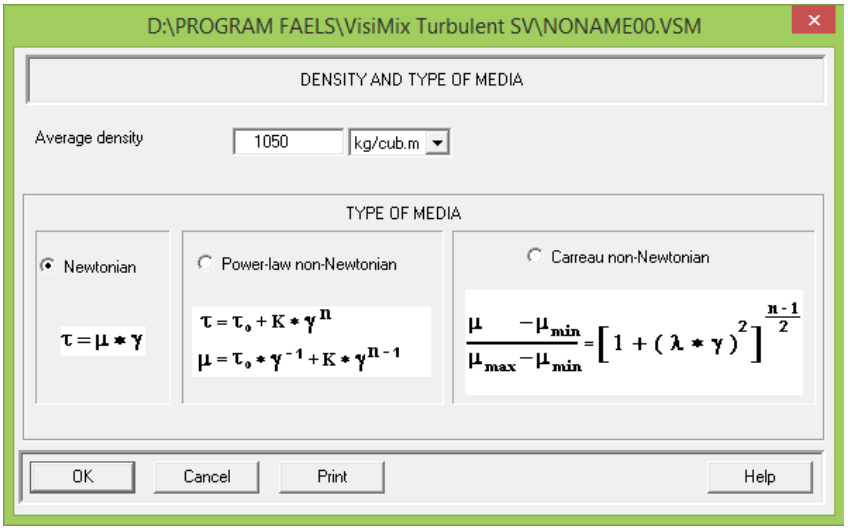


Fig. 13. Window for entering the density of the medium

The next input box is responsible for dynamic and kinematic viscosity. This window is shown in Figure 14. Here you need to enter the value of the dynamic viscosity, which is equal to 2 cP, and the kinematic viscosity will be calculated by the program automatically.

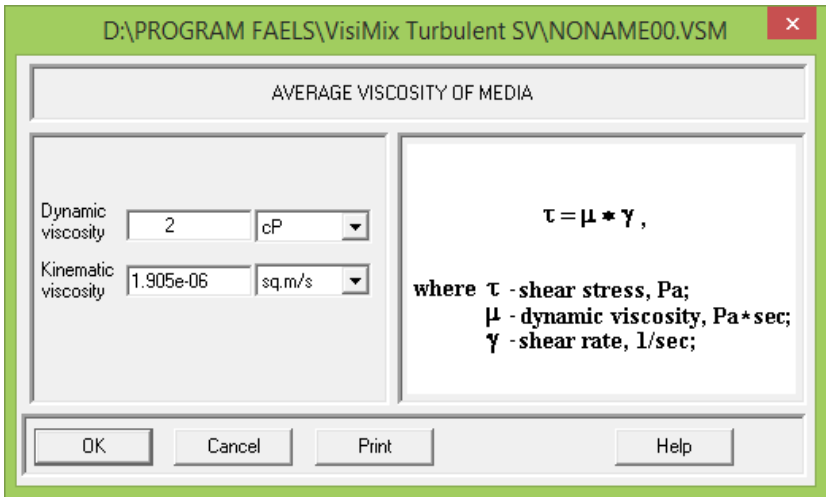


Fig. 14. Window for entering the medium viscosity

After entering all the above data, a schematic drawing of a tank with an agitator will appear. This means that the entered data is sufficient for mathematical modeling of the main hydrodynamic processes. This drawing is shown in Figure 15.

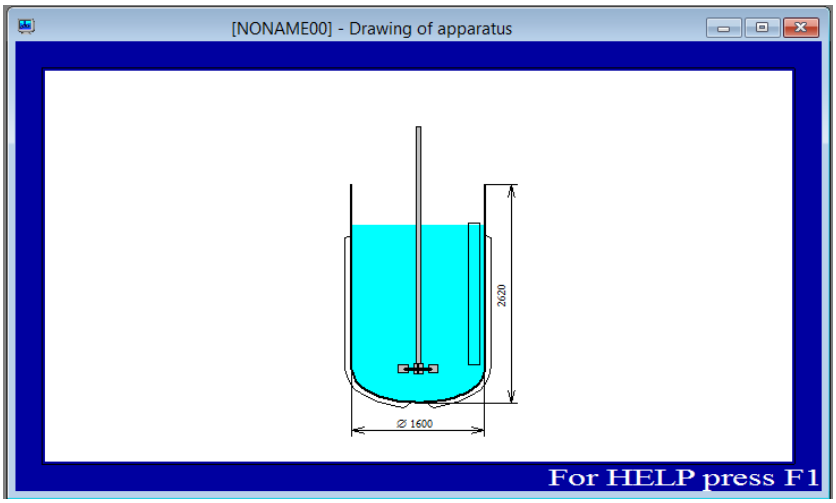
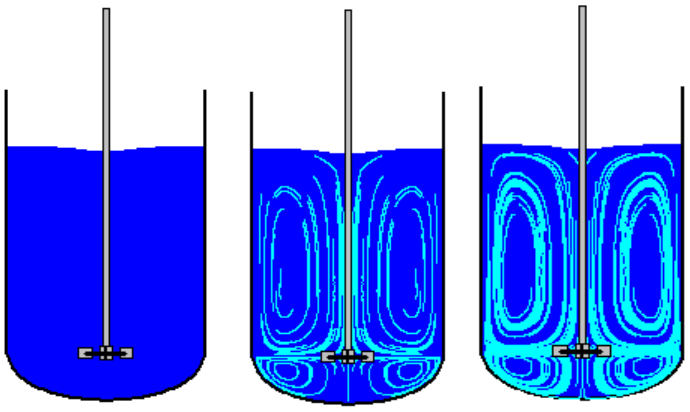


Fig. 15. Schematic drawing of the tank

Results and discussion. One of the main modeling processes is hydrodynamic modeling. The visualization of the process is based on the results of an approximate flow simulation with stabilized hydrodynamics. The mixing process simulates the movement of tracer particles that are introduced into the tank. Figure 16 shows a general diagram of the fluid flow at different times.

This process can be done by clicking on the following menu sequence: Calculate - Hydrodynamics - General Flow Pattern (Approximate).



a) b) c)

Fig. 16. General flow diagram a) start of the process 0 s; b) after 3 s; c) after 8 s

Analyzing the data presented, it is possible to identify several areas in the reservoir in which stagnant zones are formed. Thus, at the design stage or selection of the required working body, amendments can be made that will not allow the appearance of technical and technological errors in the future [8].

Also, one of the most important criteria for mixing the liquid phase is the Reynolds number. This value is based on average flow rate and tank radius. Called as follows: Calculate - Hydrodynamics - Reynolds number for flow. Figure 17 shows the result of calculating the Reynolds number.

REYNOLDS NUMBER FOR FLOW

Parameter name	Units	Value
Reynolds number for flow		1.79e+05

Fig. 17. Reynolds number

Using the software capabilities, a plot of tangential velocity versus stirrer radius has been modeled. Thus, in a well-developed turbulent flow, the profile of the tangential velocity is close to the average, practically over the entire volume of the tank, except for the area of action of the working body, which is 250 mm.

Figure 18 shows a graph of the radial distribution of the tangential velocity.

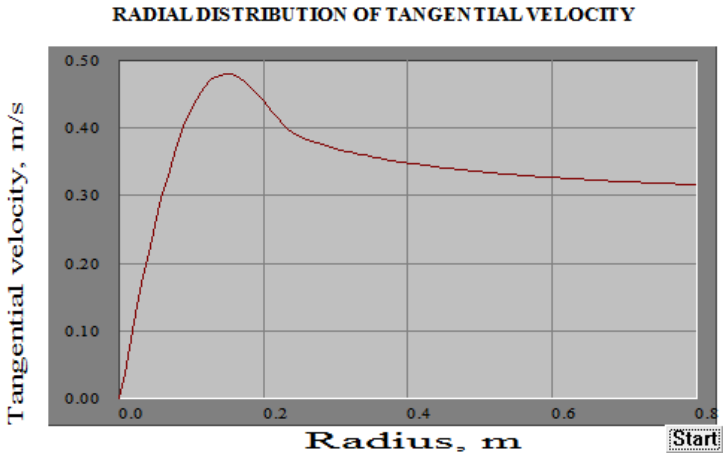


Fig. 18. Radial distribution of tangential velocity

Also, according to the results of the analysis of the graph, a table should be presented, which includes the following parameters:

- the average value of the tangential velocity;
- the maximum value of the tangential velocity;
- tangential velocity at the wall. This is the tangential velocity near the wall, outside the boundary layer;
-is the speed of the end of the impeller. This parameter represents the speed of the outer edge of the tool blade. It is used to compare blade speed and fluid flow rate.

Figure 19 shows the tangential flow characteristics.

CHARACTERISTICS OF TANGENTIAL FLOW

Parameter name	Units	Value
Average value of tangential velocity	m/s	0.347
Maximum value of tangential velocity	m/s	0.479
Tangential velocity near the wall	m/s	0.317
Impeller tip velocity	m/s	3.27

Fig. 19. Tangential flow characteristics

Figure 20 shows a graph of the dissipated energy W / kg versus the stirrer radius. The disc diameter together with the blade length is 500 mm. Thus, the greatest dissipated energy is observed in the center of rotation of the mixer within a radius of 250 mm and is 25 W / kg.

As a result of the analysis of the graph, it can be concluded that the vortex, formed due to the movement of the blades of the working element, has maximum values in the center of rotation. It is also worth noting that a significant part of the energy is dissipated within a radius of 150 mm and amounts to 3.8 W / kg. Thus, the average value of the dissipated energy over the entire volume of the container is 0.377 W / kg, and the dissipated energy near the reflectors is 0.146 W / kg. Based on these data, it can be concluded that the power of the electric motor is sufficient.

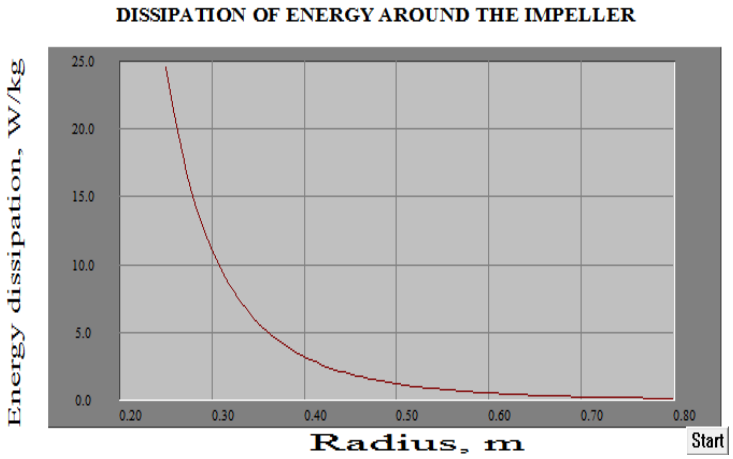


Fig. 20. Dissipated energy around the working body

Conclusion. Based on the results of the work, the rotation curve of the accompanying basis was established, which characterizes the centripetal and tangential acceleration. The visualization of the mixing process of two components is presented. Considered packages CAD / CAM / CAE in such modeling programs as Ansys and VisiMix.

As a result of computational and mathematical modeling of the experiment, using the CAD / CAM / CAE packages of the VisiMix Turbulent program, such indicators as the required motor power, Reynolds number were determined. The values of the tangential velocity are found at different points of the tank, the graph of the dependence of the tangential velocity on the radius of the mixer is modeled. Also presented is a graph of the dependence of energy loss when moving away from the mixing device.

Thus, the work done allows us to minimize technical and technological errors in the improvement of equipment and the creation of new technological schemes.

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ЭФФЕКТИВНОСТЬ ПРЕДВАРИТЕЛЬНОЙ ОБРАБОТКИ СЫРЬЯ ДЛЯ ПОВЫШЕНИЯ ВЫХОДА ПЕКТИНА

PRE-PROCESSING EFFICIENCY RAW MATERIALS TO INCREASE PECTIN'S OUTPUT

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Аннотация. *В статье рассмотрен более экологичный способ производства пектина по сравнению с классической кислотной схемой, которая требует применения сильных минеральных кислот и токсичных растворителей.*

Материалы и методы, результаты и обсуждения. *В выполненной работе не используются сильные минеральные кислоты, что должно вызывать падение выхода конечного продукта, однако сделаны попытки найти методы, устраняющие эти препятствия и повысить выход конечного продукта. Исследована возможность увеличения выхода пектина, полученного с помощью кислотного гидролиза с использованием лимонной кислоты, за счет применения предварительного СВЧ-воздействия на цитрусовое сырьё. Цель исследования состояла в оценке влияния СВЧ-обработки на стадии подготовки сырья – сушки и экспериментальном подборе параметров сушки с сохранением высоких качественных показателей получаемого пектина. Внимание уделено получению высокоэтерифицированного пектина, который широко используется в пищевой промышленности в качестве студнеобразователя и загустителя. При производстве пектина возможно использовать вторсырье. Такая переработка отходов не только экономически снижает расходы производства, но и улучшает экологическую ситуацию утилизации отходов. Для производства пектина возможно использовать отходы соковой промышленности. В качестве сырья в исследовании использовались флаведо и альбедо апельсинов, сорт которых лидирует в мире по количеству использования при производстве соковой продукции. Для получения пектина в данной работе использовался кислотный метод. Гидролиз проводился с использованием лимонной кислоты в три стадии. Осаждение проводилось этиловым спиртом. Подготовка пектиносодержащего сырья способна в значительной мере повлиять на качество получаемого пектина. В настоящее время для хранения и подготовки к переработке вторичного пищевого сырья главным образом используют конвективную сушку. Произведена оценка влияния различных видов сушки цитрусового сырья, применяемого для производства пектина. Сравниваются качественные и количественные показатели полученного пектина, такие как степень этерификации, молекулярная масса, студнеобразование и выход, для сырья, высушенного конвективным методом и комбинированным методом, сочетающим предварительную СВЧ-обработку и обдувку сухим воздухом. Представлены кривые сравниваемых методов предварительной сушки. Проанализирована скорость выхода пектина по стадиям гидролиза в зависимости от рассматриваемых методов сушки. Подобраны оптимальные мощностные режимы для предварительной СВЧ-сушки цитрусового сырья. Рассмотренный способ получения пектина с использованием СВЧ-обработки сырья позволяет при сохранении качественных показателей упростить технологию, повысить выход и сократить не только время сушки, но и продолжительность гидролиза.*

Заключение. *Полученные данные представляют ценность для разработки или усовершенствования технологии промышленного метода производства пектина, использующего экологические способы экстракции без применения сильных минеральных кислот, для увеличения выхода и качества пектина.*

Ключевые слова: пектин, экологичный метод, СВЧ, конвективная сушка, лимонная кислота, кривая сушки.

Abstracts. *The article discusses a more environmentally friendly method of pectin production compared to the classic acid scheme, which requires the use of strong mineral acids and toxic solvents.*

Materials and methods, results and discussions. *In the work performed, strong mineral acids are not used, which should cause a drop in the yield of the final product, however, attempts have been made to find methods that eliminate these obstacles and increase the yield of the final product. The possibility of increasing the yield of pectin obtained by acid hydrolysis with the use of citric acid through the use of preliminary microwave exposure to citrus raw materials has been investigated. The purpose of the study was to assess the effect of microwave treatment at the stage of raw material preparation - drying and experimental selection of drying parameters while maintaining high quality indicators of the obtained pectin. Attention is paid to obtaining highly esterified pectin, which is widely used in the food industry as a gelling agent and thickener. It is possible to use recyclable materials in the production of pectin. Such waste processing not only economically reduces production costs, but also improves the environmental situation of waste disposal. For the production of pectin, it is possible to use waste from the juice industry. As raw materials in the study, we used the oranges flavedo and albe-*

do, the variety of which is the world's leader in the number of uses in the production of juice products. To obtain pectin, the acid method was used in this work. The hydrolysis was carried out using citric acid in three stages. Precipitation was carried out with ethyl alcohol. The preparation of pectin-containing raw materials can significantly affect the quality of the pectin obtained. Currently, convective drying is mainly used for storage and preparation for processing of secondary food raw materials. An assessment of the influence of various types of drying of citrus raw materials used for the production of pectin has been made. The qualitative and quantitative indicators of the obtained pectin, such as the degree of esterification, molecular weight, gelation and yield, are compared for raw materials dried by the convection method and the combined method combining microwave pretreatment and dry air blowing. The curves of the compared predrying methods are presented. The rate of release of pectin by stages of hydrolysis is analyzed depending on the considered drying methods. The optimal power modes for preliminary microwave drying of citrus raw materials have been selected.

Conclusion. *The considered method of obtaining pectin using microwave processing of raw materials allows, while maintaining quality indicators, to simplify the technology, increase the yield and reduce not only the drying time, but also the duration of hydrolysis. The data obtained are valuable for the development or improvement of the technology of an industrial method for the production of pectin, using ecological methods of extraction without the use of strong mineral acids, to increase the yield and quality of pectin.*

Key words: pectin, environmentally friendly method, microwave, convective drying, citric acid, drying curve.

Introduction. At the present time, serious problems have arisen related to the increased environmentally unfavorable load on the environment. Much attention is paid to waste processing. This is especially true in the food industry, where waste can potentially be converted into more valuable products or raw materials for other industries.

During industrial production of orange juice, 40-60% of the orange is considered waste [1]. This waste can be the raw material for the production of essential oils, flavonoids, pectin, and other important foods.

Convection drying is mainly used for storage and preparation for processing of secondary food raw materials. In the process of drying, there is a chemical transformation of the components of pectin-containing raw materials, which can significantly affect the quality of the pectin obtained [2]. During storage, it is subject to enzymatic, biochemical and microbiological changes that lead to rapid deterioration. Thus, drying of raw materials is a necessary step in the production of pectin. Although convective drying does not always have a beneficial effect on the quality of the pectin obtained, at present, due to its simplicity and economy, it is the main method for preserving pectin-containing raw materials.

Since the beginning of the XXI century, studies of Russian and foreign scientists began to appear related to the use of microwave drying for the needs of the food industry, since this type of drying involves a significantly shorter drying time for Pekin-containing raw materials. And it's not only about saving time, but also about a different way of supplying heat to the material, which can presumably affect the quality and quantity of the final product.

On the other hand, the production of pectin is associated with the use of harmful and hazardous components, such as strong acids, alkalis and toxic solvents such as acetone, methanol, etc. Due to the large amount of hazardous waste, not every enterprise can afford the classic technology of pectin production [6]. Recently, in the development of pectin production technology, it is possible to identify a trend towards the development of environmentally friendly production methods [7].

In the work performed, strong mineral acids are not used, which should cause a drop in the yield of the final product, however, attempts have been made to find methods that eliminate these obstacles and increase the yield of pectin.

The aim of the study was to assess the effect of raw material pretreatment due to microwave exposure on the pectin yield and to select the parameters of this effect.

Materials and methods. For the purposes of the study, we used a Valencia orange. This variety is the world's leader in the number of uses in the production of juice products. Since it is advisable to consider the possibility of using industrial waste to obtain pectin, the peel of the Valencia variety is considered the most relevant raw material.

The flavedo and albedo of the fruit were removed by hand and minced.

Raw materials were analyzed for moisture content by gravimetric method. For this, three samples were taken from the mixed raw materials.

The moisture content of raw materials was determined by the formula:

$$\omega = \frac{m_1 - m_2}{m_1} \cdot 100\% \quad , \qquad (1)$$

where m_1 – sample weight before drying, g

m_1 – sample weight after drying, g.

Three samples of equal mass for drying in microwave and three samples for convective drying were isolated from the total amount. The mass of each sample is 100 g.

Part of the fresh raw material was dried using convective drying, the other part - using microwave drying, and the third part - using the combined method.

Drying was carried out to a final moisture content of the product of 10%. The moisture content of the dry product was determined by the gravimetric method, similar to that described above.

Convective drying was carried out in a drying oven at a temperature of 70 ° C.

Microwave drying was carried out in a household microwave oven at different powers.

Combined drying consisted of an alternation of microwave exposure for 5 minutes with a 5-minute period of blowing dry air.

Samples weighing 15 g were taken from each type of dry raw material and sent for hydrolysis.

The raw materials were washed in cold water (10 ° C) to remove water-soluble impurities.

Grinding was carried out in a screw grinder providing a particle size of less than 1 mm. The raw materials were mixed.

The acid method was used to obtain pectin. Hydrolysis was carried out using citric acid to achieve a pH value of 2.5 at a temperature of 70 ° C, hydromodule 1:10. The hydrolysis was carried out in three stages, each stage lasted 60 minutes. The total hydrolysis time is 180 minutes.

Evaporation of pectin was carried out on a rotary evaporator with continuous stirring, t = 70 ° C, P = 60mbar.

Precipitation was carried out with 96% ethyl alcohol. The precipitate was separated by filtration on a Buchner funnel and washed with alcohol.

The resulting pectin was dried in an oven at a temperature of 50 ° C.

Pectin is divided into highly esterified, low esterified and low esterified amidated. Each type of pectin is used for its own purposes under different conditions. The highest gelatinous ability is possessed by highly esterified pectin with a degree of esterification of more than 50%.

The degree of esterification of the obtained pectin was determined by the titrometric method according to GOST 29186-91. Pectin. Technical conditions.

The molecular weight was determined by a viscometric method using a VPZh-1 capillary glass viscometer.

The molecular weight was found using the Kuhn-Mark-Huwink formula:

$$[\eta] = k \cdot M^{a}, \quad (2)$$

where [η] – absolute viscosity of the solution,

M - molecular weight

k, a - coefficients depending on temperature and polymer-solvent system, here we take $k=1{,}1 \cdot 10^{-5}$, a=1,22 [2].

Gelling was determined organoleptically. For this analysis, jellies were prepared according to GOST 29186-91. Pectin. Technical conditions.

Results and discussion. After preliminary selection at processing plants, the moisture content of fresh raw materials was 77%.

The raw material was crushed and dried in batches of 100 g on a silicone substrate. Average particle size 7x5x2 mm. For uniform heating, this is especially important for microwave exposure, it is necessary that the linear dimension in at least one direction does not exceed 2-5 mm [5}.

When selecting the power, the recommendations of other authors on the critical influence of high temperatures during drying of raw materials on the quality of pectin were taken into account. In the case of drying raw materials using the microwave method without interruptions for blowing, the temperature of the raw materials reached 94 ° C, which negatively affects the properties of the final product. In many works it is indicated that the temperature should not exceed 70-80 ° C [2].

The literature describes a method of combined drying with alternating five-minute microwave exposure with a five-minute air blow [3]. This method does not take into account the change in moisture content of the product during drying. There is an increase in temperature at the beginning of the heating of raw materials and a drop in temperature as the humidity decreases.

The optimal power value for microwave drying was determined, equal to 300 W. At a higher power (450 W or more), the product began to burn, a lower value (180 W or less) unjustifiably lengthened the drying time.

Drying was carried out with alternating microwave exposure with air blowing. One cycle consisted of 2-4 minutes' exposure to microwave and 4-minute air blowing. This method makes it possible to take full advantage of the

main advantage of microwave heating - high speed and to avoid uneven heating of individual sections of the processed raw materials, since during cyclic heating it is possible to redistribute temperatures by thermal conductivity of the material. Table 1 shows the average temperature on the surface of the raw material, measured at five points eight times for each cycle. At the beginning of drying, with a large amount of free moisture, the energy of the microwave field is spent mainly on the evaporation of moisture and partially on the compensation of heat into the environment, then the bound moisture begins to evaporate, as well as endothermic processes associated with the chemical transformation of proteins, carbohydrates and the destruction of the tissue of raw materials. ...

Table 1

Scheme of the combined drying method with alternating microwave energy supply and air blowing

Cycle number	Drying time, minutes	Duration, minutes	Impact	Average temperature, K
1	1-4	4	Microwave	333
	5-8	4	Blowing	323
2	9-12	4	Microwave	341
	13-16	4	Blowing	318
3	17-20	4	Microwave	343
	21-24	4	Blowing	316
4	25-28	4	Microwave	344
	29-32	4	Blowing	315
5	33-34	2	Microwave	348
	35-38	4	Blowing	317
6	39-40	2	Microwave	347
	41-44	4	Blowing	317
7	45-46	2	Microwave	346
	47-50	4	Blowing	318
8	51-52	2	Microwave	344
	53-56	4	Blowing	319
9	57-59	3	Microwave	343
	60-63	4	Blowing	316
10	64-66	3	Microwave	339
	67-70	4	Blowing	317
11	71-73	3	Microwave	339

With a graphical representation of the results obtained in Figure 1, one can see a rise in temperature when the microwave energy is supplied and a decrease when the microwave energy is turned off. Ambient temperature - 27 ° C. The average temperature inside the chamber at the time of microwave exposure is 46 ° C. The average temperature on the sample surface first rises and then slowly falls. The averaged value shows that the maximum temperature falls on the sixth cycle.

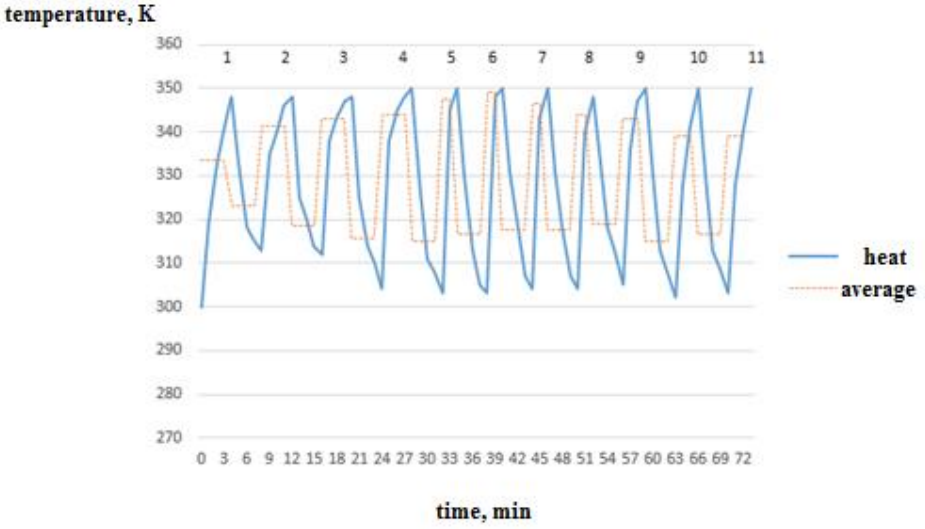

Fig. 1. Change in temperature in the drying chamber with a combined method of drying citrus raw materials

After the fourth cycle, the temperature on the surface of the raw material rises to the limiting value of 77 ° C, therefore, on the fifth cycle, it is necessary to reduce the exposure time to microwave. The peak point of the fourth cycle

corresponds to a product moisture content of 40%. The peak point of the sixth cycle corresponds to a moisture content of 33%, which, as can be seen from the microwave drying curve (Figure 3), corresponds to the critical moisture content point. Up to the point of critical moisture content, mainly free moisture is removed, but the microwave effect also affects the bound moisture, which also affects the rise in temperatures. After this point, the drying rate decreases as the moisture content of the product decreases. During this period, the bound moisture is removed, and the gradual decrease in the drying rate is explained by the increase in the binding energy of moisture with the material. During this period, the process of removing moisture depends on the moisture content, the nature of the connection of moisture with the material, the physicochemical properties of the material. As the moisture content of the product decreases, the average temperature also decreases. It is assumed that due to the temperature distribution in the center of the sample, the temperature constantly increases during the entire drying time.

With the described drying method, the threshold of 70 ° C was exceeded. However, the duration of high temperatures was short (no more than 7 minutes) and this did not significantly affect the quality of the pectin obtained. Temperature distribution over the entire drying time is shown in Figure 2.

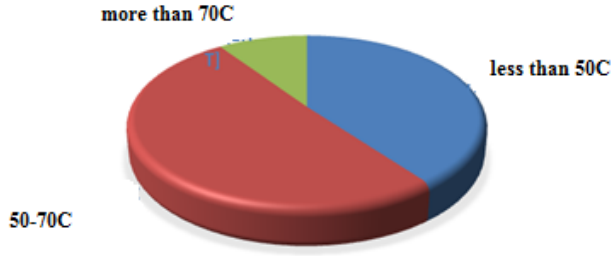

Fig. 2. Temperature analysis

Analysis of the diagram shows that microwave treatment significantly reduces drying time. For 100 g of raw materials, moisture 77%, using microwave, it took 73 minutes to dry the product to a final moisture content of 10%, while convective drying took 350 minutes.

The drying curves are shown in Figure 3.

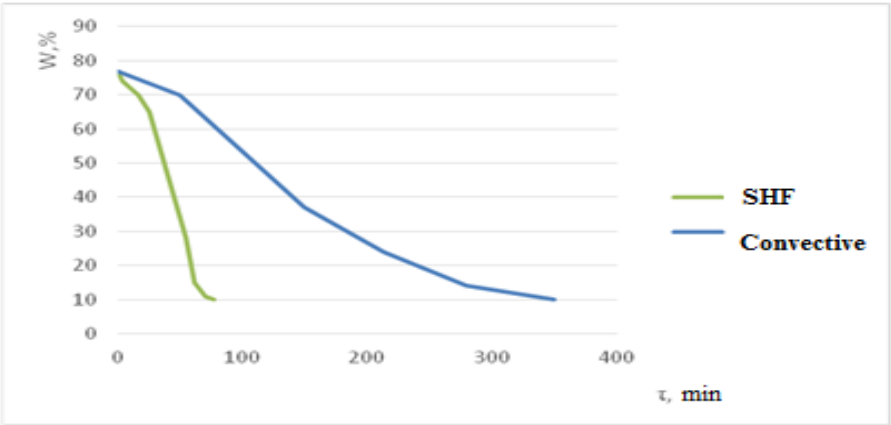

Fig. 3. Drying curve

Organoleptically dried samples did not differ from each other.

Pre-dried raw materials were subjected to extraction. For the extraction of pectin, the same methods were used for all samples. In the work performed, the use of strong mineral acids was abandoned in favor of citric acid. The extraction was carried out in three stages. After each stage, the aqueous solution was decanted and the raw material was poured with a new portion of the acidic solution. The output of pectin by stages is shown in Figure 2. It shows that the hydrolysis of raw materials dried using microwave is faster. After the second stage, it was already possible to obtain 90% of the pectin from the total pectin obtained. The raw material, convectively dried after the second stage, gave only 60% yield. Thus, to obtain pectin by the described method, two hydrolysis stages can be used, which will shorten the extraction time in general.

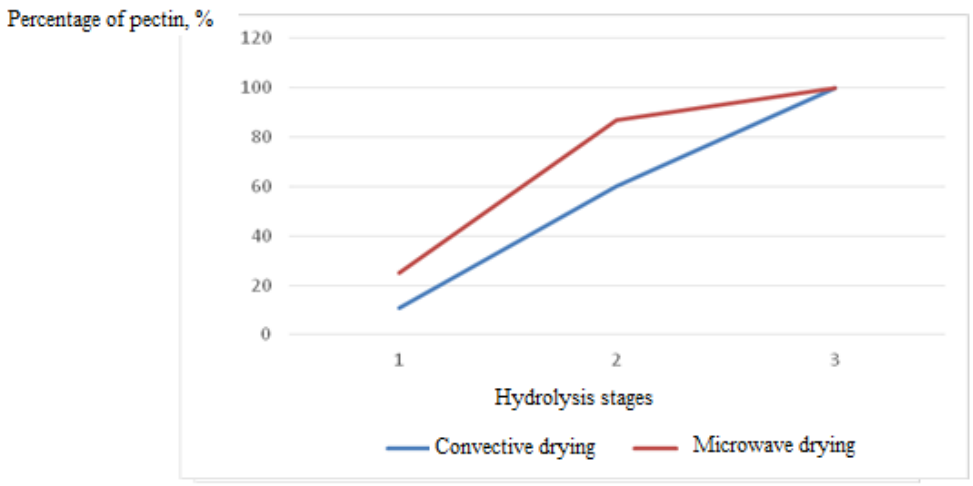

Fig. 4. The output of pectin by stages of hydrolysis

The total yield of pectin from raw materials after microwave processing of raw materials is 2.1 times higher than after convective drying.

Apparently, this can be explained by the effect of microwave energy on the raw material when heated. Orange peel has a capillary-porous structure and is a complex substance in which the components have different dielectric properties. The main role in the process of energy absorption during dielectric heating of a material is played by water molecules, which are dipoles. When an electric field is applied to a dipole molecule, its polarization occurs, caused by the attraction of negative and positive charges of the molecules in accordance with the direction of the external electric field, which subsequently under the action of an alternating field come into oscillatory motion. When exposed to an alternating electromagnetic field, the raw material, which is a dielectric material, heats up due to dielectric losses, that is, the field energy is converted into heat.

Due to its high dielectric constant, water absorbs most of the radiation, heats up and begins to evaporate. Since the water in the raw material is in a confined space, then with the beginning of its boiling, excess pressure is created. The increasing internal pressure significantly deforms the structure of the product throughout the entire volume of the material. Microwave treatment makes it possible to disrupt the continuity of the cell membranes of plant materials prior to extraction.

The structure of the raw material acquires a developed contact surface of the phases, which accelerates the mass exchange processes and at the same time ensures the uniform passage of hydrolysis of protopectin substances, regardless of their localization in the cell. As a result, the process of hydrolysis of protopectin substances is completed faster than for raw materials obtained by convective drying, which significantly increases the yield of pectin.

Moisture during microwave processing of raw materials evaporates faster, which increases the drying rate, and the cell walls containing pectin heat up less, which improves its quality.

The obtained samples can be classified as highly esterified, since the degree of esterification of all samples was more than 50%.

Molecular weight and gelation did not differ significantly between samples. For the formation of jelly 150 ° SAG, a mass of 70 kDa is sufficient [8]. All samples have an average molar mass greater than this value.

The experimental results are shown in Table 2.

Table 2

Experimental results for different methods of raw material preparation

	Convection Drying	**Combined Drying**
Pectin output to dry matter,%	10,8	21,9
Esterification degree,%	75	76,5
Average molecular weight, kDa	103	96

Conclusions. The paper describes a method of combined drying with a cyclic supply of microwave energy. The optimal power of microwave exposure is determined, equal to 300 W. The point of critical moisture content was found, on the basis of which the cycle duration was selected.

A comparison was made between microwave drying and convective drying of citrus raw materials, which were used to obtain pectin. Drying curves are given.

There was no significant difference in the quality of the pectin obtained. At the same time, microwave drying made it possible to reduce the drying time by 4.5 times and to increase the output of pectin by 2.1 times.

The method of obtaining pectin using microwave drying allows to simplify the technology, increase the yield and reduce not only the drying time, but also the duration of hydrolysis.

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РАЗРАБОТКА ТЕХНОЛОГИИ ПИЩЕВОЙ ДОБАВКИ С ПРОФИЛАКТИЧЕСКИМИ СВОЙСТВАМИ

THE DEVELOPMENT OF TECHNOLOGY OF FOOD ADDITIVES WITH PREVENTIVE PROPERTIES

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Аннотация. *Исследованы квантово-химические характеристики молекул флавоноидов выжимок красного винограда. Установлены оптимальные режимы экстракции сопутствующих ингредиентов из виноградных выжимок (титруемые кислоты, сахара и другие органические соединения). Осадок отделяли от раствора, измельчали и сушили. В результате получали пищевую профилактическую добавку с антиоксидантными свойствами.*

Ключевые слова: флавоноиды, виноградные выжимки, молекулярные свойства, экстракция, оптимизация, антиоксиданты, пищевая антиоксидантная добавка.

Abstract. *The investigated quantum-chemical characteristics of the molecules of flavonoids of pomace from red grapes. The optimal modes of extraction of the accompanying ingredients from grape pomace (titrable acids, sugars and other organic compounds) are established. The sediment was separated from the solution, crushed and dried. As a result, we received a food preventive additive with antioxidant properties.*

Key words: flavonoids, grape pomace, molecular properties, extraction, optimization, antioxidants, food antioxidant additive.

Introduction. In the Russian Federation, the average annual grape processing is 250 thousand tons. In the Stavropol Territory, 18 primary winemaking enterprises are engaged in the cultivation and processing of grapes, the production capacity of these organizations is 120 - 130 thousand tons of grapes per year. However, grape pomace is used to feed livestock or transported to the fields as organic fertilizer. The main reason for the irrational use of secondary raw materials for grape processing is the lack of effective technology [1; 2].

In modern theories about nutrition, much attention is paid to biologically active components of food, which determine the therapeutic and therapeutic-prophylactic effect. Special interest is paid to the development of a technology for processing grape pomace of red grapes, which contains a significant amount of biological antioxidants that reduce the activity of oxidative processes of radicals. Unsaturated fatty acids, which are part of phospholipids, are mainly subjected to oxidation in biological membranes. At the stage of initiation (in the alpha position), a proton (H •) is abstracted along the double bond between the carbon atoms. The CH bond is also weakened in adjacent carbon atoms, facilitating the elimination of a proton. The radical with carbon undergoes rearrangement and combines with oxygen to form a peroxide radical capable of separating a hydrogen atom from another unsaturated fatty acid [5, 6].

Phenolic compounds (with an aromatic ring) are the largest group among natural and synthetic antioxidants. As a result, a negative charge is shifted to the hydroxyl group, which contributes to the abstraction of a proton from the OH group and the formation of phenoxy radical isomers. Consequently, antioxidants flavonoids reduce the formation of peroxide radicals [1, 2].

Materials and methods. As a result of numerous studies, it has been found that red grapes, consumed regularly in the diet, have a beneficial effect on the human heart and circulatory system. It turns out that the polyphenolic compounds (flavonoids) contained in its composition significantly reduce the likelihood of blood clots. Dry red wine and

red grapes (wine itself and grape pomace) contain powerful antioxidants - quercetin, resveratrol, epicatechin, catechin, epicatechin gallate, rutin and others [7, 8].

The purpose of this research was to develop a technology for obtaining an antioxidant food supplement enriched with flavonoids from grape pomace.

The object of research was grape pomace obtained from the red grape variety "Levokumsky resilient" grown in Zarya CJSC of the Levokumsky region of the Stavropol Territory. Extraction of sugars, tartaric acids and protein from grape pomace was carried out on a laboratory extractor of the ES-8110 brand. Temperature control during extraction was carried out in a 1TG-0-03 water thermostat. During the experimental studies, ingredients and materials approved for use by the state sanitary epidemiological supervision were used.

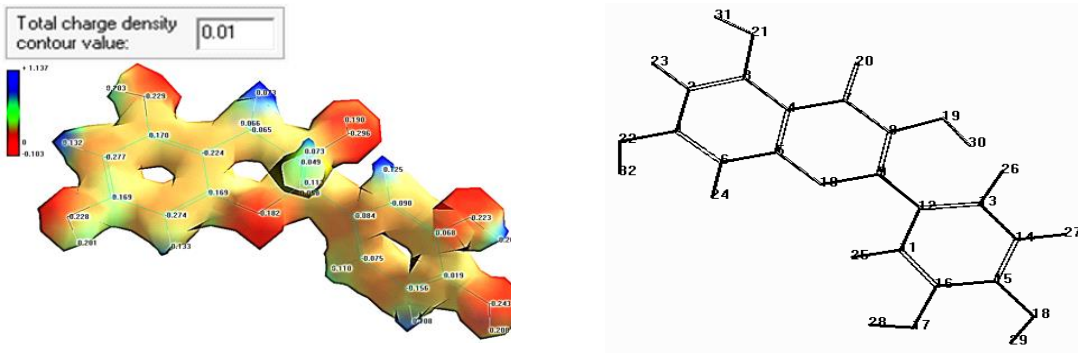
The pH value was determined in aqueous extracts by potentiometric method on a pH-meter-340. The protein content (in mass fractions) was determined by the Kjeldahl method; ash - by burning in a muffle furnace, followed by calcining a sample of the mineral residue; mass fraction of moisture - on a moisture analyzer brand OHAUS MB 45. Determination of the quantitative content of sugars was carried out by photocolorimetry, the interaction in an alkaline medium of carbonyl groups of sugars with iron cyanide potassium [4]. The mass concentration of titratable acids of the test solution was determined by titration with sodium hydroxide (concentration 0.1 mol / dm3) in the presence of phenolphthalein [3].

The data obtained was analyzed in Statistic v. 10 and the StatisticNeuralNetworks module. The experiments were carried out in 3–5 repetitions. Prediction of the molecular properties of chemical compounds was carried out in HyperChem v. 8.

When in contact with air, grape pomace quickly oxidizes and becomes moldy, acetic acid is formed instead of alcohol, and tartaric acid compounds are destroyed by propionic fermentation bacteria. Therefore, it is advisable to process the pomace immediately after pressing by extracting sugars, tartaric acids and other compounds.

The diffusion phenomenon underlies the extraction of tartaric acids and sugars from grape pomace. The diffusion process consists in the penetration of solutions of different concentrations of the solute into each other. Based on this, at the initial stage of the research, the molecular characteristics of the flavonoids quercetin, resveratrol, rutin, epicatechin, catechin, and epicatechin gallate were studied using computer simulation methods.

Results and discussion. When studying the distribution of the charge density on the surface of molecules and structures of flavonoids, it was revealed that almost all the compounds under study have hydrophobic properties (the deviation of the values of the charge values from zero is small), although there are insignificant hydrophilic zones. In fig. 1 shows the surface of the charge density distribution and the structural formula of the catechin molecule.



a) b)

Fig. 1. Catechin molecule: a - charge density distribution surface; b - structural formula

The proof of the hydrophobicity of flavonoids can be the value of the total charge density, presented in table. 1.

The data obtained indicate that it is advisable to use non-polar organic solvents for the extraction of flavonoids; at the same time, it is known that polar solutions are usually used for the extraction of sugars (alcohol) and tartaric acid compounds.

The temperature, the value of active acidity (pH), the duration of the process, and the ionic strength of the solution have a significant effect on the conditions for the diffusional distribution of substances between liquid phases. (t, pH, τ, C_{NaCl}).

Table 1

The final charge density of the investigated flavonoid molecules

Specifications	Flavonoids					
	catechin	epicatechin gallate	rutin	resveratrol	quercetin	epicatechin
Final charge density, eV	0,010	0,010	0,095	0,050	0,010	0,010

The study of extraction modes from grape pomace of sugars and tartaric acid compounds was carried out using mathematical planning (uniform rotatable plan) in a laboratory reactor. The influence of the extraction time, processing temperature, concentration of sodium chloride (NaCl) in solution and active acidity (pH) was studied on the process. Extracts with a given value of active acidity were prepared using a NaOH (sodium hydroxide) solution. The extraction rate is calculated by dividing the quantitative content of the substance in the extract by the total content in the system.

In each experiment of the plan, after extraction, the content of solids and their extracted amount (% of the total mass of pomace), as well as the quantitative content and degree of extraction of flavonoids from the feedstock, were determined in the solution. The results obtained indicated a significant effect on the extraction process of temperature, active acidity (pH), extraction time and ionic strength of the solution (NaCl concentration) on the degree of extraction of flavonoids and dry substances from grape pomace.

Based on the results of the experiment, a neural network model of the multilayer perceptron was developed to create a data array using artificial intelligence, which served as the basis for optimizing the extraction modes. The optimization was carried out taking into account the fact that it is necessary to extract the minimum amount of flavonoids from the grape pomace and extract the maximum amount of other dry substances.

As a result of analyzing the data of the array, the optimal parameters of the factors for extracting chemical compounds from grape pomace (7.9 - 8.2% of the total mass of pomace), soluble in polar solvents, were identified and checked in laboratory conditions (Table 2), the degree of extraction of flavonoids was insignificant and amounted to 0.5-2.3% of their total amount in the feedstock.

Table 2

Optimal parameters for the purification of grape pomace from sugars and tartaric acid compounds

Time (τ), min.	**Temperature (t), ° C**	**Active acidity (pH)**	**NaCI concentration in solution (C_{NaCl}), %**
20 – 25	85 – 90	7,2 – 7,4	0,3 – 0,5

At the end of the extraction process, the precipitate was separated from the liquid fraction, crushed (~ up to 30-50 microns) and dried at 70-80 ° C to a water content of no more than 8%. As a result, an odorless, dark cherry-colored, antioxidant powder supplement enriched in flavonoids was obtained.

The antioxidant activity of the food additive was determined by the change in the rate of lipid oxidation by monitoring the peroxide value, which characterizes the accumulation of lipid breakdown products, which is inversely proportional to the antioxidant activity.

The lipid model system was unsalted butter "Krestyanskoe" with a mass fraction of moisture 25% and fat 72.5%. This choice is explained by the short shelf life of this product (up to 10 days at a temperature of no higher than 8 ° C), which makes it possible to visually simulate the process of inhibiting lipid oxidation with the help of antioxidants contained in the food supplement.

A food antioxidant additive was added to the unsalted Krestyanskoe butter in an amount of 3% per 100 g of the model system (taking into account that the quantitative content of flavonoids in the system should be about 0.15%) and placed in a thermostat at a temperature of 37C, a control was prepared in parallel. a sample without additive, which was stored together with the experimental sample under the same conditions. The research results are presented in table. 3 and fig. 2.

Table 3

Accumulation of primary oxidation products in model lipid samples q ≤ 0,05

№ of sample	Sample	Storage duration, days				
		0	7	14	21	28
		Peroxide number, mmol of active oxygen / kg				
1	"Krestyanskoe" unsalted butter (control)	0,007	0,019	0,035	0,042	0,055
2	Unsalted "Krestyanskoe" butter with food antioxidant additive (experience)	0,007	0,013	0,018	0,022	0,033

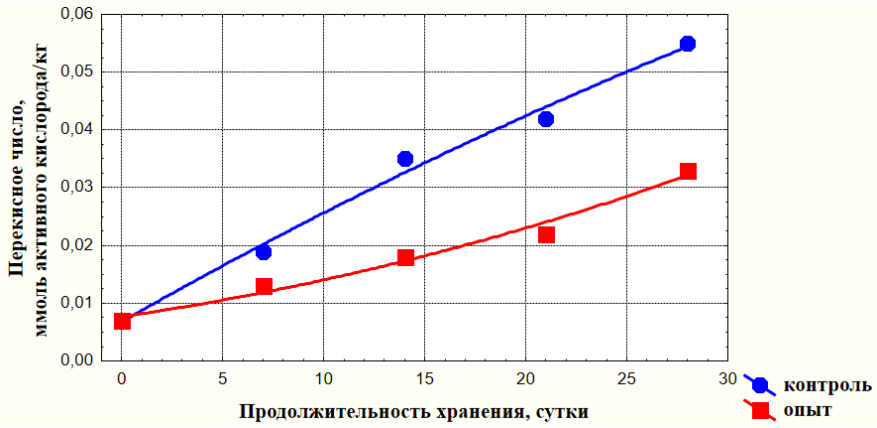


Fig. 2. Dynamics of the accumulation of primary oxidation products

The experimental results (Table 3, Fig. 2) show that the experimental sample after technological treatment had a peroxide number less than the control one (0.033 versus 0.055 mmol of active oxygen / kg).

Thus, studies of the molecular characteristics of grape pomace flavonoids confirmed the antioxidant properties of these compounds, and the expediency of using polar solutions for the extraction of tartaric acids and sugars was established.

The optimal technological modes (t = 85–90oC, = 20–25 min., PH = 7.2–7.4, NaCl concentration in the solution - 0.3–0.5%) for extracting sugars and tartaric acids from the grape peel were revealed. compounds providing insignificant losses of flavonoids (0.5 - 2.3% of the total amount in the feedstock).

The technology of an antioxidant food additive with preventive properties has been developed, which consists in extracting tartaric acids and sugars from grape pomace by extraction, separating the liquid fraction, crushing and drying the sludge.

Experiments on lipid model samples confirmed the antioxidant activity of the developed food additive.

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ИССЛЕДОВАНИЕ ПРОДУКТОВ РАСТИТЕЛЬНОГО ПРОИСХОЖДЕНИЯ НА НИТРИТЫ, НИТРАТЫ И РАДИОАКТИВНОСТЬ

STUDY OF PLANT PRODUCTS ON PRESENCE OF NITRITES, NITRATES AND RADIOACTIVITY

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Аннотация. *В данной статье будут рассмотрены образцы продуктов растительного происхождения и их соответствие на маркировку «organic». Действительно ли в магазинах, которые позиционируют себя, как Organic, реализуются органически чистые продукты, или это является маркетинговым ходом и подобные продукты ничем не отличаются от тех, что были выращены при традиционном сельском хозяйстве. Была поставлена цель сравнить продукты растительного происхождения трех разных производителей, включая производителя органических продуктов на содержание в них нитритов, нитратов и радиоактивного фона, так как эти показатели являются одними из важных, при производстве органической продукции.*

Ключевые слова: огурцы, органические продукты, нитраты, нитриты, радиоактивность, производители.

Abstract. *The samples of plant products and their compliance with the labeling "organic"are examined in this article. It is being investigated whether the stores that position themselves as «organic» sell organically pure products, or whether this is a marketing trick and there is no difference between such products and those grown in a traditional way. The goal of the research is to compare plant products of three different manufacturers, including the manufacturer of so-called organic products on presence of nitrites, nitrates and radioactivity, since these indicators are important in assessing the quality of organic products.*

Key words: cucumbers, organic products, nitrates, nitrites, radioactivity, manufacturers.

Introduction. Currently, the concept of "healthy eating" is relevant and many people become adherents of a healthy lifestyle. It is impossible to imagine a single store in which there would be no "organic" or "non-GMO" labels on any of the products now. What is organic food and why is it in demand these days?

Depending on how the food is grown, it can have a serious impact on a person's mental and emotional health as well as the environment. Organic foods often contain more beneficial nutrients, such as antioxidants, than their regular counterparts, and people who are allergic to food, chemicals, or preservatives often find their symptoms diminish or disappear when they eat only organic foods. [1.15]

When growing such products, no pesticides, herbicides, radioactive radiation, synthetic fertilizers and other technologies that do not meet the requirements for the production of organic products are used. Vegetables and fruits grown on specialized farms, due to this, contain less nitrogen-containing compounds, and the radioactive background is less than that of products grown in a traditional way. There are three international systems of standards in the world that are guided by farmers in the production of organic products, these are:

1. EU Regulation 2092/91 (EC 834/2007)
2. Codex Alimentarius Guidelines for Organically Produced Food 1999/2001
3. IFOAM Basic Standards (IBS).

The production of organic products is not controlled at the federal level in Russia now, so unscrupulous producers can pass off such as products those that were grown in traditional agriculture. The federal law "On the produc-

tion and circulation of organic products (organic products)", which allows the production of organic products, will enter into force on January 1, 2020. [2.12]

Four regulatory documents have been introduced in Russia for the production of organic products at the moment:

1. GOST R 56104-2014 “Organic food products. Terms and Definitions"
2. GOST R 56508-2015 “Organic products. Rules for production, storage, transportation "
3. GOST R 57022-2016 “Organic products. The procedure for conducting voluntary certification of organic production "
4. SanPiN 2.3.2.1078-01 "Hygienic requirements for safety and nutritional value of food" (from Chapter 2, Clause 2.18 and Chapter 6) [1,3,4,5].

There are no exact data showing the maximum permissible concentration of nitrites in plant foods, however, when they enter the body, nitrates pass into nitrites, which, with their high content, can deprive the body of oxygen, thereby being a catalyst for oxygen starvation, and also cause diseases of the gastrointestinal tract. So, the more nitrites there is in the product, the more nitrates in it, which are one of the main indicators of organic production.

The task in this article is to compare products of plant origin from three different manufacturers, including a product labeled "organic" on presence of nitrites, nitrates and radioactive radiation, since according to the normative European standards [6, 7], nitrates and background radiation are some of the important indicators that prove the purity of the product and justify its name as organically pure product.

Materials and methods. Cucumbers were chosen as the object of research, since it was easier to obtain a water extract from this product. The method for the determination of nitrites with the Griss reagent was chosen as a method of research for nitrites. This method is based on the fact that in the presence of nitrite ions, the reagent stains them red, and, as a result, the more intense the color is, the more nitrite in the product. [2,10]

The following cucumber samples were taken for this experiment:

1. Medium-sized cucumbers of Agrofirm "Vyborzhets" Company.
2. Medium-fruit cucumber "Meva" of "Greenhouse Complex Belogorya" Ltd – «Green garden bed»
3. Short-fruited fresh cucumbers "Mirinda", of «Organica» supplier.

Water extracts were taken from the presented names of cucumbers, which were then filtered.

To assess the content of nitrites in the samples under study, standard solutions of NaNO3 of various concentrations were prepared. It was necessary to construct a calibration graph from the data of standard solutions. A standard working solution of NaNO3 was brought for this into 9 volumetric flasks of 50 ml in an amount of 0 - 0.1 - 0.2 - 0.5 - 1 - 2 - 5 - 10 - 15 ml, which corresponds to 0 - 0.1 - 0.2 - 0.5 - 1 - 2 - 5 - 10 - 15 μg of nitrite ions. Then, distilled water and 2.5 ml of the prepared Griss reagent were added to these flasks to the mark.

Then, the resulting solutions were photometrically measured on a photoelectric colorimeter with a green filter at a wavelength of 540 nm for subsequent construction of a calibration graph in the coordinates «optical density - nitrite content» (μg). The optical density of each concentration is shown in Table 1.

Table 1

Optical density

Nitrite content (μg)	Optical density
0	0,001
0,1	0,018
0,2	0,007
0,5	0,019
1	0,015
2	0,047
5	0,123
10	0,199
15	0,306

A calibration graph based on the results of Table 1 is shown in Figure 1.

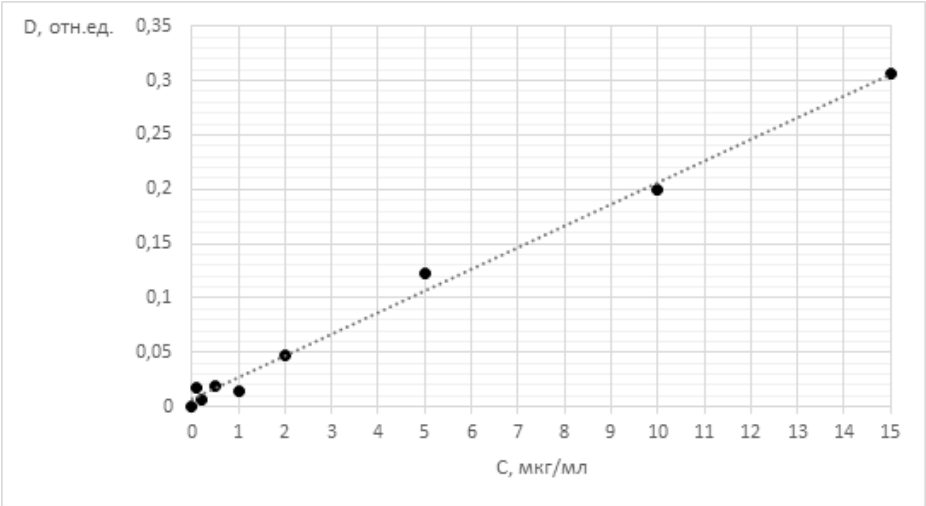

Fig. 1. Calibration graph of standard solutions

In 20 ml of each of the tested filtered aqueous extracts of the presented cucumber samples, 1 ml of Griss reagent solution was added and left for 40 minutes until a stable color was obtained.

The obtained extracts were photometric, the obtained optical densities are presented in Table 2.

Table 2

Optical densities of extracts

Sample No.	Optical density, rel. units
3	1,09
1	1,05
2	1,13

Based on the obtained optical density results, the concentration of nitrite ions obtained in the extracts was calculated on the basis of the calibration straight line. The results are shown in Table 3.

Table 3

Concentration of nitrite ions in the test solutions

Sample No.	Optical density, rel. units	Concentration of nitrite ions by optical density (μg / ml)	Content of nitrite ions in the test sample (μg)
3	1,09	1,07	22,47
1	1,05	1,03	21,63
2	1,13	1,12	23,52

A graph, based on the Table 3 data, is presented in Figure 2.

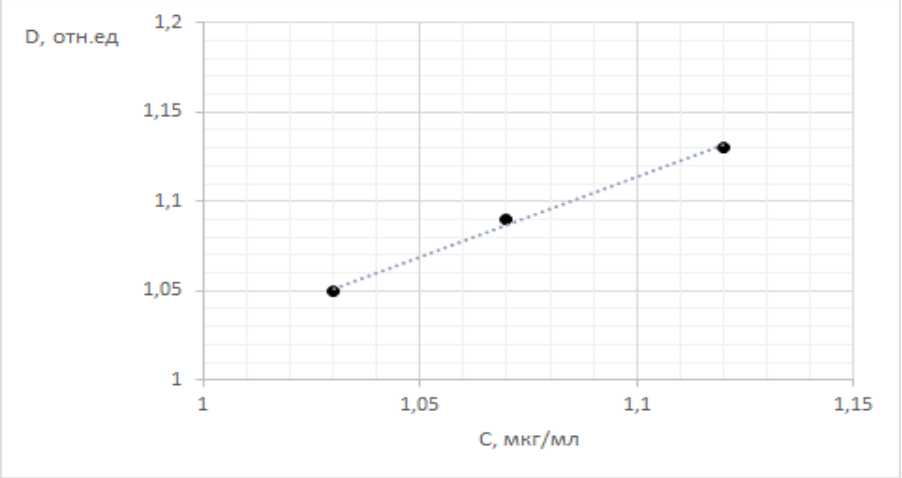

Fig. 2. Graph of optical densities of the investigated solutions

In addition to the study of the three types of cucumbers for nitrites using the Griss reagent, they were also tested for nitrates and radioactivity by the express method, using a SOEKS nitrate meter.

Table 4 shows the obtained measurement results and standardized indicators for cucumbers: sample 3 is a greenhouse cucumber, which corresponds to a nitrate norm of 400 mg / kg, samples 1 and 2 are ground and the nitrate norm is 150 mg / kg, according to the Resolution of the Chief State Sanitary Physician of the Russian Federation from November 14, 2001 N 36 "On the introduction of sanitary rules". Table 5 shows the background radiation.

Table 4

Content of nitrate ions

Sample No.	Average value, mg / kg	Norm, mg / kg	% of the norm
3	58	400	14,5
1	78,3	150	52,2
2	88,7	150	59,13

Table 5

Background radiation

Sample No.	Background radiation, μR / h	Norm, μR / h	% of the norm
3	18,3	30	61
1	24	30	80
2	21,3	30	71

Results and discussion. Based on the results of the study, it was found that the extract from the sample marked "organic" contains much more nitrite ions than in other samples, but it should be borne in mind that when examined with a photoelectric colorimeter, the extract from the sample was turbid, and it could lead to distortion of results. However, this extract has a less intense color, unlike other samples presented. However, sample no. 2 contains more nitrites than sample no. 1.

According to the data of table 4 – cucumbers labeled "organic" contain the least amount of nitrates relative to the norm, and from table 5 it can be seen that this type of cucumber contains the lowest level of radiation background, in contrast to the other two samples presented. However, all tested samples comply with the prescribed standards.

Conclusions. According to the data that were obtained as a result of the study, it was revealed that cucumbers labeled "organic" actually contain significantly less nitrates, as well as the lowest radiation background, in contrast to other samples presented. Thus, the sample under No. 3, unlike other samples, can be considered organic and a man will not receive much harmful substances by eating it.

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ИНТЕЛЛЕКТУАЛЬНАЯ СИСТЕМА КОНТРОЛЯ КАЧЕСТВА ТВОРОГА

INTELLIGENCE SYSTEM OF COTTAGE CHEESE QUALITY CONTROL

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Аннотация. *В статье обоснована необходимость создания автоматизированной системы диагностики качества творога. Для базы знаний разработан метод обратного нечеткого вывода зависимости качества конечного продукта от качества используемого сырья и правильности организации технологического процесса.*

Ключевые слова: нечеткий логический вывод, сырье, технологический процесс, фактор, эксперт, нечеткая импликация, база знаний.

Abstract.*The need of creation of the automated system for diagnostics of cottage cheese quality is proved in the article. The inverse fuzzy inference method of dependence of the final product quality on the quality of the raw materials and the correctness of the technological process organization has been developed for the knowledge base.*

Key words: fuzzy inference, raw materials, technological process, factor, expert, fuzzy implication, knowledge base.

The development of computer technology has led to the creation of automated control systems for technological processes (ACS). One of the important areas of use of ACS are quality control systems in the food industry. The importance of this problem is determined by the concept of life safety. Non-automated food quality control methods are subjective and imprecise. Rospotrebnadzor intends to create a modern food quality control system using digital technologies. To solve this problem, it is necessary to develop expert systems for product quality control. The basis of an intelligent expert system is a knowledge base containing inference rules. Various methods can be used to set inference rules, for example, neural networks [1-4], fuzzy logical inference rules [5].

A method to control the quality of curd and curd products by building an intelligence system for assessing the quality of a product applying input and output data based on fuzzy inference has been developed in this work.

The relevance of the research is determined by the fact that cottage cheese is one of the main food products, which is included as a main component in many therapeutic diets. Sales of cottage cheese and curd products in Russia increased in 2017 compared to 2013 by 5.1% and amounted to 802.5 thousand tons. Demand for cottage cheese and curd products in January-July 2018 increased by 6.8% compared to with the same period in 2017. This trend will continue in the coming years.

According to GOST [6], the quality of cottage cheese is determined by organoleptic indicators, which include: taste, smell, consistency, color and acidity (Table 1).

Table 1

Organoleptic characteristics of cottage cheese

Indicator name	Characteristics
Consistency and appearance	Soft, smudgy or crumbly with or without noticeable milk protein particles. For a fat-free product, there is little whey emission.
Taste and smell	Clean, fermented milk, without foreign flavors and odors. For a reconstituted milk product with a milk powder flavor.
Colour	White or creamy, even throughout the mass.

Examples of flavor fading of cottage cheese: unexpressed (insipid) or too sour, bitter taste. The presence in the product of flavors: fodder (wormwood, silage), ammonia, metal, yeast.

Violation of consistency: coarse, dry, crumbly, smeared, strappy. Changes in appearance: flabby clot, serum secretion.

In addition to organoleptic methods, instrumental methods are used, which determine the mass fraction of protein, fat, moisture, dry matter, acidity, phosphatase or peroxidase, the presence of food additives, the temperature of the product.

The quality of cottage cheese depends on the quality of the raw materials and the correctness of the technological process of manufacture.

In the manufacture of cottage cheese, as a primary raw material cow's milk is used. It must be of at least second grade and with acidity of not more than 21%, as well as its processing products (skim milk obtained by separation). In addition, special additives are used (for example, ferment for cottage cheese on pure cultured lactic acid streptococci, calcium chloride or calcium chloride 2-water), as well as drinking water.

The technological process for the cottage cheese production consists of a set of typical operations. These include primary operations: acceptance of primary raw materials (milk), cooling, creation of a reserve. Then milk is cleaned, heated, separated, pasteurized. After that, the sequence of operations is as follows: cooling, fermentation, clot formation, clot processing. The final operations include packaging and storage. Defects in the cottage cheese can occur at various stages of the technological process.

In the production of cottage cheese, statistical methods are currently used to control quality [6].

Let us consider the construction of an artificial intelligence system based on the inverse fuzzy logical inference to control the quality of cottage cheese. The quality is assessed by organoleptic indicators depending on the characteristics of the used raw materials and the correct organization of the technological process.

The logical conclusion can occur in direct order (from premises to conclusion) and in reverse order (analysis of conclusions is carried out until premises that confirm one of the conclusions are identified). Reverse search is used in cases where conclusions are known and their number is small. In some expert systems, inference is based on a combination of reverse and forward order (circular output).

Let us show the withdrawal rules using the following simplified example (at the output of an intelligence system, only organoleptic indicators of the quality of cottage cheese are considered and instrumental indicators are not affected, and at the input the factors of poor-quality raw materials and the reasons for breakdown in the technological process are not detailed).

Let the set of premises (factors) $X = \{x_1, x_2\}$ consist of two elements:

x_1 - low-quality raw materials;

x_2 - breakdown in process of making cottage cheese.

The set of values of the output variable (conclusions about the quality of the product) $Y = \{y_1, y_2, y_3, y_4, y_5\}$ consists of five elements:

y_1 - imbalance of the taste of the product;

y_2 - nonconformity of the smell of cottage cheese to the requirements of GOST;

y_3 - imbalance of the consistency of cottage cheese;

y_4 - the wrong color of the curd;

y_5 - excessive acidity of cottage cheese.

It is required to determine, on the basis of the experts' knowledge (producers' of cottage cheese), which of the factors influenced the quality of cottage cheese to the greatest extent.

Consider a fuzzy implication $R: X \to Y$ (a fuzzy rule of the form "If, $x = \tilde{A}$, then $y = \tilde{B}$"). The premises $\tilde{A}$ and conclusions $\tilde{B}$ of the expert system are fuzzy sets or values of a linguistic variable.

In the problem under consideration, the direction of conclusions is inverse with respect to the direction of the premises. Thus, there is an expert's $\tilde{R}$ knowledge base, it is necessary, on the basis of observations of the values of the output variable $\tilde{B}$, to determine which of the set of factors $\tilde{A}$ determines the production of low-quality cottage cheese to the greatest extent.

Let us assume that the knowledge base of an expert in the production of cottage cheese is given by the matrix:

$$\tilde{R} = \begin{pmatrix} 0,9 & 0,1 & 0,6 & 0,2 & 0,3 \\ 0,7 & 0,4 & 0,5 & 0,3 & 0,4 \end{pmatrix}.$$

Let the results of the analysis of the quality of cottage cheese be evaluated on a scale from 0 to 1 and the following data are obtained as a result of the assessment:

$$\tilde{B} = (0,9/y_1;\ \ 0,2/y_2;\ \ 0,1/y_3;\ \ 0,3/y_4;\ \ 0,4/y_5).$$

From the given results of assessing the quality of cottage cheese, it follows that the greatest criticism is caused by the taste of cottage cheese.

It is required to determine the reason for the production of a low-quality product, that is, find the input factor a_i ($i = \overline{1,2}$) from a set of factors $\tilde{A} = (a_1/x_1;\ \ a_2/x_2)$, which is the main reason for the production of a low-quality product.

Let's assume that a_1 and a_2 change from 0 to 1.

According to the compositional rule of fuzzy inference Zadeh [7],

$$\tilde{B} = \tilde{A} \circ \tilde{R},$$

where $\circ$ is the composition operation.

Then, for the given values of the input and output variables, we can write the ratio:

$$(0,9;\ \ 0,2;\ \ 0,1;\ \ 0,3;\ \ 0,4) = (a_1;\ \ a_2) \circ \begin{pmatrix} 0,9 & 0,1 & 0,6 & 0,2 & 0,3 \\ 0,7 & 0,4 & 0,5 & 0,3 & 0,4 \end{pmatrix}.$$

Expanding the (max-min) -composition we obtain the following five relations:

$$0,9 = \max(\min(0,9; a_1); \min(0,7; a_2)); \quad (1)$$

$$0,9 = \max(\min(0,9; a_1);\ \min(0,7; a_2)); \quad (2)$$

$$0,6 = \max(\min(0,6; a_1);\ \min(0,5; a_2)); \quad (3)$$

$$0,2 = \max(\min(0,2; a_1);\ \min(0,3; a_2)); \quad (4)$$

$$0,3 = \max(\min(0,3; a_1);\ \min(0,4; a_2)). \quad (5)$$

In relation (1), the element $\min(0,7; a_2) \le 0,7$. Therefore, it does not affect the left side of the ratio, hence $0,9 = \min(0,9; a_1)$. From here $a_1 = 0,9$.

Substituting this value into relation (2), we obtain $a_2 = 0,2$.

The obtained values of the variables satisfy relations (3) - (5).

Thus, given the initial data of the observations, the factor most influencing the violation of organoleptic indicators of the quality of cottage cheese is the use of low-quality raw materials, and not a breakdown in the technological process of making cottage cheese.

The factors $\tilde{A}$ and values $\tilde{B}$ of the output variable can be linguistic variables. In this case, when applying the compositional rule, their functions should be determined using commonsense reasoning or expert judgment.

The considered rules of fuzzy inference can be expanded through the use of instrumental indicators, as well as detailing the factors of poor-quality raw materials and the reasons for the breakdown in the technological process.

Consequently, the automation of the cottage cheese diagnostic system using artificial intelligence methods will increase the quality of the finished product. The introduction of expert systems into the food industry will make it possible to predict the quality of cottage cheese when the characteristics of primary raw materials and technological parameters change.

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МЕТОД НАПОРНОЙ ФЛОТАЦИИ. РАСЧЕТНАЯ ОЦЕНКА РАЗМЕРОВ И ФОРМЫ ИЗВЛЕКАЕМЫХ ТОНКИХ ФРАКЦИЙ ДРАГМЕТАЛЛОВ

PRESSURE FLOTATION METHOD. THE ESTIMATED ASSESSMENT OF THE SIZE AND SHAPE OF RECOVERABLE FINES OF PRECIOUS METALS

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Аннотация. *В работе рассмотрен процесс извлечения частиц драгоценных металлов методом напорной флотации. Произведены оценочные расчеты размеров и массы поднимаемых частиц золота из отвалов. Приведены выводы, позволяющие определить применение метода напорной флотации в зависимости от применяемого сырья, содержащего мелкие фракции золота.*

Материалы и методы. *Новый метод извлечения тонких фракций драгоценных металлов (например, из рудных пульп) на первом этапе включает в себя обработку пульпы флотореагентами с целью гидрофобизации поверхности извлекаемых избранных частиц. При работе по этому методу вода предварительно должна насыщаться воздухом под давлением. Далее подготовленная кондиционированная пульпа смешивается с водой, сатурированной воздухом при атмосферном давлении. Затем эту смесь обрабатывают потоком пузырьков воздуха соответствующих флотационных размеров.*

Заключение. *Предложенная технология, в основе которой используется метод напорной флотации [7] может применяться для извлечения тонких фракций драгоценных металлов, которые не могут извлекаться методом классической флотации. Но это происходит только с ограниченными типами сырья с извлекаемыми частицами определенной формы и размеров.*

Выводы. *Задача извлечения тонких фракций драгоценных металлов может быть решена посредством применения новой технологии, сырьем для которой является пластинчатое золото, имеющее необходимые геометрические параметры и размеры, рассчитанные в данной статье. Показано, что данным методом можно извлекать пластинчатое золото с толщиной от 0,005 (мм) и менее.*

Ключевые слова: флотационные методы, флотореагент, обогащение золотосодержащего сырья, пульпа, гидрофобные частицы.

Abstract. *The process of extracting fines of precious metals by the method of pressure flotation is considered in the paper. Estimated calculations of the size and mass of the raised from the dumps gold fines were made. The author gives the conclusions that allow to determine the application of the pressure flotation method depending on the used raw materials containing fine gold fractions.*

Materials and methods. *A new method for extracting fine fractions of precious metals (for example, from ore pulps) at the first stage includes treating the pulp with flotation reagents in order to hydrophobize the surface of the selected fines to be extracted. When using this method, the water must first be saturated with air under pressure. Then the prepared conditioned pulp is mixed with water saturated with air at atmospheric pressure. Then this mixture is treated with a stream of air bubbles of appropriate flotation sizes.*

Results.*The proposed technology, based on the method of pressure flotation [7], can be used to extract fine fractions of precious metals that cannot be extracted by the method of classical flotation. But this method is applicable only for a limited type of raw material with recoverable fines of a certain shape and size.*

Conclusions. *The task of extracting fine fractions of precious metals can be solved by using a new technology, the raw material for which is plate gold, which has the necessary geometric parameters and dimensions calculated in this article. It is considered that this method can be used to extract plate gold with a thickness of 0.005 (mm) and less.*

Key words: flotation methods, flotation agent, enrichment of gold-bearing raw materials, pulp, hydrophobic particles.

Introduction. Flotation methods of ore beneficiation are based on the use of the kinetic component, which is expressed in the inertial motion of hydrophobized fines during the implementation of the elementary flotation action – hitting an air bubble and sticking to it with the formation of a floating particle-bubble aggregate. In all these cases, particle size is critical. With a decrease in the size of the particles, their kinetic component decreases and they become unable to perform an elementary flotation action. As follows from literary sources, from 40 to 50% of unrecovered gold of fine fractions remains in the tails of gold placers enrichment [1].

The flotation method operates on the principle of adhesion of hydrophobized particles of individual minerals to air bubbles in the pulp environment through their collision. With this interaction, the formed particle-bubble aggre-

gates float to the surface of the pulp under the action of the Archimedean force. The result is foam that is discharged into the tank. Further, the resulting foam is dehydrated to obtain a product – a concentrate of the extracted mineral particles. The remaining depleted slurry from the chamber is discharged in the form of flotation tailings into a storage facility. In this case, the pulp before the flotation process is treated with specially selected flotation reagents, which convert the particles of selected minerals into hydrophobic particles subject to flotation. The particles of the remaining minerals turn into hydrophilic, water-wetted, and therefore non-floatable particles [2].

By dispersing atmospheric air in the pulp, appropriate conditions are created for the adhesion of hydrophobized particles with air bubbles in the pulp. The adhesion of the obtained hydrophobized particles to air bubbles with their subsequent retention on the surface occurs under the action of the forces of intermolecular interaction. These forces exist on the surfaces of a floating particle and bubble in the form of surface free energy created by uncompensated forces of molecules and atoms located on this surface [3, 8].

The action of van der Waals forces begins to manifest itself at a distance of 1000 pm (picometers 1 * 10-12m), and their maximum effect occurs at a distance of 500 pm, but further convergence of reacting particles is counteracted by the repulsion of electrons of molecules of approaching particles [4,5].

As the mass of hydrophobized particles decreases to less than 0.05 mm, the inertial forces of such particles are weakened, and it becomes more difficult for them to break through the hydration layers and the elementary effect of flotation of these small particles does not occur, therefore, they will not float. But the flotation of such particles is of great importance for the beneficiation of gold-bearing sands, in which a significant part of the precious metals is in the form of fine particles less than 0.05 mm in size, which are not recovered either by gravity or flotation methods [6, 9]. That is why a number of sources indicate that when such sands are enriched, up to 50% of the gold contained in them is not recovered and goes into the tailings. Consequently, raw materials from such deposits require a new method of flotation, in which air bubbles would stick to such small particles and be carried out into the foam layer [10].

As the external pressure decreases, the gas solubility in the liquid decreases. In the technological process of flotation, an aqueous solution of air created under pressure, being at atmospheric pressure, turns out to be supersaturated with air and unstable. In this case, the excess dissolved air begins to pass from the solution into the gas phase. Such a phase transition occurs in the form of very small bubbles, the nuclei of which can form and grow on hydrophobic particles by diffusion of air from the solution medium. This occurs by shifting the H2O molecules from the hydrophobic surface. If there are not enough hydrophobic particles, very small bubbles will begin to emerge in the total volume of water. This is due to the fact that on the hydrophobic surface, the particles, attracted water molecules, have a weak bond with it, and the nuclei of small bubbles formed on this surface can shift them without high energy consumption [11]. And with the appearance of nuclei of air bubbles in the total volume of water and their further growth, they need to destroy the strong bonds of polar H2O molecules, at significantly higher energy consumption.

The process of pressure flotation can continue as long as particles with a free hydrophobic surface area and the remainder of an aqueous solution supersaturated with air remain in the initial pulp. And only in the process of reducing the area of particles with a hydrophobic surface can the energy-intensive process of the appearance of air bubbles in the total volume of the aqueous phase of the pulp occur. In this regard, the process of obtaining a mixture of conditioned pulp with water, previously saturated with air, must be of high quality. In this case, the resulting mixture of saturated water with the aqueous phase of the pulp should be evenly distributed over the volume of the pulp. But, due to the small size of the resulting mini-particle-bubble aggregates, which have a low ascent rate, the pulp must be constantly processed with flows of air bubbles of appropriate sizes for transportation.

A patent for an invention No. 2507007 dated 20.02.2014. "A method of extracting selected minerals from ore pulps by pressure flotation and a device for its implementation is received on this subject." [7]

When working with gold-bearing raw materials, it should be taken into account that the density of gold is high – $\rho = 1.96 \cdot 104$ (kg / m3). In order to lift a gold particle from the pulp, it is necessary to have a buoyancy force obtained due to the adhesion of air bubbles to it with a total volume of approximately 20 times the volume of this gold particle.

The surface of a gold particle must be covered in the general case with at least 20 bubbles of the same volume each as the original gold particle. Theoretically, it is possible to assume the shape of a gold particle in the form of a cube (grain) with 6 faces, which will allow only 6 air bubbles of the corresponding volume to be attached to the surface, while the calculation requires at least 20 bubbles of the same volume to lift a particle. In this case, particles of a substance with a density not exceeding 6 (kg / m3) can be subjected to flotation – according to the number of particle faces. Therefore, the flotation process is highly dependent on the shape of the gold particle (for example, in the form of flakes).

Let's make the necessary calculations. Let's designate the average geometric parameters of a cube-shaped particle (length, width, height): l = 0.05 (mm) = 5 10-5 (m). The volume of such a particle is V aurum = l3 = 125 10-15 (m3). The density of gold is ρ aurum = 19.3 (g / cm3) = 19.3 103 (kg / m3).

Let us determine the mass of the selected gold particle m = V aurum · ρ aurum = 125 · 10-15 · 19.3 · 103 = 241.25 · 10-11 (kg).

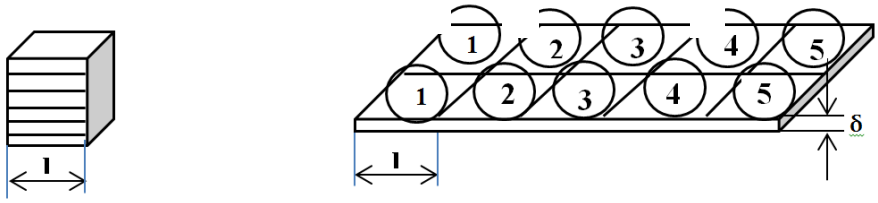
Particle weight is $P=m\cdot g=241{,}25\cdot 10^{-11}\cdot 9{,}81\approx 2{,}5\ 10^{-8}$ (kg ·m/c^2). Here g=9,81 (m/c^2).

At the same time, we take the density of water ρ = 1 (g / cm^3) = $1\cdot 10^3$ (kg / m^3). The lifting force acting on the gold particle must be higher than its weight, therefore, the volume of the air bubbles participating in the rise must be proportionally larger than the volume of the gold particle due to the difference in density between the water and the lifted particle. $P=m\cdot g=\rho_{water}\cdot V_{water}\cdot g\approx \rho$ aurum V aurum ·g (kg ·m/c^2); V air > 20 · V aurum.

As a result, the total volume of air bubbles should be more than 20 times greater than the volume of a grain of gold, determined by the difference in the density of water and the floating element.

From the above calculations, it can be seen that for the example of a particle with a face size of 0.05 (mm) x 0.05 (mm), the volume of the particle will be V particle = $125\cdot 10^{-15}$(m^3). To lift such a particle, an air volume of at least 20 times is required.V air.=20·V particle= $20\cdot 125\cdot 10^{-15}=250\cdot 10^{-14}$(m^3).

If a particle of a given volume is divided into 10 thin plates, then 20 air bubbles (on top of the plate and bottom of the plate) necessary for lifting can be placed on it, placed on the corresponding area (see Fig. 1). In this case, the particle has the same mass, but a much larger surface. This allows the particle to be lifted, since the number of bubbles will provide the required lifting force. Thus, the shape of the particle affects its rise.



a) b)

Fig. 1. Elementary particle for lifting by pressure flotation. a) a particle of a cubic shape; b) a plate-shaped particle (bubbles are shown only on one upper side of the plate)

Conclusion. As a result, the following conclusions can be drawn:

1. For lifting gold particles by the method of pressure flotation, a promising raw material can be mainly plate gold, which has the necessary geometric parameters and dimensions.

2. This method can only lift plate gold with a thickness of l = 0.005 (mm); δ = 0.005 (mm).

3. Materials with a density ρ <6 (g / cm^3) can be lifted in the form of grains, because sufficient lifting force will be provided by the total number of bubbles attached to the particle.

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СВОЙСТВА ОРТОГОНАЛЬНОСТИ И ПОЛНОТЫ СИСТЕМЫ СФЕРИЧЕСКИХ ФУНКЦИЙ

THE PROPERTIES OF ORTHOGONALITY AND COMPLETENESS OF THE SYSTEM OF SURFACE HARMONICS

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Аннотация. *Сферические функции представляют собой угловую часть семейства ортогональных решений уравнения Лапласа, записанную в сферических координатах. Использование этих функций достаточно разнообразно, они имеют большое значение в теории дифференциальных уравнений в частных производных и теоретической физике.*

Материалы и метод, результаты и обсуждения. *В статье доказывается ортогональность и полнота системы сферических функций вида (4).* ***Сферическими функциями*** *называют специальные функции одного переменного, являющиеся решениями дифференциальных уравнений, получающихся при применении метода разделения переменных для уравнения Лапласа, записанного в сферических координатах. Авторами рассматривается разложение сферической функции, имеющей непрерывные вторые производные в ряд Фурье. В процессе такого разложения используется оператор сферических функций, далее применяется метод интегрирования по частям на поверхности сферы. Записаны формулы Грина для оператора сферических функций, анализ полученных результатов доказывает ортогональность сферических функций. Впоследствии, рассматривая коэффициенты ряда Фурье, как непрерывные функции и, доказывая возможность равномерной аппроксимации линейными комбинациями присоединенных функций любой дважды дифференцируемой функции $f(\theta,\varphi)$, доказывается полнота системы функций, определяемых формулой (4).*

Заключение. *В результате исследования выяснилось, что любую непрерывную функцию можно равномерно аппроксимировать полиномом сферических функций, что и доказывает полноту системы функций, определяемых формулой (4). Из полноты этой системы следует её замкнутость. Таким образом, доказано, что уравнение сферических функций не имеет ограниченных решений при $\lambda \neq n(n+1)$ и что всякая сферическая функция n-го порядка (при $\lambda = n(n+1)$) представима формулой (5).*

Ключевые слова: сферические функции, ортогональность и полнота сферических функций, сферическая гармоника.

Abstract. *Surface harmonics represent the angular part of the family of orthogonal solutions of the Laplace equation, written in spherical coordinates. The use of these functions is quite diverse, they are of great importance in the theory of differential equations in partial derivatives and theoretical physics.*

Materials and method, results and discussions. *The article proves the orthogonality and completeness of a system of surface harmonics of the form (4).* ***Surface harmonics*** *are special functions of one variable that are solutions of differential equations obtained by applying the method of separation of variables for the Laplace equation written in spherical coordinates. The authors consider the decomposition of a surface harmonics having continuous second derivatives in a Fourier series. In the process of such decomposition, the operator of spherical functions is used, then the method of integration by parts on the surface of the sphere is used. Green's formulas for the operator of surface harmonics are written, an analysis of the obtained results proves the orthogonality of spherical functions. Subsequently, considering the coefficients of the Fourier series as continuous functions and proving the possibility of uniform approximation by linear combinations of the adjoint functions of any twice differentiable function $f(\theta,\varphi)$, and the completeness of the system of functions defined by formula (4) is proved.*

Conclusion *As a result of the study, it turned out that any continuous function can be uniformly approximated by a polynomial of surface harmonics, which proves the completeness of the system of functions defined by formula (4). From the completeness of this system follows its isolation. Thus, it is proved that the equation of surface harmonics does not have bounded solutions for $\lambda \neq n(n+1)$ and that any surface harmonics of the n-th order (for $\lambda = n(n+1)$) is representable by formula (5).*

Key words: surface harmonics, orthogonality and completeness of surface harmonics.

Introduction. Let us write a system of n-th order surface harmonics. Let us agree to assign a negative superscript to those functions that contain $cos(k\varphi)$, and a positive one to those functions that contain $sin(k\varphi)$. Then we will have:

$$(k = 1,2, \dots, n). \quad (4)$$

The number of different n-th order surface harmonics $Y_n^{(m)}$ is $2n + 1$. Linear combination of these 2n + 1 surface harmonics (4)

$$Y_n(\theta, \varphi) = \sum_{m=0}^{n}(A_{nm}cosm\varphi + B_{nm}sinm\varphi)\, P_n^{(m)} \quad (5)$$

or

$$Y_n(\theta, \varphi) = \sum_{m=-n}^{n} C_{mn}Y_n^{(m)}(\theta, \varphi),$$

where $C_{mn} = \begin{cases} A_{nm} for\ m \le 0, \\ B_{nm} for\ m > 0. \end{cases}$ is also a spherical function and is called a surface harmonic [3].

Materials and methods. Let us prove the completeness of the system of surface harmonics defined by formula (4). First, let us prove that any function $f(\theta, \varphi)$with continuous second derivatives can be uniformly approximated by some polynomial of surface harmonics.

Consider the expansion of such a function in a Fourier series

$$f(\theta, \varphi) = \sum_{m=0}^{\infty}[A_m(\theta)cosm\varphi + B_m(\theta)sinm\varphi].$$

$$\Delta_{\theta,\varphi} = \frac{1}{sin\theta}\frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial}{\partial\theta}\right) + \frac{1}{sin^2\theta}\frac{\partial^2}{\partial\varphi^2}.$$

It is easy to see that we get the formula

$$\iint_{\Sigma} Y_2\Delta_{\theta,\varphi}Y_1 d\Omega = -\iint_{\Sigma}\left\{\frac{\partial Y_1}{\partial\theta}\frac{\partial Y_2}{\partial\theta} + \frac{1}{sin^2\theta}\frac{\partial Y_1}{\partial\theta}\cdot\frac{\partial Y_2}{\partial\theta}\right\} d\Omega \quad (9)$$

$$(d\Omega = sin\theta d\theta d\varphi),$$

easily obtained by integration by parts.

On the surface of a sphere

$$gradu = \frac{\partial}{\partial\theta}i_\theta + \frac{1}{sin\theta}\frac{\partial u}{\partial\theta}i_\varphi,$$

$$divA = \frac{1}{sin\theta}\left[\frac{\partial}{\partial\theta}(sin\theta A_\theta) + \frac{\partial A_\varphi}{\partial\varphi}\right],$$

so that $\Delta_{\theta,\varphi}u = granu$, and formula (9) can be written in the form

$$\iint_{\Sigma} Y_2\Delta Y_1 d\Omega = -\iint_{\Sigma} gradY_1 \cdot gradY_2 \cdot d\Omega.$$

Changing places in the formula (9) functions Y_1 *и* Y_2 and subtracting the resulting formula from formula (9), we will have:

$$J = \iint_{\Sigma}\left\{Y_2\Delta_{\theta,\varphi}Y_1 - Y_1\Delta_{\theta,\varphi}Y_2\right\}d\Omega = 0 \quad (10)$$

Результаты и обсуждения. Formulas (9) and (10) are Green's formulas for the operator of surface harmonics. The orthogonality of the functions Y_1 and Y_2. easily follows from formula (10). Indeed, using equation (8), we obtain from formula (10)

$$J = (\lambda_2 - \lambda_1)\iint_{\Sigma} Y_1Y_2\, d\Omega = 0,$$

whence, for $\lambda_1 \neq \lambda_2$

$$\iint_{\Sigma} Y_1Y_2 d\Omega = 0$$

or

$$\int_0^{2\pi}\int_0^{\pi} Y_1(\theta, \varphi)\, Y_2(\theta, \varphi)sin\theta d\theta d\varphi = 0.$$

This proves the orthogonality of surface harmonics corresponding to different λ

Above, we obtained for $\lambda = n(n + 1)$ a system of $2n +$ surface harmonics of the n-th order. Let us prove that these surface harmonics are orthogonal to each other on the sphere.

Let $Y_n^{(k_1)}$ and $Y_n^{(k_2)}$ be two surface harmonics. By integrating their products and using them, we get:

$$\iint_{\Sigma} Y_n^{(k_1)}Y_n^{(k_2)}d\Omega = \int_0^{2\pi}\int_0^{\pi} Y_n^{(k_1)}(\theta, \varphi)\cdot Y_n^{(k_1)}(\theta, \varphi)sin\varphi d\theta d\varphi =$$

$$\int_0^{2\pi} cosk_1\varphi cosk_2\varphi d\varphi \int_0^{\pi} P_n^{(k_1)}(cos\theta)P_n^{(k_2)}(cos\theta)sin\theta d\theta =$$

Using the boundedness of the second derivative, it is easy to estimate the coefficients A_m *и* B_m of this decomposition

$$|A_m| < \frac{M}{m^2},\ |B_m| < \frac{M}{m^2},$$

where $M = max|f_{\varphi\varphi}|$.

Hence it follows that the remainder of the Fourier series satisfies the uniform estimate

$$\left|f - \sum_{m=0}^{m_0}[A_m(\theta)cosm\varphi + B_m(\theta)sinm\varphi]\right| = \left|R_{m_0}\right| < 2M\sum_{m=m_0}^{\infty}\frac{1}{m^2} < \varepsilon', \quad (11)$$

where $\varepsilon' > 0$ – any predetermined number.

Based on the closedness properties of the system of associated functions [4], the Fourier coefficients $A_m(\theta)$ and$B_m(\theta)$, which are continuous functions of θ, vanishing at θ equal to 0 and π, can be uniformly approximated by linear combinations of associated m-th order functions.

$$\left|A_m(\theta) - \sum_{k=0}^{n} a_k P_k^{(m)}(cos\theta)\right| < \frac{\varepsilon'}{2m_0+1}, \left|B_m(\theta) - \sum_{k=0}^{n} b_k P_k^{(m)}(cos\theta)\right| < \frac{\varepsilon'}{2m_0+1}. \quad (12)$$

Then from inequalities (11) and (12) it will follow:

$$\left|f(\theta,\varphi) - \sum_{m=0}^{m_0}\sum_{k=0}^{n}\left[a_k P_k^{(m)}(cos\theta)cosm\theta + b_k P_k^{(m)}(cos\theta)sinm\theta\right]\right| < 2\varepsilon'$$

This proves the possibility of uniform approximation of any twice differentiable function *f*(θ,φ) by a polynomial of spherical functions.

Conclusion. Any continuous function can be uniformly approximated by a polynomial of surface harmonics, which proves the completeness of the system of functions defined by formula (4). The completeness of this system implies that it is closed. Thus, we have proved that the equation of surface harmonics has no bounded solutions for $\lambda \neq n(n+1)$and that any n-th-order surface harmonics (for $\lambda = n(n+1)$) can be represented by formula (5). Obviously, the surface harmonics are the values of the surface harmonics (6) and (7) on the sphere of radius one.

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КОНЦЕПТ «БОЛЬШОГО КАСПИЯ» В КОНТЕКСТЕ ГЕОПОЛИТИЧЕСКОГО ИЗМЕРЕНИЯ

THE CONCEPT OF THE «GREAT CASPIAN» IN THE GEOPOLITICAL CONTEXT

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Аннотация. *Каспийская проблематика рассматривается в различных аспектах многочисленными отечественными и зарубежными исследователями. Особое значение регион приобретает в связи с подписанием Конвенции о правовом статусе Каспийского моря (от 12.08.2018 г.), которая сформировала новые геополитические и геоэкономические реалии и новый вектор интеграционного развития на евразийском континенте. Все большее внимание уделяется тематике пространственного развития Большого Каспия в системе координат «Восток-Запад» и «Север-Юг». Политика США на Ближнем Востоке, включающая санкционное давление на Иран, направлена на дестабилизацию политико-экономической ситуации в регионе, также предусматривает сдерживание поступательного развития крупнейших азиатских экономик мира. В настоящей работе рассмотрены некоторые концептуальные подходы к формированию концепта и многомерной модели Большого Каспия, как геополитического центра региональных и глобальных интересов, динамично меняющего пространственное сопряжение разновекторных сил международного влияния на основе институциональных преобразований. Рассмотрен подход создания нового геополитического пространства в рамках «Большого Евразийского треугольника РИК» с основанием треугольника «Большого Каспия», стягивающего на себя ведущих игроков мировой политики и опоясывающегося Евразийский континент важнейшими транспортными маршрутами. Формирование «многомерных пространств» – треугольников, как наиболее устойчивых политико-экономических и физико-географических международных конструкций (образований), представлятт собой пространственные реалии Большого Каспия, как нового геополитического измерения – мегарегиона.*

Ключевые слова: геополитика, геоэкономика, Прикаспийский регион, Черноморско-Каспийский макрорегион, Большой Каспий, мегарегион, пространство, треугольники, пространственное развитие.

Abstract. *The Caspian issues are considered in various aspects by numerous domestic and foreign researchers. The region is gaining particular importance in connection with the signing of the Convention on the Legal Status of the Caspian Sea (dated 12.08.2018), which formed new geopolitical and geo-economic realities and a new vector of integration development on the Eurasian continent. More and more attention is paid to the subject of the spatial development of the Great Caspian in the East-West and North-South coordinate systems. The US policy in the Middle East, including sanctions pressure on Iran, is aimed at destabilizing the political and economic situation in the region, and also provides for restraining the progressive development of the largest Asian economies in the world. This paper considers some conceptual approaches to the formation of a concept and a multidimensional model of the Great Caspian Sea, as a geopolitical center of regional and global interests, dynamically changing the spatial conjugation of multi-vector forces of international influence based on institutional transformations. An approach to creating a new geopolitical space within the framework of the "Great Eurasian Triangle RIC" with the base of the "Great Caspian" triangle pulling together the leading players in world politics and encircling the Eurasian continent with the most important transport routes is considered. The formation of "multidimensional spaces" – triangles, as the most stable political-economic and physical-geographical international structures (formations), represent the spatial realities of the Great Caspian Sea, as a new geopolitical dimension – a mega-region.*

Key words: geopolitics, geoeconomics, the Caspian region, the Black Sea-Caspian macro-region, the Great Caspian, mega-region, space, triangles, spatial development.

Introduction. The Caspian region is of particular importance in modern geopolitics. More and more attention is paid to the subject of the spatial development of the Great Caspian in the East-West and North-South coordinate systems. Despite the lack of a clear interpretation of the concept of "Caspian region", which is considered by various scientific theories and interpreted in both narrow and broad senses, there is an attempt to integrate it into the Black Sea-Caspian region; Mediterranean-Caspian, Caucasian-Caspian and other regions.

Initially, according to American studies, the energy and geopolitical prospects of the Caspian region lay in the fact that it is a continuation of the oil fields of Iran and the entire Middle East. As a result, the Caspian basin and the Persian Gulf began to be considered as a single structure, and the Caspian basin was inscribed by the West in its geopolitical megaprojects [17, p.39-40].

The Convention on the Legal Status of the Caspian Sea initiated an increase in the processes of regional and transboundary cooperation, incl. on the formation of a transport and communication framework and a common economic space of the Caspian states. With a new stage in the development of integration processes and the implementation of energy megaprojects, the geopolitical status of the region is changing.

In the scientific literature, the concept of the "Great Caspian" is introduced, which is characterized by the physical and geographical features of the region and does not fully fit into the ideology of Eurasianism, leaving significant theoretical gaps in these studies.

So, in the terminology of the European Council, GKR ("The Greater Caspian Region") means a territory that includes, in addition to five coastal countries (Russia, Azerbaijan, Kazakhstan, Turkmenistan, Iran), also closely located countries, historically, economically and culturally related to the Caspian Sea, these are Armenia, Georgia and Uzbekistan [28, p.30].

In the work of the former American diplomat R.E. Hoagland “Greater Caspian Region: Competition and Cooperation” (2019) The Caspian is represented by “a center of growing strategic importance”, “quiet background buzz”, “one of the largest hydrocarbon deposit centers in the world”, having “growing interest and strategic importance throughout the world ", For whose influence" four global powers are fighting: Russia, China, the United States and Europe – all for different reasons and with sometimes conflicting interests. " As a result of growing competition, the Greater Caspian region really has a growing interest and strategic importance all over the world [36, p.10-11].

In the geo-economic dictionary-reference book, the "Greater Caspian" is defined as a geopolitical region that emerged in Eurasia as a result of the collapse of the Soviet Union. The Caspian region includes five countries directly facing the sea-lake (Russia, Kazakhstan, Turkmenistan, Iran and Azerbaijan). In an extended interpretation, it includes the South Caucasus and Central Asia [6, p.15].

Professor A.K. Magomedov also used “an extended interpretation of the term, referring to it as the“ Greater Caspian, ”including the Russian North Caucasus, Transcaucasia and Central Asia – key areas of geopolitical and energy struggles in modern Northern Eurasia. These areas are united in the “Greater Caspian” by the logic and the struggle to form oil and gas pipelines and transport corridors ”[16, p.11].

A broader interpretation was suggested by Professor P.L. Karabuschenko, according to which the geopolitical space of the Caspian cannot be limited to five states that have direct access to the sea. The Caspian Five (Russia, Kazakhstan, Turkmenistan, Iran and Azerbaijan) is supplemented by the Caspian Ten (Ukraine, Turkey, Georgia, Armenia, Iraq, Kyrgyzstan, Uzbekistan, Tajikistan, Afghanistan, Pakistan) and the world three of interested states are added (USA, EU, China) [14, p.17]. In his opinion, such an expanded interpretation of this geopolitical space makes it possible to comprehensively take into account all the changes that occur here or that have an impact on it from outside. Therefore, in the structure of the Caspian geopolitics, he singles out such components as the "Caspian axis" – (Caspian five) and "Caspian arc" – (Caspian ten). In the presence of all these components, we can talk about the existence of a "Great geopolitical Caspian region", great in the literal and figurative sense of the word, because it will really be the center or the core of the entire Eurasian continent [14, p.17].

P.L. Karabuschenko in his understanding of the "Great geopolitical Caspian region" was based on the logic of the reasoning of the English geopolitical scientist Kh.D. Mackinder on the “heart of the world” or “Heartland” and the “Pivot Area”. In his opinion, the Central Asian space is indeed acquiring the meaning of the "Heartland" of classical German geopolitics. Here the lines of force of civilizational and confessional, ethnic and political faults, aggravated by a tough struggle for natural resources and living space, converge [21, p.331].

The variety of views and assessments allows us to state that the definition of the Greater Caspian contains some historical geopolitical characteristics, and in terms of content – a set of geopolitical projects of "energy and economic influence" and, first of all, against the growing role of China and Russia in the formation of a new world order.

Spatial development as a factor of communication connectivity of territories (international spaces).

With the changes in the geopolitical situation in the world, there have been corresponding alteration in the Caspian region, which has become a global geopolitical object, around which the diplomatic struggle of the leading world powers for the possession of natural resources and control of transport routes has developed [20, p.89].

The peculiarity of the directions of development of spatio-temporal concepts consists in giving them the processes of "social evolution" [23, p.13]. Comprehensive analysis and programming of human life, considered from the point of view of the territorial organization of society, acquires special relevance at the present time, when "contradictory processes of globalization and regionalization, spatial integration and differentiation, democratization and monopolization have been activated" [31, p.4].

The structure of the territorial social system, which forms a multidimensional space, determines [31, p.7]:

– human life environment, including a set of subsystems: economic, natural, social, spiritual, recreational;

– infrastructural components of subsystems: production, market, environmental, social, spiritual, recreational, military, institutional, etc.

According to numerous studies, the concept of economic space is divided into two extreme views, both real (physical) space and abstract (conceptual). At the same time, some scholars believe that economic space is both a concentration of socio-economic infrastructure and economic relations, that is, they allow the existence of both real and conceptual spaces [3].

Obviously, in the context of the task set by the authors – the formation of the concept of the "Greater Caspian", this topic needs more in-depth research, taking into account modern geopolitical and geo-economic processes at the macroeconomic level.

Black Sea-Caspian macro-region in the system of spatial geopolitical development.

In scientific literature, the concept of "macroregion", in contrast to the mega-region, is purely economic in nature, since it does not include a historical, social and cultural community [30, p. 131]. According to V.I. Suprun, the macro-region belongs to the sphere of economics and fixes the correlation of economic relations, both in resource and production relations, therefore Europe, and in its person the European Economic Union, can be considered a developed macro-region [29, p. 171].

At the same time, the Black Sea-Caspian region is considered a special segment of the world geopolitical space, which found itself at the crossroads of the most important transit communications [27]. Within the framework of modern Russian foreign policy and the formation of an international transport framework, the region also plays an important geo-economic significance in the strategy of the country's spatial development and the common economic space of Europe.

The specified macro-region, also defined as the Caucasus-Caspian region, according to the estimates of many researchers [10; 15; 33] represents: 1) from a geographical point of view – a bridgehead, pulling together the Black Sea and Caspian sea spaces; 2) from the military-strategic point of view – the most important springboard for pressure and offensive in any direction, on any country, not only in this region, but also in adjacent regions; 3) a springboard for control over communications; 4) from an economic point of view, it is not only a world crossroads of transport routes along the East-West, North-South axes, but also a region with huge hydrocarbon resources.

At the same time, the potential of the Black Sea-Caspian space is assessed "by the expected large-scale development of Caspian energy resources and the development of transit communications" [24], although in the European vision the region is presented as "a kind of peripheral zone that has its own specifics and generates problems of an economic and migration nature" [24].

In the Black Sea-Caspian space, Iran is the main supplier of hydrocarbons [35], which is of great interest to the world's leading economies (China and India) as a transit corridor. However, the main routes of the Silk Road Economic Belt (SREB) pass through the vast territories of Central Asia, Russia and Europe; Western Asia to the Persian Gulf and the Mediterranean Sea. It is also supposed to create "a new continental bridge between Europe and Asia, international corridors of economic cooperation" China-Mongolia-Russia "and" China - Central Asia - West Asia "" [5, p.87].

The most important document of the European Union, which outlined its desire to strengthen influence in the Black Sea region – the resolution of the European Parliament of January 20, 2011 "EU Strategy for the Black Sea", which notes that "the Black Sea region is a strategic bridge connecting Europe with the Caspian Sea basin, Central Asia and the Middle East, and further, with Southeast Asia and China, and is characterized by its close ties and enormous potential, but also diversity and rivalry "[22, p. 81].

This statement testifies that the Black Sea basin and its infrastructure are considered by the EU and NATO alliance countries as an important element in the transit chain of the strategic (global) transport route in the Eurasian space. Given the limited availability of these routes through the territory of the Russian Federation, bypass options for spatial development along southern streams are being considered: through Georgia, Azerbaijan, Kazakhstan, etc.

The well-known concept of the "Greater Black Sea Region" by R. Asmus has actually transformed into the political direction of the Euro-Atlantic Black Sea region. Its significance is determined by a number of important factors: as "the pivot between the main part of Europe and the" Greater Middle East ""; the attachment of the Black Sea region to the West; the possibility of achieving energy security through diversification of their supplies and new transport routes [2]. At the same time, there remains "an open question about the institutional expression of such a" feedback "", as well as "doubts about the" Europeanness "of the Black Sea states" [2].

In development of Western initiatives, the Istanbul Declaration was signed on June 26, 1992, which proclaimed the creation of the Black Sea Economic Cooperation Organization (BSEC). However, according to A.R. Nikiforova, over the twenty-year period of its operation, "not a single large-scale project has been implemented and practically did not advance along the path of economic integration of the Black Sea region", therefore "the time has come to understand the Black Sea region as a political region" [22, p.79].

A number of experts are rather skeptical about the socio-political integrity of the region, the presence and prospects of the Black Sea identity. According to P. Dimitrov's estimates, there is no Black Sea political and cultural identification. "People living on and around the Black Sea coast identify themselves as residents of the Balkans, Caucasians, Turks, and even as former Soviet people, but never as people of the Black Sea zone" [34]. Therefore, the region "is not a direction for any separate geopolitics," it is viewed as a space where the interests of the EU, Russia and the United States clash, but "not in the form of geopolitics," but "in the form of infrastructure policy" [7, p. 8].

These features of the formation of the Black Sea region and the identity of its population on the principles of "natural-material" parameters and physical space, are fundamentally different from the ideology of Eurasianism, which is inherent, including the peoples of the Caspian region.

The space of the Greater Caspian Sea as a new geopolitical mega-region.

According to the conceptual ideas of the mega-region, which, in addition to economic (production and resource), is distinguished by "socioeconomic" characteristics, the South Asian zone can be said as a macro-region, agglomerations, and various kinds of unions [30, p.129-130]. Therefore, "the economic space of the mega-region is located between the world and national economies [12, p.207].

E.I. Inshakova suggests considering mega-regions as institutional and organizational "forms of transformation of the global economic system (GES)", since they form a group of contiguous countries of the world economy, linked by the joint performance of global functions [11, p.12]. However, this definition gives a very abstract description of the concept, since the subject of these functions has not been formulated, and an attempt to unite countries into international regional unions can hardly serve as such a criterion, especially if it "is formed and developed under the influence of ... national character" [11, p. .12].

Analytical studies of the concept of "mega-region" made it possible to group the totality of their characteristic features [4; 9; 13; 29]:

– the development potential of the "mega-region" system is formed by a wide range of factors designed to ensure sustainable development of the regional economy;

– mega-regions are "locomotives" of sustainable economic development of their countries on the basis of integration-balanced interaction;

– the institutional factors of a mega-region's development are determined by its institutional environment, which, in accordance with the theory of institutionalism, is a set of fundamental political, social and legal rules that form the basis for production, exchange and distribution;

– the institutional environment of the mega-region – the rules of behavior determined from the outside (by the external environment, or exogenously set) in political, social and legal aspects, and the relations underlying the organization – the mega-region, that is, set endogenously;

– assumes the presence of large centers of attraction. Within the mega-region, rich regions appear, elites who do not want to share not economically, not power, "they do not want to share culturally either";

– does not imply the obligatory existence of an administrative capital;

– changes the ideology of international cooperation: from the paradigm of liberal globalization in the interests of private capital of the leading countries of the world is being replaced by the paradigm of sustainable development in the interests of all mankind;

– forms the concept of socially conservative synthesis as an ideological basis for reforming international monetary, financial and economic relations based on the principles of justice, mutual respect for national sovereignty and mutually beneficial exchange.

According to N.V. Gorbacheva energy sector is an important factor in ensuring the sustainability and development of mega-regions [29, pp. 173-174]:

– energy security, ensuring the sufficiency of energy resources for sustainable development;

– energy independence, determined by import-export dependence and the reliability of these flows;

– environmental challenges accompanied by climate change and an increasing impact on the environment.

In these conditions, the most important factors in the development of the mega-region are distinguished, accompanied by global effects – an increase in the quality of life of the population on the basis of its sustainable reproduction development and the formation of an attractive institutional environment [9, p.97]:

– development of innovative potential and increasing investment activity;

– increasing investment attractiveness;

– integration-balanced interaction of the mega-region vertically (with systems of a higher level) and horizontally (with equal-level systems and with elements of the system itself);

– increasing the competitiveness and competitive stability of the mega-region.

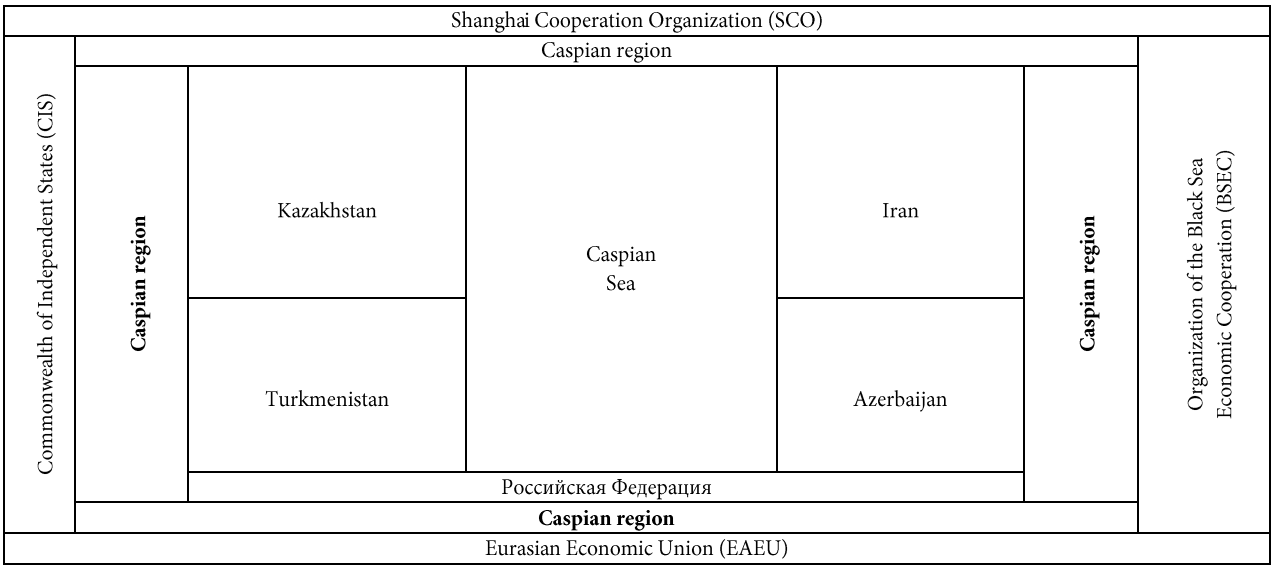
In the new geopolitical realities, the Caspian region is viewed as: part of the vast territory of the "Eurasian Balkans"; part of a vast territory – Eurasia; a connecting link between the Central Asian and Black Sea areas or a connecting link in the North - South direction (Russia - Persian Gulf). In this context, the point of view of S.A. Proskurin and K.G. Landa, considering the Caspian region as a logical continuation of the Indo-Persian, Caucasian-Black Sea, Central Asian and Volga-Ural geopolitical regions [26, p.192].

In our opinion, the concept of "Caspian region", which is actively used in periodicals and scientific literature, is based more on intuitive understanding than on a clear definition based on certain characteristics, is still interpreted ambiguously and sometimes contradictory. Recently, as an ideological justification for the integration of the CIS countries, they started talking about a new understanding of Eurasianism. The Caspian region is the center of Eurasia, so it is here that these ideas have always met the most direct interest [19, p.15].

Considering the region in a narrow sense, as a territory adjacent to the sea, it can be represented schematically as a model of the small Caspian region (Fig. 1).

The proposed model, in contrast to those traditionally described in the literature, shows the presence of developing partnerships between all countries in the region. The multi-vector nature of further development of cooperation within the framework of the model of the small Caspian region (similar to the accepted interpretation of the region in the narrow sense) is ensured through the participation of five Caspian states in the activities of various international organizations.

The diversity of the interweaving of these relationships both between the Caspian countries and their indirect political, trade and economic participation with third states through bilateral or multilateral relations through international organizations, form a new configuration of the spatial development of the Eurasian continent.



Source: author

Fig. 1. Model of the space of the small Caspian region

For example, Iran is an important state through which the implementation of the Eurasian integration policy of Russia and China is ensured; Russia and India. The resource potential of hydrocarbons passing through the Strait of Hormuz reaches 40% of world trade and 20% of oil trade, its geographical position connects the Caucasus and Central Asia with the Arabian Peninsula, India with Sweden, Afghanistan with Turkey, etc. [25].

Coupling Eurasian integration based on the construction of the Eurasian Economic Union and the Silk Road Economic Belt provides the formation of a transit space between China and Europe according to various options (along the Trans-Siberian Railway along its entire length; transportation of Chinese goods to Russia through Kazakhstan; transit from China to Europe bypassing Russia – through Kazakhstan and Iran) [18, p.46-47].

Simultaneously with the formation of the vast space of Greater Eurasia (from the ASEAN countries and Korea in the east, India in the south to the Transcaucasus in the west), new geopolitical and geoeconomic systems of "interconnections – transport, trade and investment, human, political", as well as free trade zones, unity of norms and standards are being created. At the same time, the economic potential of "China and India provide a safety cushion for the new co-development space" [17, p. 54].

Given the special modern geopolitical and geo-economic strategic importance, the Caspian region has become the epicenter of international processes. The uniformity of most points of view lies in its recognition as a transboundary macro-region, in the formation of which "more than 30 regional, extra-regional and global political, economic, military actors, represented by states, organizations and companies, are involved" [1, p.53]. The transboundary status of a region is an institutional form of organizing transboundary cooperation [32], which can be characterized as a "natural economic zone" [37] of regional development.

In terms of the combination of these factors and conditions, the Caspian region as a "subject" appears to be a more complex configuration of geopolitical relations that requires clarification of the modern concept. Initially, it was not so united and did not have a common legal framework and a specific legal status. Therefore, there were several levels of "maturation" of the subject's essence of geopolitical characteristics: (a) the unity and integrity of the cultural, historical and geographical space; (b) cooperation of political and economic activities of all entities; (c) common strategic interests and priorities; (d) formation or presence of a "territorial (regional) idea"; (e) a unified legal field [8, p.35-36].

The participation of the Caspian states in the activities of various international organizations, as well as the development of bilateral and multilateral political, trade and economic relations, allow us to form a developing vector of the spatial model of the "small Caspian region". The matrix and status of states in the main international organizations that form the Greater Caspian Sea space (Table 1) indicates the possibility of creating a multi-vector and multidirectional space for further development of international cooperation within the Greater Caspian Sea.

Table 1

Matrix and status of states in the main international organizations, forming the space of the Greater Caspian

Countries of Caspian region	Commonwealth Independent States (CIS)		Shanghai Cooperation Organization (SCO)			Organization of the Black Sea Economic cooperation (BSEC)			Eurasian Economic Union (EAEU)			
	Full members	Associate members	Participants	Observers / Observer Application	Dialogue partners	Participants	Observers	Partners	Members	Observers	Free zone trade	
											agreement	Conversation / interest
The status of the states parties to the Convention on the Legal Status of the Caspian Sea dated 12.08.2018												
Azerbaijan	X				X	X						
Iran				X/				X			X	
Kazakhstan	X		X						X			
Russia	X		X			X			X			
Turkmenistan		X										
States – strategic partners of the countries of the Caspian region, the EAEU and the SCO												
Armenia	X				X	X			X			
Belarus	X			X/			X		X			
India			X									negotiation
China			X								X	
Kyrgyzstan	X		X						X			
Pakistan			X									

Moldova	X					X				X		
Serbia						X					X	
Tajikistan	X		X									
Turkey					X	X						
Uzbekistan	X		X									
States that are among the leading and developing economies of the world												
Egypt				/X			X					negotiation
Vietnam				/X							X	
Korea								X				interest
Singapore											X	
Japan								X				

Source: author

The proposed matrix and status of states in the main international organizations that form the space of the Greater Caspian Sea (see Table 1) is characterized by a combination of the diversity of geopolitical subjects. The linear model of their construction and institutional transformations determines the status of states that are part of interconnected international organizations, which are distributed at the appropriate levels:

1) First – regional level:

1.1. The countries of the Caspian region, forming the space of the small Caspian region (see Fig. 1);

1.2. The legal status of the countries of the Caspian region in the main international organizations operating in the Eurasian space (full or associate member; participant, observer or dialogue partner; participant, observer or partner; members, observers, participants in the free trade zone).

2) The second is the macro level:

2.1. The main international organizations in which the Russian Federation participates in the Eurasian space (CIS, SCO, BSEC, EAEU);

2.2. The legal status of states in a particular international organization (full or associate member; participant, observer or dialogue partner; participant, observer or partner; members, observers, participants in the free trade zone).

3) The third – mega-level:

3.1. States parties to the Convention on the Legal Status of the Caspian Sea;

3.2. States are strategic partners of the countries of the Caspian region, the EAEU and the SCO;

3.3. States that are among the leading and developing economies of the world.

As a result of institutional transformations, the physical and geographical space of the Greater Caspian Sea can be gradually formed, which is represented by a large number of various states of almost all continents of the Earth, differing in the level of development: productive forces and production relations; political systems and political structure, foreign and domestic policy, as well as other historical, socio-economic and cultural characteristics. At the same time, a basis for building a multidimensional model of the Greater Caspian Sea is being created, a dynamically changing spatial conjugation of various forces of international influence. Within the framework of this space, a set of two and - trilateral ties and relations is formed as the most stable geopolitical and "spatial units".

Thus, the Syrian events (from September 30, 2015 to the present) contributed to the creation of the most effective military-political coalition of states (Russia – Iran – Turkey), which is actually transforming into the southwestern vector of the "Greater Caspian Triangle" – a zone of collective security in the south Caspian space. The strategic triangle also covers the most “explosive regions” of the world: the Caspian and Black Sea basins – the Mediterranean – the Persian Gulf – the Arabian Sea.

The Caspian southeastern Eurasian vector (Eurasian turn), which forms a new geopolitical space of the Greater Caspian Sea, is carried out within the framework of the “Greater Eurasian Triangle RIC” (Russia – India – China), as an established format of political interaction between states. The importance of this cooperation is determined by the traditionally developing trade and economic relations, as well as the possibilities of conjugating Eurasian integration in the implementation of global projects: the Chinese Economic Belt of the Silk Road and the International North-South Transport Corridor, which expands India's accessibility to international transport communications and hydrocarbon resources.

Conclusions. The new geopolitical space, formed within the framework of the “Greater Eurasian Triangle RIC” with the base of the “Greater Caspian” triangle, which pulls together the leading players in world politics, encircling the

Eurasian continent with the most important transport routes, is characterized by specific economic, geopolitical and physical and geographical features of this mega-region.

The changing geopolitical alignment in the world based on the formation of "multidimensional spaces" – triangles, as the most stable political and economic international structures (formations), represent new spatial realities of the geopolitical dimension of the multipolar world order in the system of world coordinates and their increasing influence in the Eurasian space, "axial zone "which is occupied by the Greater Caspian.

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ФОРМАЛЬНЫЕ МОДЕЛИ И АЛГОРИТМЫ В ПОЛИТОЛОГИИ: ТЕОРЕТИКО-ИГРОВОЙ ПОДХОД

FORMAL MODELS AND ALGORITHMS IN POLITICAL SCIENCE: GAME-THEORETIC APPROACH

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Аннотация. *Вопросы междисциплинарной интеграции методов исследования политических процессов представляют определенный интерес как с теоретической, так и с практической точек зрения. Приложение методов системного анализа, теории принятия решений, математического и имитационного моделирования к исследованию политических, социально-экономических систем задача нетривиальная, позволяющая выявить закономерности и тенденции в развитии систем, обладающих поведением, приобрести опыт прогнозирования и сравнительного анализа результатов исследования.*

В статье представлены результаты исследования, предметом которого является определение условий применимости теоретико-игрового подхода к исследованию политических процессов.

Статья, посвященная теоретико-игровому подходу к исследованию политических процессов, определяет возможности, которые открывает применение теории игр к анализу сложных систем, обладающих поведением.

Актуальность темы исследования определяется недостаточным, по мнению авторов, вниманием научной общественности к инструментальным средствам, которые готовы предоставить представители точных наук политологам и социологам. Современное состояние формального моделирования в политологии находится на этапе начального определения предмета исследования и формирования концепции.

Материалы и методы, результаты и обсуждения. *Авторами выполнен анализ возможностей, который предоставляет теоретико-игровой подход исследователю, показаны различные варианты применения игр разного класса.*

Целесообразность применения методов теоретико-игрового подхода в политологических исследованиях обусловлена современным состоянием политологической науки, верификации инструментальных средств исследования и результатов в сложных условиях роста объемов информации, подлежащей систематизации и анализу.

Заключение. *Проведенное исследование раскрывает новые возможности в развитие нового направления в системе политологических исследований, в основе которого лежат методы системного анализа и технология формального моделирования на базе теоретико-игрового подхода к анализу сложных систем.*

Теоретическая ценность идеи применения методов теории игр к исследованию политических процессов и явлений состоит в расширении предметного поля политологических исследований.

Практическая ценность идеи состоит в определении условий применимости классической теории игр в политологии, интеграции традиционных методов политологических исследований и методов формального моделирования для анализа политических процессов, явлений, поведения социально-политических систем.

Ключевые слова: антагонистические игры, игры с ненулевой суммой, коалиционные и корпоративные игры, игра с природой.

Abstract. *The issues of interdisciplinary integration of research methods of political processes are of particular interest from both theoretical and practical points of view. Application of methods of system analysis, decision theory, mathematical and simulation modeling to the study of political, socio-economic systems is a non-trivial task that allows you to identify patterns and trends in the development of systems with behavior, gain experience in forecasting and comparative analysis of research results.*

The article presents the results of the research, the subject of which is to determine the conditions for the applicability of the game-theoretic approach to the study of political processes.

The article is devoted to the game-theoretic approach in the study of political processes. The authors define the possibilities that open up the application of game theory to the analysis of complex systems with behavior.

According to the authors, the relevance of the research topic is determined by the insufficient attention of the scientific community to the tools that representatives of exact Sciences are ready to provide to political scientists and sociologists. The current state of formal modeling in political science is at the stage of initial definition of the subject of research and formation of the concept.

Materials and methods, results and discussions. *The authors analyze the possibilities that provide a game-theoretic approach to the researcher, and show various applications of games of different classes.*

The expediency of applying the methods of game-theoretic approach in political science research is due to the current state of political science, verification of research tools and results in difficult conditions of increasing volumes of information to be systematized and analyzed.

Conclusion. *The research reveals new opportunities for the development of a new direction in the system of political science research, which is based on methods of system analysis and formal modeling technology based on a game-theoretic approach to the analysis of complex systems.*

The theoretical value of the idea of applying the methods of game theory to the study of political processes and phenomena is to expand the subject field of political science research.

The practical value of the idea is to determine the conditions for the applicability of classical game theory in political science, the integration of traditional methods of political research and formal modeling methods for the analysis of political processes, phenomena, and behavior of socio-political systems.

Key words: antagonistic games, non-zero-sum games, coalition and corporate games, games with nature.

Introduction. Political science, possessing a historically established toolkit for research, which was traditionally based on methods of qualitative assessment of the objects / phenomena under study, in the context of the modern information society and the growth of the amount of information required for analysis, faced the problem of complicating political processes and, as a result, with the need improve research methods. Analysis of the history of the issue allows us to assert that the date of the appearance of formal modeling in the subject field of political science research can be considered the 50s of the XX century [1]. Thus, the historical method, which traditionally was based on non-formalized methods of studying social and political processes and phenomena, supplemented by the methods of mathematical statistics and integral calculus, makes it possible to visually display the economic and political situation using numbers and graphs, to more correctly determine the causes and consequences, for example , social inequality, correlations between the mechanisms of distribution of material wealth and social tension in society, etc. The interest in systems modeling in political science, the joint use of methods based on the analysis of behavioral principles and standard methods of analysis of random and non-random processes opens up new theoretical and applied aspects of formal modeling as applied to political science.

The game-theoretic approach to political science is an example of the integration of rational and irrational methods of complex systems. The game, as a mathematical model of a real conflict situation, allows each participant (player) to make a reasonable choice of behavior strategy, takes place in certain conditions, has a multi-aspect character: one should distinguish between descriptive, constructive and normative aspects. The behavior of the players in the game is governed by some rules established for this game, which determine the strategies of the players, stability in relation to information about the behavior of the opponent, the outcome of the game and the size of the winnings. It is proposed to consider, within the framework of this article, antagonistic games (zero-sum games), non-antagonistic games and games of one player (games with nature) and their application to models of justification of choice, which are based on methods of expert assessment. The theory of games, in its classical positions, determines the norm of the player's behavior in order to achieve his goal; the result of the game, as a rule, are recommendations to the player on the formation of an optimal strategy of behavior that maximizes the average value of the utility function when the game is repeated many times. Previously, the authors considered the possibility of using a zero-sum game in the construction of an arms race model (Richardson's model) [2]

The construction of a formal model and the development of the corresponding algorithm are carried out in stages. At the first stage, the problem that must be solved is formulated, and the subject of research is determined. So, considering the elections as an antagonistic zero-sum game for two candidates, let us formulate the problem: for each of the candidates, the main problem is the lack of information about the system of preferences of the electorate participating in the elections, and, as a consequence, the difficulty in determining the target group to which the vector will be directed pre-election program. The challenge facing the player: to develop an election program that best suits the system of preferences of the electorate and / or target group, which is characterized by activity. The peculiarity of the mathematical model of this situation is that the players do not have sufficient information about each other's behavior, they cannot change their stock of resources, the amount of gain is equal to the amount of loss. At the next stage, it is necessary, in accordance with the principles of symmetric fair entry into the game, to determine the finite number of player strategies and the size of the win / loss when implementing each of the strategies. In this case, the fairness of the entry means equal chances of the players to win, the symmetry of the entry means that the corresponding strategies of the

players have the same payments. The next stage is the construction of a mathematical model: player A has strategies A_1, $A_2 \ldots A_m$, and player B, respectively, B_1, B_2,…,B_m.

The matrix of the game in which the gain of one player is equal to the loss of another player has the form

$$V = \begin{pmatrix} v_{11}\ v_{12} \ldots v_{1m} \\ v_{21}\ v_{22} \ldots v_{2m} \\ \ldots\ldots\ldots\ldots \\ v_{m1} v_{m2} \ldots v_{mm} \end{pmatrix}$$

The game-theoretic approach to the election procedure allows one to determine the optimal strategy of the player's behavior, the lower and upper game prices, that is, the guaranteed minimum win / loss. Example: Two candidates running for election and competing with each other are counting on a certain percentage of the electorate. Trying to attract electors, applicants choose alternatives: a1 (b1) – increase the activity of electors in their target group; a2 (b2) – attract media for advertising; a3 (b3) – adjust the electoral program in order to increase the attractiveness; a4 (b4) – zero alternative (no new decisive actions are taken). The solution of the situation in the form of matrix games will make it possible to determine the likelihood of success for each of the applicants, the appropriate frequency of applying a particular strategy, the dominant and most effective strategy.

The possibility of applying this model to a real situation, according to the authors, is constrained by a large number of restrictions that are introduced when constructing a model: in real practice, players may have an unequal number of strategies; the different types of resources that players will use have different "weights" and this fact violates the necessary conditions for fair and symmetrical participation.

To put it precisely, a game-theoretic approach to modeling and predicting the dynamics of development of systems with behavior is not a tool for obtaining clear instructions “what and how to do in a particular situation,”but the possibility of conducting a comparative variant analysis of the characteristic functions of the system under study and analyzing the internal structure of the optimal solutions. In the absence of unambiguously specified measurable criteria and the impossibility of applying the criterion approach to a qualitative description of a problem situation, the game-theoretic approach is advisable to apply for a comprehensive analysis of the situation. So, the situation with the divergence of interests of the parties, presented above as an antagonistic game, can be considered in the same formulation of the question as a game with a nonzero sum, that is, as a variant of divergence of interests of the players, when the gain of one contender does not mean the loss of the other. Interpretation of elections as games with a non-zero sum is acceptable if there is negative feedback between the players:

– player A can directly or indirectly influence player B's choice of behavior strategy and, accordingly, influence the size of his payoff;

– with multiple choices, player B forms his strategy taking into account previous experience and information about the choice of player A at the previous step.

Non-zero-sum games can be non-cooperative, where the players make decisions on their own, without colluding, and cooperative, where decisions are made after certain agreements have been reached.

Elections, as a part of the political life of society from the standpoint of formal modeling and system analysis, is a procedure for agreeing a system of electors' preferences on a finite / infinite set of alternatives, which can be single and multiple, be one- and multilateral. If the selection procedure involves a finite set of experts / electors, it makes sense to talk about the group selection procedure, for the study of which it is advisable to use other game-theoretic models.

Statement of the problem of multi-sided choice: there is a finite set of comparable alternatives A, on which a finite set (community) of electors needs to make a reasoned, consistent choice in accordance with their preferences. If each of the participants has their own preference system (profile), then the task is reduced to creating a common (collective) profile and finding an alternative with properties that correspond to this profile. This selection mechanism, in fact, is an analogue of direct democracy and the main difficulty, according to the authors, lies in the formation of a general profile of the applicant that meets the preferences of each elector. The second possible variant of the search for the optimal alternative involves the formation of a collective profile of preferences after the available alternatives are ordered, this is the so-called representative democracy. Example: a lot of electors and applicants for vacancies in government. The electors, not knowing in advance what sphere of activity in the power structure will be determined by their “chosen one”, arrange alternatives in descending order of attractiveness; on the basis of this list, a unilateral choice is made by a certain representative of the electors. A group choice is possible based on the use of previously accumulated experience, the so-called precedent method [3], which involves the adaptation of a tested optimal strategy to new conditions with the reuse of algorithms, models and rules to solve the current problem.

The seeming simplicity of the model has at least two pitfalls: the first is the influence of the well-known voting paradoxes that electors encounter in the process of agreeing on the preference profile and / or ordering alternatives [4]; second – the need to choose the "best" method that will ensure equilibrium and fair entry of players into the game, the symmetry of their participation in the game; by an equilibrium entry we mean the presence of conditions under which it is unprofitable for the participants in the game to change their decision unilaterally.

The variety of models used by game theory has expanded the subject field of research. If antagonistic matrix games assume directly opposite goals of the participants and the presence of no more than two parties participating in the game, then it is obvious that this is a special case that has limited application.

It is advisable to consider a more general case that takes place in real socio-political practice, when a conflict situation is interpreted as a non-antagonistic divergence of interests, while there may be more than two participants in the game. The term non-antagonistic divergence of interests means that the gain of one participant is not the loss of another, which can be explained by the example of the "prisoner's dilemma" model [5] or the exam, as a conflict situation in which a student has two options for behavior: prepared – not prepared, the teacher also two options for behavior, took the exam, did not. In this model of a conflict situation, four outcomes are possible: 1. learned – passed; 2. did not learn – did not pass; 3. did not learn – passed; 4. learned – did not pass. Obviously, the gain of one person is not the loss of the other: a mark obtained by a student fraudulently does not mean a loss of the teacher.

In the event that players can make a decision based on mutual agreements, which they make as a result of a pre-game discussion of possible strategies of behavior, game theory speaks of so-called coalition games, that is, games with a voluntary association of participants for cooperation. From the point of view of game theory, such collusion means the formation of a certain subset on a finite set of game participants, for which a set of behavior strategies, game outcomes and win-sharing rules must be formed. So, political parties that do not collect the required percentage of the electorate's votes can create coalitions, the formal representation of which is as follows: if S = {s} (s = 1,2, ... n) is a set of players, then their union is an arbitrary coalition C , and the number of subsets of such coalitions is defined as the number of combinations of C from m to n, where m is the number of participants in the conspiracy (coalition):

$$C_n^m = n!|(n-m)!*m!$$

Each of the coalitions has its own set of strategies, the choice of which determines the outcome of the game. For each outcome of the game, at the stage of coalition creation, a winning sharing scheme is determined, in which the rules of collective and individual benefit must be observed. The collective benefit rule normalizes the distribution of the winnings: all winnings must be distributed among the participants. The rule of individual benefit is that the payoff of each participant must be no less than the payoff that he could get without joining the coalition, making decisions on his own.

The coalition game model can be projected onto the group choice problem.

Results/Conclusions. The study reveals new opportunities for the development of a new direction in the system of political science research, which is based on the methods of system analysis and the technology of formal modeling based on the game-theoretic approach to the analysis of complex systems.

The theoretical value of the idea of applying the methods of game theory to the study of political processes and phenomena lies in expanding the subject field of political science research.

The practical value of the idea lies in determining the conditions for the applicability of the classical game theory in political science, integrating traditional methods of political science research and methods of formal modeling for the analysis of political processes, phenomena, behavior of socio-political systems.

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КОНФЕССИОНАЛЬНЫЙ ФАКТОР ОБЩЕСТВЕННО-ПОЛИТИЧЕСКОГО И ПАРТИЙНО-ПОЛИТИЧЕСКОГО ПРОЦЕССА СОВРЕМЕННОЙ РОССИЙСКОЙ ФЕДЕРАЦИИ

CONFESSIONAL FACTOR IN THE SOCIO-POLITICAL AND PARTY-POLITICAL PROCESS OF THE MODERN RUSSIAN FEDERATION

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Аннотация. *Статья посвящена выявлению акцентирования конфессионального фактора в общественно-политическом процессе РФ на фоне его стабилизационно-стагнационных векторов. Прослеживаются тенденции включения конфессионального фактора в официальный дискурс государственных лидеров, позиция главы Российского государства в отношении религии, веры, а также роли религиозных институтов. Анализируются политические программы и дискурс политических лидеров в отношении роли, целей и задач религиозных институтов.*

Ключевые слова: дефициты общественно-политического и партийно-политического процесса**,** конфессиональный фактор, роль религии и веры, светский характер Российского государства, политические партии, политическая программа, религиозные организации.

Abstract. *The article is devoted to identifying the accentuation of the confessional factor in the socio-political process of the Russian Federation against the background of its stabilization and stagnation vectors. There are trends in including the confessional factor in the official discourse of state leaders, the position of the head of the Russian state in relation to religion, faith, and the role of religious institutions. Political programs and discourse of political leaders in relation to the role, goals and tasks of religious institutions are analyzed.*

Key words: deficiencies of the socio-political and party-political process, confessional factor, the role of religion and faith, the secular nature of the Russian state, political parties, political program, religious organizations.

Deficiencies of modern socio-political and party political process. The modern socio-political and party-political process in its global and also in Russian terms is marked by significant deficiencies. Among them, the obvious is the lack of effective leaders, optimal organizational technologies, and reliable images. There is a deficiency of attractive programmatic and statutory ideas of political parties and, accordingly, a deficiency of social trust in party political institutions.

Since the 2010s, the Russian socio-political and party-political process has been demonstrating a certain stabilization and stagnation pace, both intrinsically-structural and technical and technological. This is largely determined by the general stabilization of socio-political relations, the strengthening of the political system and the ordering of political governance, the optimization of partogenesis, and the neutralization of conflict-generating factors in relations between the authorities and citizens. At the same time, this is due to a gradual slowdown in the overall economic, social, and infrastructural dynamics of Russian society. The stagnation of the Russian socio-political and party-political process is carried out in parallel with the negative phenomena of the economy and social life. They have been growing since 2014, intensifying since 2018, and manifesting openly since 2019–2020 in the context of the global and Russian economic and financial crisis, falling oil prices, as well as in the context of the COVID-2019 pandemic. The influenza epidemic, in addition to the death of people, causes large-scale damage to the economy and the social sphere (shutdown of enterprises, reduction of the business segment, loss of income and earnings, rising unemployment, social pessimism, uncertainty about the future, etc.). Under these conditions, trends that are relatively new in content occur.

Firstly, further verticalization of power is carried out through its personalization in the person of one leader – the current President of the Russian Federation. The personalization of power has been consolidated since 2018 as a technology of political, managerial and administrative tightening of regions, the fight against corruption and crime, as well as the reintegration of socio-economic ties and strengthening of the ruling positions of the state. Also, the centralization of power through its personalization is due to the increasing role of Russia in the geopolitical architecture of our

time. The concentration of power in the functional of the President of the Russian Federation is directly related to the strengthening of the sovereignty of Russian foreign policy in resisting sanctions and hostile actions against the Russian Federation by Western states and alliances.

Secondly, further nationalization of the socio-political and party-political process is carried out, the embryonic middle class is disavowed, as well as the factors of its formation, as well as favorable preconditions for business initiatives, entrepreneurship, and self-employment. Also, the space of public policy is narrowing and control is increasing not only over the socio-economic and material-financial condition of the population, but also over political and electoral trends (remote voting: voting by mail, electronic voting, etc.) as part of further strengthening the Russian limited "sovereign democracy ", the framework of which is established by the state. The socio-political and party-political process is becoming more and more formatted, its conservative-protective, distinctive Russian traditional-spiritual agenda is determined by the authorities.

Thirdly, the index of political activity of citizens who are indifferent to direct participation in political organizations and movements and are limited by their electoral presence is decreasing. Interest in politics as an institutional activity and influence on political decision-making is reduced. The general level of political culture and political competence is declining, while non-political forms of self-organization (volunteering, charity, collective humanitarian actions, mutual support) are expanding. At the same time, citizens show traditional patriotism as devotion to the Motherland and in large numbers demonstrate recognition of the glorious military heroic stories, first of all, the Victory in the Great Patriotic War of 1941-1945. The 75th anniversary of Victory was celebrated in the Russian Federation in May 2020 in a special regime due to quarantine measures due to the coronavirus pandemic, but with a high index of sincere participation of the population.

Fourthly, the general dissatisfaction of the population with the government remains, distrust of the Government of the Russian Federation and certain key figures of the ruling and oligarchic establishment, whose names have become common nouns (G.O. Gref, D.A.Medvedev, E.S. Nabiullina, I.I.Sechin , A.G. Siluanov, A.B. Chubais). At the same time, citizens trust the President of the Russian Federation, support the actions of the head of state and express a certain enthusiasm in connection with the amendments to the Constitution of the Russian Federation proposed by the President of the Russian Federation, primarily in terms of their social component. Socially oriented initiatives of V.V. Putin, set out in the Address to the Federal Assembly of the Russian Federation on January 15, 2020, as well as subsequent measures for social support of the population in the framework of countering the coronavirus pandemic in April – May 2020, were approved by 66–98% of the population [5]. The majority of citizens express their readiness to support the amendments to the Constitution of the Russian Federation by voting under the democratic slogan "Our country. Our Constitution. Our solution". There is some support for the idea of "zeroing" the normative term of a candidate for the highest post in the state, probably in relation to V.V. Putin.

New perspectives of the confessional factor in the post-secular world. The long-term economic crisis, political performances, the transformation of populism from political technology into political ideology and the "rediscovery" of deep states have had a significant impact on the established political world order, modifying the factors of the socio-political and party-political process. One of the new factors in the socio-political and party-political process is the confessional factor, which indirectly, and in other cases and directly, intrudes into public and political life.

In the middle of the XX century. it seemed that a secular world, that is, free from confessional influence, would only enhance secularism in all planes of human existence. However, at the beginning of the new millennium, the post-secular reality clearly demonstrates and challenges the viability of the victory of a secular society [14].

The revival of the confessional factor in the socio-political and party-political process took place in the course of the reduction of classical democratic civil norms, irresponsibility, lack of will and inactivity of many democratic corporations. Processes and institutions of a socio-political nature take on a religious connotation in some cases, which is manifested in visualized and hidden forms. An objective consideration of the confessional factor indicates that it not only retains its relevance and relevance for many communities, but also stimulates social processes, exerting both constructive and destructive influence on society.

Here we will make a reservation that in this analysis we do not provide for the methodological nomination of the confessional factor. We will use general definitions and popular ideas about the confessional factor not in its worldview expression, but in the expression of social practices and moods, rituals, which are recorded by modern Russian philosophers, political scientists, sociologists. Modern philosophical, socio-political, cultural knowledge reflects latent discussions about the role of the confessional factor, goals and objectives of religious institutions at the stage of metamodernism [4]. Religion not only returned to the public agenda (and did not leave somewhere), but also clearly

claims to revenge the positions lost in the course of scientific, technical, sexual, technological, information revolutions and the release of mankind into outer space, which again actualized the problem of integration religious elements, practices and dogmas for naively sincere and cynically targeted use in politics.

Russian scientists note that "the influence of the religious factor is expressed in the incorporation of religious foundations (including in a" transformed form ") into the political process and in the formation of new forms of collective identity." It is obvious here that "religious and confessional coloring becomes a marker of political events, that a religious element is often introduced into political ritual in order to give political events and persons acting in them ontological status and legitimacy" [19].

The actualization of the confessional factor in the socio-political and party-political process is also manifested in the Russian Federation. After the political atheistic ideology of Marxism-Leninism has lost its dominant position, the state and society are trying to fill the gap. The society continues to search for ideology that could unite society, for some spiritual foundations designed to unite citizens, including through the strengthening of the Russian state identity [1].

Institutional tendencies of the confessional factor in the Russian socio-political and party-political process

First. Inclusion of confessional topics, attributes in official texts, regulatory documents of the secular Russian state. It is directly proclaimed in the Constitution of the Russian Federation that "no ideology can be established as state or obligatory" and that "ideological diversity is recognized in the Russian Federation" [15]. The basic law of the Russian Federation indicates the secular nature of the Russian state, which, in our opinion, is an uncontested legal and political basis for strengthening the national civic consciousness of Russian citizens. However, recently, some state and political figures, public activists, literary and artistic figures have been making attempts to include the postulates of the main religions of the Russian Federation as integrative ideological clamps in socio-political and party-political contexts.

The confessional factor is manifested in the content of the National Anthem of the Russian Federation, where God has been mentioned since 2000, which is explained by the cultural and historical peculiarities of Russia [34]. At the same time, it is obvious that the citizens of the Russian Federation with an atheistic worldview are forced to show special loyalty to the text of the National Anthem of the Russian Federation, which emphasizes that "the native land is protected by God."

In this regard, one of the problems of the socio-political and party-political process is the problem of relations between the state and religious institutions, as well as the place of religion in the general system of ideological and ideological attitudes, but also in the system of relations between political and bureaucratic institutions. There are obvious questions about a possible state religion, about the optimal confessional policy, as well as about some signs of clericalization of the state and balancing the state between the secular nature of the state and the needs of religiously minded and churched citizens. At the same time, the Russian state has taken under legal protection the "feelings of believers", which raises many doubts and creates dubious law enforcement precedents, since it is extremely difficult in legal terms to define what "feelings" are and who "believers" are, not to mention discrimination of feelings atheists who also need protection [16 and 38].

The presence of the confessional factor in the socio-political and party-political process of the Russian Federation from 2020 can be fixed in the amendments to the Constitution of the Russian Federation, proposed during the discussion of «The 2020 Presidential Address to the Federal Assembly» on January 15. The amendments contain the following thesis: " The Russian Federation, united by a thousand-year history, preserving the memory of ancestors who passed on to us the ideals and belief in God, as well as the continuity of the development of the Russian state, recognizes the historically established state unity "[23 and 35]. At the same time, DS Peskov, in connection with possible amendments to the Constitution of the Russian Federation, noted that "the state in no way loses its secular character" [29].

The fixation of "confessional motives" in the regulatory and political-doctrinal documents of the Russian Federation, as experts note, is based on "the presumption of the importance of the religious factor in public life" [17], which in itself cannot be interpreted as inevitable and necessary.

Second. Public positioning of statesmen and political leaders in relation to religion and belief in interaction with religious institutions. When asked whether religion should play an important role in national culture, Russian President Vladimir Putin, in an interview with the «Financial Times», answered: "It should play the role that has developed today, it should not be pushed out of this cultural space. ... Have we forgotten that we all live in a world based on biblical values? Even atheists. But we all live in this world. You don't have to think about it every day and not go to church, there you shouldn't hit your forehead on the floor, showing what kind of Christian or Muslim you are, or a Jew, but in your soul, in your heart there should be some fundamental human rules and moral values"[26]. During his speech at the World Congress of Russian Compatriots V. V. Putin addressed representatives of the Russian Orthodox

Church, as well as other religions: “Many of the representatives of these confessions ... I want to thank them for strengthening the cultural and humanitarian ties with Russia of our compatriots abroad” [28].

The leaders of the Russian state and the subjects of the Russian Federation often use religion to retain the sympathies of citizens, who, according to general data, for the most part belong to Orthodoxy and Islam [30]. At the same time, the researchers note “Orthodox-centered rhetoric of officials and a demonstration of the Kremlin’s special disposition towards the Russian Orthodox Church”, but emphasize that such rhetoric has “a fairly rigid spatial reference and is successful in territories with a predominance of ethnically Russian population”, in contrast to other territories where the majority of the population belongs to Islamic or Buddhist religious tradition [17].

Often state and municipal employees openly demonstrate their religious beliefs by visiting temples, church services, and also work closely with ministers of confessions. Thus, the President of the Russian Federation V.V. Putin, as well as the former President of the Russian Federation and the former Prime Minister of the Russian Federation D.A. Medvedev, regularly attend Orthodox services, primarily Christmas and Easter [27], open churches and mosques [7], interact with Patriarch of Moscow and All Russia Kirill, taking into account the expansion of social service of the Russian Orthodox Church. The first persons of the country's political elite systematically congratulate believers on confessional holidays, for example, Christians Merry Christmas (it is a public holiday not only in the Russian Federation, but also in many other states) and Easter, as well as Muslims with the beginning of the month of Ramadan and its end (Eid al-Fitr), Jews with Passover [22] and Buddhists with the onset of the New Year according to the lunar calendar [11], etc.

In the modern Russian Federation, several government organizations and departments are engaged in state-religious relations: the Commission on Religious Associations under the Government of the Russian Federation, the Committee of the State Duma of the Federal Assembly of the Russian Federation for the Development of Civil Society, Issues of Religious and Public Organizations, the Council under the President of the Russian Federation for Interaction with Religious Associations, which reflects the multi-confessional nature of Russian society. At the same time, “the presence of representatives of the clergy near the authorities is considered by the authorities as desirable” [17]. The hierarchs of religious institutions, in turn, publicly support the positions of secular leaders, which, in fact, is traditional for relations between the state and religious institutions that periodically compete with each other ("the war of the scarlet mantle and blue mantle"), but most often act together in managerial and organizational impact on society at the sites of many councils, commissions, collegia [32].

In different regions of the Russian Federation, there is a public performance by officials and politicians of the Russian secular state of religious rituals, as well as the wearing of religious attributes and symbols of faith in public places. At the same time, in some cases, the leaders of religious organizations seek to impose religious dogma on politicians and statesmen as the basis for resolving contradictions. Extreme plots are conflicts between politicians and religious leaders, in which the latter seek to apply measures of "religious influence" to officials and politicians (excommunication, condemnation, etc.). In some regions of the Russian Federation, belonging to the traditional tribalist segment (in particular, in the North Caucasus), there are attempts to preserve religious and cultural rituals and radical opposition to modern forms of leisure (shows, concerts, disco parties, flash mobs, competitions), some methods of "reverse emancipation of women", as well as the widespread use of ethno-religious attributes in external appearance (public wearing of symbols of faith).

A peculiar manifestation of the confessional factor was the protest of some religious leaders and their followers (both traditional and reformist) against the quarantine policy of the Russian state in the context of the COVID-2019 pandemic and bans on visiting places of worship. Suppose that the COVID-2019 pandemic, which showed distrust of government and other government institutions, spawned an attempt by citizens to find consolation in the pillars of faith and increased the influence of the confessional factor.

Third. Inclusion of the confessional factor in the functioning of educational, security and military structures. In Russian schools there is a variable academic discipline "Foundations of Religious Cultures and Secular Ethics" [10]. The introduction of this discipline, taking into account its various modules, on the one hand, gives parents the right to choose a specific module for students, and, on the other hand, in a sense, divides students according to different worldview and cultural positions. In general, the choice of a module presents some difficulties, but in any case, each of the modules does not presuppose the propaganda of religious views, but the transmission of information about the historical development of religious systems and institutions in the general historical and cultural context. At the same time, there is some risk of violation of ideological neutrality when teaching modules on world and traditional religions, which are widespread in Russian communities [20].

Also, obvious problems can be traced in the formation of the content of the direction of training "Theology" in state universities, which is aimed at the formation of secular specialists in the field of state-confessional relations. However, expert and bureaucratic discussions at the level of ministries, departments and the Federation Council of the Federal Assembly of the Russian Federation indicate that the ratio of informational, educational and ideological components in the implementation of the corresponding curriculum and the formation of relevant competencies is highly controversial [31]. Here it is appropriate to highlight the opinion of Vladimir Putin, which also gives rise to a large-scale problem field. So, V.V. Putin noted, "As for the activities of religious confessions, representatives of religious confessions in educational institutions, I repeat once again – my personal opinion is that we should support and preserve the secular nature of our state, but, of course, the activities of religious confessions in educational institutions, as well as in the army and in places of imprisonment, is not prohibited, it will only be welcomed "[37].

The Russian Armed Forces are also subject to the influence of the confessional factor. Thus, a new position appeared in the staffing table – military priest (chaplain) [13]. Clergy often bless conscripts and approve of individual military-political operations.

The symptomatic media story of 2020 was the construction of the main temple of the Russian Armed Forces, which was erected in honor of the 75th anniversary of Victory in the Patriot Park in Kubinka near Moscow on the initiative of the Russian Defense Ministry. The side-altars of the cathedral are dedicated to the holy noble Prince Alexander Nevsky, the holy prophet of God Elijah, the holy apostle Andrew the First-Called, the holy great martyr Barbara, who are patrons of various types of troops. "Along with the faces of the saints, the images of the legendary commanders Suvorov, Minin and Pozharsky, Shuisky will be placed on the panel of the temple." [21] ... On the walls of the cathedral there are compositions "depicting the victories of Russia from ancient times to the present day: from the Battle of Kulikovo to the operation in Crimea", first of all, the composition "Victory Parade" and the composition "Bloodless joining of Crimea in 2014" "Crimea is ours! ". Other topics include "the fight against international terrorism in Southeast Asia, Africa, Central America, Central Asia, the Caucasus and Syria." At the same time, along with the heroes of the historical past, the panel should have depicted government officials, military leaders, the leaders of the power structures of the modern Russian state (V.V. Putin, S.K.Shoigu, N.P. Patrushev, V.V. Volodin, V. I. Matvienko, V. V. Gerasimov, A.V. Bortnikov). At the same time, the rector of the main temple of the Armed Forces of the Russian Federation, Bishop Stephen of Klin, said that "the depiction of historical events and historical figures on the walls of churches is a tradition" [2].

Fourth. The manifestation of the confessional aspect in the party programs and in the party discourse. It is natural that the confessional factor began to manifest itself in the content and technologies of party functioning. There is no doubt that for a political party its program is the most important basis for ideological and organizational activity. Program ideas, program goals, corresponding events and actions, as follows from the paradigms of classical partology and from the algorithms of practical revolutionary or reformist activity, form the basic foundations of party functioning and provide parties with either success or electorate indifference.

The 2016 elections to the State Duma of the Federal Assembly of the Russian Federation showed that the programs of Russian political parties lost their individuality, conceptuality, and also attractiveness. The programs of the main political parties of the Russian Federation are monotonous and do not reflect the individual face of the parties, as in fact, and do not imply a prominent inter-party competition. At the same time, modern Russian political parties are looking for new program ideas that meet the needs of the social base, the electorate and that can revive the party design, both essential and technological, and, in particular, resort to using the confessional factor [33].

Researchers emphasize that the 2001 Federal Law "On Political Parties" "does not allow the creation of political parties on the basis of, among other things," religious affiliation, "that is, a party has no right to proclaim and protect religious interests" [36] ... However, the accentuation of the confessional (primarily Orthodox) factor for expanding the social base of parties occurs in parallel with the accentuation of the correlation of national and ethnic in the Russian – Russian dichotomy in the general context of culture, spirituality, security, national and migration policy [9].

Considering the political program of "United Russia", it is important to note that this party does not have a main political program, but puts forward a number of theses of support for the "Putin doctrine." Therefore, the topic of religion is not directly raised in the political texts of "United Russia", except for the election program for the presidential elections in 2012, where the block "Spirituality and Unity of the Russian People" states: "We will contribute in every way through the development of culture to the revival and strengthening of these values cooperation with traditional Russian religions. We welcome and will support the work of the traditional religions of Russia in the education and enlightenment system, in the social sphere, and in the Armed Forces. At the same time, the secular character of our state must, of course, be preserved. Any person living in our country should not forget about their faith and ethnicity. But he must,

above all, be a citizen of Russia and be proud of it. No one has the right to put national and religious characteristics above the laws of the state. However, the laws of the state themselves must take into account national and religious characteristics "[24].

A number of prominent party figures use the confessional factor in their speeches and statements. For example, the Chairman of the State Duma of the Federal Assembly of the Russian Federation V.V. Volodin notes that "Strengthening the institutions of family and marriage, counteracting the erosion of moral and ethical norms is our common task, which requires joint efforts of the state, the Russian Orthodox Church and our entire multinational society." [8].

The position of the Communist Party of the Russian Federation is also symptomatic, in the political program of which the strengthening of the confessional factor is not directly recorded. However, the leader of the Communist Party of the Russian Federation, GA Zyuganov, links the idea of socialism with certain pillars of Orthodoxy, which became the basis for the development of such properties of the Russian people as conciliarity, responsiveness, collectivism, and mutual assistance. At the same time, the party cooperates with religious organizations in spite of the doctrinal incompatibility of the ideology of socialism of the 21st century with religious ideology [3].

In the political program of the Liberal Democratic Party in paragraph 7, it is explicitly stated that it is necessary "to ensure the protection of Christians throughout the world" [18]. The opinion of the LDPR leaders on the confessional factor has a pronounced emotional and subjective component. Thus, the chairman of the Liberal Democratic Party V.V. Zhirinovsky noted: "You see, the Orthodox do not win! Atheists are in power. Atheists win! For me, for the Orthodox – they do not vote! I am the only Orthodox Christian, and they don't vote for me!" [6]. But later he said: "Religions are the past of mankind. Today the states are secular. Laws and constitution are in force."[12].

In the political program of "Fair Russia" in the section "National Policy" it is noted: "Russia is a country that, in the course of centuries of history, has managed to organically unite different peoples, religions and cultures. The unity of the multinational people should be strengthened by common values, ideas, common civic ideology, which firmly bind people of different nationalities and confessions living in Russia. " Therefore, the party proposes: "To intensify educational work among the population, aimed at understanding the characteristics of national cultures and religions of the peoples inhabiting our country" [25].

Some generalizing considerations

Optimization of the socio-political and party-political process in the modern Russian Federation provides for further research efforts to understand the invasion, application and use of the confessional factor. They are important both in the essential structural and technical and technological vectors. The problematic field of such efforts, as it seems to us, can be constituted by the following points:

– the possibility of neutralizing the contradictions between the secular nature of the Russian state and the ideological demand of a part of Russian society, as well as contradictions between its secular and clerical parts;

– the legitimacy of the inclusion of confessional ideological, figurative and plot content and the corresponding thesaurus in the normative-legal and political-doctrinal texts of the authorities, political organizations;

– the need to declare the significance of the confessional factor not so much by default in the framework of the high landmarks of Russian history and culture, as well as the attractive moral and mental properties of Russians, but in the framework of correlating and opposing different interests of different groups of citizens;

– the admissibility of the use of the confessional factor in the practices of political management and bureaucratic rhetoric of state and municipal employees, as well as the use of ethno-religious attributes in the organizational and administrative impact on the population;

– the relevance of combining traditional religious views and rituals with modern practices in education, sports, leisure, communication, show business, entertainment, self-presentation in the course of social modernization of Russian society, the degree of which is significantly differentiated by region.

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ГЕОПОЛИТИЧЕСКАЯ КОСМОЛОГИЯ: «СЛОНЫ ЕВРАЗИИ»

GEOPOLITICAL COSMOLOGY: "ELEPHANTS OF EURASIA»

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Аннотация. *В название настоящей работы выведен термин «геополитическая космология» под которым мы подразумеваем способность геополитиков конструировать абстрактные схемы, наглядно объясняющие суть разработанной ими геополитической стратегии. Это своего рода проверка на логическую прочность конкретных геополитических доктрин. Если они выдерживают эту проверку, у них есть будущее. В противном случае – перед нами мертворожденная доктрина. Анализ большинства подобного рода стратегий указывает на то, что они чаще всего имели целью запугать противника своей смелостью и оригинальностью, и кроме психологического воздействия не имели никакой практической ценности.*

Рассматриваемая в настоящей работе проблема касается ныне широко обсуждаемой темы смены геополитических полюсов в системе мирового лидерства. Речь идет о новой геополитической конфигурации Евразии, где выстраивается два треугольника – Западный (Германия, Франция, Великобритания) и Восточный (Иран, Индия, Китай). Оба они находятся на разных полюсах российской границы и оказывают на нее определенное влияние. В свою очередь и сама Россия становится главным геополитическим участником этих международных отношений, на которые оказывает конкретное влияние, реализуя свои национальные интересы. Именно России мы отводим объединительную роль, налаживание равновесного партнерского диалога между Востоком и Западом, которые должны встретиться согласно сформулированной ею международной повестке и предложенной картине мира. Именно рассмотрению ряда этих проблем и вопросов и посвящена настоящая работа.

Ключевые слова: Евразия, международные отношения, геополитика, лидер и аутсайдер, гегемония, многополярность, конфликт интересов, война и мир, интеграция, элиты и лидеры, карнавальная политическая культура.

Abstract. *The title of this work is derived from the term "geopolitical cosmology" by which we mean the ability of geopolitics to design abstract schemes that clearly explain the essence of their developed geopolitical strategy. This is a kind of test of the logical strength of specific geopolitical doctrines. If they pass this test, they have a future. Otherwise, we are faced with a stillborn doctrine. Analysis of most of these strategies indicates that they were most often intended to intimidate the enemy with their boldness and originality, and other than psychological impact had no practical value.*

The problem considered in this paper concerns the now widely discussed topic of changing geopolitical poles in the system of world leadership. We are talking about a new geopolitical configuration of Eurasia, where two triangles are built – the Western one (Germany, France, Great Britain) and the Eastern one (Iran, India, China). Both of them are located at different poles of the Russian border and have a certain influence on it. In turn, Russia itself becomes the main geopolitical participant in these international relations, which it exerts a specific influence on, realizing its national interests. It is Russia, in our opinion, that plays a unifying role, ensures the establishment of an equilibrium partner dialogue between East and West, which should meet in accordance with the international agenda formulated by Russia and the proposed picture of the world.

Key word: Eurasia, international relations, geopolitics, leader and outsider, hegemony, multipolarity, conflict of interests, war and peace, integration, elites and leaders, carnival political culture.

Introduction. The three most ancient Eurasian cultures and civilizations – Chinese, Indian and Persian (Iranian) – represent in our time very serious political systems that play a leading role in the field of geopolitical and economic relations. And in our time, these three states are the pillars of the Eurasian processes, the stability and prosperity of which will mean the stability and prosperity of the entire Eurasian space as a whole. This is the arc of Eurasian civilizations, a belt of cultural stability.

In recent political history, we see how these three countries (Iran, India and China) were in the 20th century in the humiliating position of colonies and third-rate countries. At the beginning of the 21st century, we are actually witnessing the revival of these states in the status of regional and then world leaders. The spirit of empires is reawakening

in them. The fire of the passionary movement starts to ignite in them again. And this growth of them is already beginning to seriously disturb the former world hegemons, who feel that their power is beginning to gradually slip out of their hands.

Against the backdrop of the dying West, the Asian giants look especially menacing to it. These three countries are potential gravediggers for US-European geocentrism. We called them the "Elephants of Eurasia" because we believe that it is on them that the world order of this region is mainly kept. In the past, all three countries have an imperial history of their states. These are the powers with the potential of international leadership inherent in them. And they themselves feel better and understand adequately when they are in a state of empire. The fourth such power (with imperial features) is Russia. But we'll talk about it next time ...

Geopolitical cosmology. Geographically and politically, Eurasia covers the area from Lisbon to Vladivostok, but splits into two unequal zones – Europe (West) and Asia (East). In the past, this inequality was also expressed in the political superiority of the West and the general lagging behind of the East. But at the present time the situation has not only leveled off, there has been a clear lag in the West and the rapid growth of the East. At the beginning of the 21st century. a new geometry of the world's geopolitical structure appears. The world is rapidly rebuilding its geopolitical poles, changing the "magnetic field" of international relations. The monopolar world is being replaced by multipolarity. The United States is losing its monopoly on decision-making in international relations and is increasingly beginning to reckon and put up with the dissent of other strong geopolitical players.

Geopolitics always constructs its own international Universe, the structure of which is in a state of constant restructuring and clarification of the leader's status and the position of an outsider. At present, the Western (European) part of Eurasia is already relegated to the category of periphery, and its Asian part is taking the first place. For a more adequate understanding of the essence of this changing world structure, we will resort to the services of the so-called. geopolitical cosmology and see what these three powers are.

Geopolitical cosmology – elevation to the rank of higher schemes and formulas of abstraction, allowing to comprehend complexity in its simplified form. As an example, we can give the scheme of perception of the assessment of the central geopolitical region – the continent of Eurasia.

Eurasia, from the point of view of geopolitical cosmology, is a world "turtle" on which there are three elephants (Iran, India and China), which in turn hold the "roof of the world" – Russia. The simplicity of this formula ("Turtle Scheme") contains our concrete understanding of the essence of the geopolitical space of Eurasia, in which there is no place for third countries – third world countries (primarily the United States), which in the past carried colonial oppression and a military threat to this region.[1]

The "Eurasian elephants" are three empires in the past and potentially in the future, which are reviving in the present time in their former great-power status. The Turtle diagram illustrates Eurasian unity, which is what the United States and its allies fear most, as it threatens their global hegemony.

What other images arise when analyzing this geopolitical triad? This is an image of the four primary elements (elements) of nature: Iran is “fire”, India is “water”, China is “earth” (we will keep silent about the fourth element for now, although this fourth element [“air”] is Russia). These elements are the spiritual symbols of these countries, what they are associated with in the eyes of the world community. In the scheme of the four elements, the idea of Eurasian unity and the Eurasian world order is again expressed.

From the point of view of the fabulous Russian worldview, Iran, India and China are semi-legendary distant kingdoms, full of wonders and other eastern riches (tea, silk, spices, precious metals, etc.). In Russian epics and fairy tales, the heroes visited these countries and their very journey brought them fame and fortune.

China, India and Iran constitute the cultural security belt of Eurasia. If Eurasia is associated with anyone in the first place, it is with these three countries and Russia. Three elephants of Eurasia – "green elephant" (Iran), "white elephant" (India) and "red elephant" (China) – a symbol of stability and power of the continental powers and the main challenge and threat to the sea power of the Anglo-Saxons and their satellites.

What unites them is their specific attitude to the colonial past of the British Empire. All of them at one time fully drank the cup of London's colonial hegemony and are unlikely to want to have a trusting relationship with the Anglo-Saxons.

[1] Author's note. This formula has some universality, since it can be applied to the European part of Eurasia: Western Europe is a world "turtle" on which there are three elephants (Germany, France and Great Britain), which in turn hold the "roof of the world" - the United States. The last part of the "formula" indicates who claims to be existential leadership in the world and who poses a real threat to the world hegemony of the other. He is also the "conductor" of this scheme, since he determines the strategy and tactics of their joint behavior.

If you look at these three elephants, then with the naked eye we will notice that each of them is surrounded by "smaller" countries that are in the zone of attraction of their geopolitical gravitational fields: Iran has always influenced the countries of the Middle East and the Arab world, India has influenced countries Hindustan, China – to the countries of the Indo-Chinese region. And each has its own management traditions.

Culturally, these countries are the custodians of the invaluable world spiritual heritage, which constitutes the true universal human wealth. History is the main asset of these states, which have enriched world science, culture, and religion. In the past, scientists from these countries have made discoveries that continue to be used by all of humanity. In the ranking of historical scientific achievements, they occupy all the first places.

One more concept that is important for our common understanding should be pointed out, which is conventionally fashionable to call "geopolitical strings". The concept of geopolitical strings points to the existing schemes of linear relations between states, which unite them with a certain commonality of ideas, values and goals, making them situational allies and competitors of others, united in the same "structure-strings". For example, we have the right to speak about the “string” of “NATO”, which unites 30 countries into a military-political bloc, or the “string” of BRICS, or the “string” of MERCO-SUR. The quality of each string is determined by the weight and quality of those players who line up and take part in it. The more such strings a state has, the more complex its “geopolitical tools” and “geopolitical concert” turn out to be. But the most important thing is that it should not be a cacophony, but a symphony. "Strings" – lines of demarcation of interests and the expression of certain common goals. "Strings" cut through geopolitical space both linearly and along a broken curve. They unite, they force, they define.

The first group of "Eurasian elephants" (Iran, India, China) do not yet have a common geopolitical string, but as soon as it takes shape, there will be no need for many geopolitical mediators and advisers. The second group of "Eurasian elephants" (Germany, France, Great Britain) have a disorganized sound and their trio has gone to pieces, after their conductor (USA) actually refused to lead them.

About the change of geopolitical "magnetic poles". It is known that all modern Western geopolitical strategies (Z. Brzezinski, S. Huntington, G. Kissinger, F. Fukuyama) [2, 5, 10-11] are aimed at explaining why the United States is the main global hegemon. Unlike Anglo-Saxon and German geopolitical thought, the Russian geopolitical school (A.E. Vandam, A.S. Panarin, E.M. Primakov) [See: 3, 8-9] never justified and encouraged colonial policy, but on the contrary, she has always acted with its sharp criticism.

Geopolitical magnetic poles indicate which gravitational forces of attraction or rejection are acting in the world community, and how they, due to these indicated forces, are distributed among leaders and outsiders. The present epoch is characterized by the painful process for the collective West of breaking down the monopolar and building a multipolar world order. This is a very painful process. Over the past century, the West has got used to sewing under the "American umbrella" and has forgotten how to think independently and make responsible decisions. This cannot be abandoned immediately, because there is a "terrible Russia", the demonization of which has reached its apogee at present.

The fact that the collective West is now losing its entire influence and influence can already be seen with the naked eye. The crisis is seen in the negative selection of the elites. On the political Olympus of the West, open dullness has broken through and has taken hold. The personnel crisis is observed in almost all countries of the Western alliance. Instead of real problems, the elites begin to deal with themselves invented problems that lead their public to an incomprehensible direction. The obvious carnivalization of political culture is evident.[2]

The political class of the West has gathered a critical mass of political "clowns" and tricksters, immersed in games with simorons, which completely supplants real politics. Such politicians begin to believe in miracles more than in reality itself. Their practices are aimed at distorting reality so that it is convenient and manageable for them. In fact, they create a parallel reality, a kind of looking glass, in which they can again be in leadership positions.

Diagnostics of modern political reality indicates that elements of carnival political culture are increasingly being introduced into the geopolitics carried out by Western world leaders – Western "clowns" are turning international relations into a theater of absurdity. Under far-fetched pretexts, they impose sanctions, arrange provocations, blaming their political opponents for, sowing controlled chaos everywhere and persistently promoting the doctrine of a conflict

[2] We know about the carnival culture itself thanks to the works of Russian scientists (M.M. Bakhtin, A.F. Losev, D.S. Likhachev), [1; 6-7] who managed to reveal the cultural code of this phenomenon. Political carnival is an action divorced from reality, aimed at asserting one's position in an obviously losing situation; it is an attempt to construct such an unnatural situation that would create a more preferable position for its authors, giving them a preponderance of forces in their favor.

of civilizations. The political carnival organized by them begins to suck in all the more minor participants in international relations. But the main goal of these provocateurs is to draw the main competitors into this carnival they manage, in order to ruin them, weaken them, and incline them before their imperial will.

At the same time, the Western political elites do not care what will happen to this region and to these countries and peoples. The main thing for them is to organize a new robbery of Eurasia under a plausible pretext (there is no one to rob in Africa, Latin America has already been robbed by them).The policy of robbing the world comes to a second circle. The political history of the West indicates that it can prosper only by plundering colonies. He is sorely lacking his own resources. This explains the collective Russophobia of the West towards Russia.

Threats and challenges: real and imaginary. In Eurasia, too often in the past, great wars have flared up for the peoples of this region today to wish for a repeat of these tragic events. The peoples and states of Eurasia must learn to speak not in the language of war, but in the language of culture and science. Unfortunately, military tensions are currently growing around all the key countries of Eurasia. Conflicts are kindled and supported from outside, by those world players who are trying to prevent their unification and prosperity, which would mean the end of their monopoly in the world.

Eurasia is too vast to be governed from one single center. Eurasia is a true symbol of pluralism and tolerance. She doesn't need to be taught these categories. The teachers only spoiled her, for they brought in and tried to introduce their foreign elements.

The most serious threat that the countries of Eurasia have faced over the past two centuries has been imperial Anglo-Saxon expansion. And at the beginning of this skirmish, they succumbed to the technological superiority of the overseas aliens. But having lost the first battle, they nevertheless won the civilization war and proved to the whole world their political vitality and historical viability.

Robbing others is the norm for the Anglo-Saxons. Looting is a historical habit of this nation. The United States is a predator with only its profit figures in its head and no moral and intellectual regrets. "Nothing personal just business"! Such a business also erases the identity of those who put the question in this way. Therefore, the political elites of the Anglo-Saxon world are political groups of swindlers with erased identities. Their personalities begin to wear off and overwrite as they lie. By now, the United States and Great Britain have finally become empires of lies. Lies (fakes) have become the meaning and norm of their political routine.

Western analysts acknowledge that the United States always has its own national interests in mind when it comes to security. [13, p.16] But peace and order will be established in this region only when the Anglo-Saxons, represented by the USA and Great Britain, leave it. Consolidation ideas should prevail over confrontational ideas. Namely, the Anglo-Saxons have historically been the bearers of the idea of confrontation – they have long lived and thrived in a war of all against all. It has long been noticed by analysts that the West deliberately creates only such political world structures in which it will obviously play the first role, eliminating competitors on the distant approaches to leadership. [See: 12, p. 219] Therefore, there is no need to rely on fair rules of the game from the West (especially the Anglo-Saxons).

Geopolitical competition is always on a key issue – determining who is the leader and who is the outsider. The collective West for a long time perceived and evaluated the East as an outsider and it is now especially difficult for it to come to terms with the fact that it is losing leadership qualities and leadership status and is gradually turning into a banal outsider. The destruction of the hegemony of the West was a consequence of its aggressive foreign policy, associated with the extremely harsh (brutal) exploitation of the colonies in the previous time. The echoes of this policy are still visible. The collective West, represented by its leaders, is used to living by robbing its colonies and now it still cannot get used to and learn to live without this criminal "doping". The fact that colonialism is a crime is beginning to reach the leaders of Western countries only now.

At a time when the entire political collective West is infected by the virus of carnival political culture, in the political everyday life of the three leading powers of Eurasia + Russia, this carnival is either completely absent, or has a minimal spread. These countries have a certain cultural immunity against this virus, and all attempts by the United States and its satellites to drag them into this nasty tradition have not yet been crowned with success.

Let us especially note the existing mental differences between the countries of the Western and Eastern Triangles. These differences relate to the images of their perception and evaluation. “Asia” for the West is everything that it has not occupied. In this regard, Japan and South Korea are the West, because is under US occupation. For the same reason, Russia has always been, is and will be "Asia" for the West, since it has never allowed itself to be enslaved, but has always given an adequate rebuff to Western aggressors. This is the insistence of the West in Russophobia, which should

long ago be equated with racism and anti-Semitism. And no one knows what needs to happen in the world for it to be done.

Eurasian three +. The geopolitical structure we are describing (the Eurasian three will effectively solve its problems if another participant, another Eurasian country, Russia, takes part in their projects. Russia's presence in this scheme is an undoubted plus, a stabilizing factor. It is precisely to remove this plus that the foreign policy of the United States is directed, striving to be the only leading player in this region.

Russia occupies an advantageous geopolitical position, since all the leading Eurasian countries are actually located along its borders from East to West: Japan, China, India, Iran, Germany, France, Great Britain ... Ideally, these countries are not restrictive forces that hinder Russia in its progressive development, but a kind of "necklace" of the most qualitatively developed countries, the achievements of which can and should be fed by Russia. Therefore, it is in the interests of Russia itself not to conflict with these countries, but to build good-neighborly relations that guarantee its peace and prosperity. Unfortunately, Moscow has not yet learned how to use this advantageous geopolitical position and extract full profit from it. It is precisely those who themselves who benefit from this "*belt of the Eurasian necklace*" are hindering it.

It should be noted that, unlike the Anglo-Saxons, the geopolitical thought of Russia has never considered Eurasia as its colonial possessions [4] and has never engaged in the use of Western technologies of "controlled chaos". [14] Eurasia was a goal for Russia, but not as a means. And this is the main value of Russia – its civilizational "kinship" with the ancient civilizations of Eurasia. The presence of the United States in this region only multiplies the lie and the resulting political and economic risks. The United States has shown itself to be the most deceitful country.[3]

The history of the United States itself is the history of crooked mirrors, where everything is distorted beyond recognition. Official Washington's policy is built on lies. Without lies, the United States simply does not have politics. To customize reality for yourself means distorting objective reality, giving it a carnival character. Carnival politicians have clip thinking and an advertising worldview, when the wishful is passed off as reality. The United States wants to dominate all of Eurasia from Lisbon to Vladivostok. But they simply do not have enough resources to fulfill these desires. Lies are the last resource at their disposal, which they actively and very skillfully use. The US lies in the fact that they call good evil and present their evil as good. US President R. Reagan called the USSR an "evil empire." Perhaps the Soviet Union was not a saint. In global politics, the concepts of good and evil are becoming abstract. The problem of good and evil is exacerbated as one approaches a specific person. But as we move away from it into the sphere of politics and especially international relations, these basic categories are blurred and become interchangeable. As recent political history testifies, ironically, it was the United States that, since 1991, became an empire of evil and lies.

Russia is a civilization of kindness.

If we compare the activities of the Western intelligence services with the Russian ones, the latter will turn out to be just humanitarian organizations ...

* * *

The geopolitical schemes we have considered make it possible to understand most clearly what location today's Russia is and what challenges and threats these "Eurasian triangles" pose for it.

Currently, the Eurasian elephants do not have a triple political union. Their relations are being built along the lines of separate bilateral agreements. The contradictions between India and China hinder their geopolitical rapprochement. At present, Iran cannot become their connecting link. Therefore, Russia is the main Eurasian peacekeeper. It is Moscow that could and should act as the very integrating force that would tie Tehran-Delhi-Beijing together.

And then the scheme «Turtles» immediately comes to mind…

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[3] The analysis of political liberalism in the United States demonstrates a cognitive dissonance: for a long time the United States asserted itself as a model for the realization of human rights, but in 2020 it unexpectedly began to fight against racism, which has been actively flourishing there all this time. It turned out that human rights in the United States were not for everyone, but only for the elite.

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ВЗАИМОДЕЙСТВИЕ ОБЩЕСТВЕННЫХ ОРГАНИЗАЦИЙ СКФО: ПРОБЛЕМЫ, ПОТЕНЦИАЛ, РАЗВИТИЕ

INTERACTION OF PUBLIC ORGANIZATIONS OF THE NORTH CAUCASUS FEDERAL DISTRICT: PROBLEMS, POTENTIAL, DEVELOPMENT

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Аннотация*: представлено авторское исследование общественных организаций в современной России, их способов взаимодействия. Проведено сравнительное изучение проблем общественных организаций в региональном пространстве.*

Р*азличные Форумные компании являются практико-ориентированными образовательными площадками для общественных организаций, где в условиях благоприятной среды для общения, культурного обмена и саморазвития НКО могут активизировать раскрытие своего потенциала, решение проблем в контексте развития гражданского общества.*

Методы и материалы исследования: *в статье охарактеризованы тенденции развития общественных организаций в современной России, исходя из собранных данных на Северо-Кавказском молодежном Форуме «Машук – 2019». Автор использовал системный и сравнительный подходы при изучении проблематики общественных организаций Северного Кавказа.*

Результаты исследования *акцентируют внимание на активном, но все же недостаточном развитии общественных организаций. Российские общественные организации на данном этапе проходят путь становления, это молодой сектор, который требует особого внимания, так как является неотъемлемой составляющей для функционирования гражданского общества и государства в целом.*

Заключение: *подтверждает авторские выводы о том, что российские общественные организации на данном этапе проходят путь становления, это молодой сектор, который требует особого внимания, так как является неотъемлемой составляющей для функционирования гражданского общества и государства в целом. Общественные организации с помощью участия в Форумах могут решать актуальные проблемы, которые встречаются на пути реализации идей, но данное направление требует систематической поддержки со стороны государства, так как данный сектор способен решать общественно-социальные проблемы в обществе.*

Ключевые слова: общественные организации, некоммерческие организации, проблемы, «Машук», гражданское общество, развитие, молодежь, органы власти, государство.

Abstract. *The author presents the research of public organizations and their methods of interaction in modern Russia. It is a comparative study of the problems of public organizations in the regional space.*

Introduction. *Various Forum companies are practice-oriented educational platforms for public organizations. And NGOs can enhance their potential and solve problems in the context of the development of civil society in a favorable environment for communication, cultural exchange and self-development.*

Methods and materials of the study. *The article describes the development trends of public organizations in modern Russia, based on the data of the North Caucasus Youth Forum «Mashuk – 2019». The author used a systematic and comparative approach in studying the problems of public organizations in the North Caucasus.*

The results *of the study focus on the active, but still insufficient development of public organizations. Russian public organizations are currently on their way to becoming a young sector that requires special attention, as it is an integral part of the functioning of civil society and the state as a whole.*

Conclusion. *The findings confirms the author's conclusions that Russian public organizations are at the stage of development. This is a young sector that requires special attention, as it is an integral component for the functioning of civil society and the state as a whole. Non-governmental organizations through participation in the Forums can solve current problems that are encountered in the implementation of ideas, but this area requires systematic support from the state, as this sector is able to solve social problems in society.*

Key words: public organizations, non-profit organizations, problems, Mashuk, civil society, development, youth, government, the state.

Introduction. The North Caucasus Youth Forum "Mashuk" is the largest youth forum in the south of Russia. The 10th Anniversary Forum of 2019 was attended by 3,000 young people from the subjects of the North Caucasus Federal District, other subjects of the Russian Federation and neighboring countries [1].

The venue for the event, as in previous years, was the city of Pyatigorsk, where, according to the established tradition, a camp was set up at the foot of Mashuk Mountain from August 9 to August 30, 2019 to implement the educational and cultural program of the Forum.

The Mashuk Forum is a practice-oriented educational platform for young people, where, in a favorable environment for communication, cultural exchange and self-development, participants can intensify the disclosure of their personal potential in the context of the country's development.

The North Caucasian Youth Forum "Mashuk" is not just a platform for training and communication of young people from the North Caucasus Federal District, it is a place where young leaders jointly seek solutions to the problems facing the region and the country. The Forum participants are called to work on the challenges facing the regions of the North Caucasus, to make a personal contribution to the development of the North Caucasus Federal District.

The sources of information for the analysis of the "problem field" were:

– National projects and national programs of the Russian Federation;

– The State Program "Implementation of the State National Policy";

– The Strategy for Socio-economic development of the North Caucasus Federal District until 2025;

– The concept of state Youth Social Policy in the subjects of the Russian Federation included in the North Caucasus Federal District until 2025;

– Strategy for the Development of Tourism in the North Caucasus Federal District until 2035.

The forum includes aspects related to the involvement of young people of the North Caucasus Federal District in meaningful socially useful activities, including the development of volunteership, the involvement of youth in the socio-economic development of cities and settlements, strengthening and development of interethnic relations and preserving the immateriality heritage of the peoples of the Caucasus.

The goal of the Mashuk Forum is to form a vector of development “A happy and self-realized person in his comfortable and modern territory” by creating teams and network projects to implement “points of growth” in the North Caucasian Federal District and developing the personal potential of Forum participants [2].

The main mechanics of the Forum program is built around the direct work of participants with stakeholders.

Stakeholders are individuals or organizations that are interested in the development of certain sectors of the economy and social sphere and are able to influence these sectors. Stakeholders represented by directors of companies and organizations, heads of federal and regional authorities, representatives of HR services pose specific problems and tasks of their industries to the participants. In this connection, the participants get the opportunity not only to engage in abstract design activities, but to immediately focus their project on solving the problem of a particular employer, thereby proving their professional suitability.

The chosen structure for the development and construction of such a Forum program provides:

– simultaneous training of beginners and more experienced participants;

– building a system of conscientious learning that allows you to start successful activities after the Forum;

– the relationship between the participants who prepare the projects within the Competition of Youth Projects of the North Caucasus Federal District and of the other subjects of RF and a network of like-minded people and teams;

– meaningful communication with guests of honor, outstanding figures of culture, sports, education and economics.

The North Caucasian Youth Forum "Mashuk – 2019" was held in three productive work shifts. Let us consider each of them separately.

The first shift "Breakthrough Directions" took place from August 9 to August 16, 2019, on the agenda of which was the analysis of the following topics: career growth, business and technology.

The goals and objectives of the first shift were achieved by interacting with employers and solving industry cases, championships in programming and IT solutions, the work of career services, including professional assessment.

In the period from August 16 to August 23, 2019, the participants arrived at the second shift of the Forum – "Civil Society". Based on the name of the shift, the topics of its study were social problems and interethnic relations.

For a more detailed analysis and consideration of problems, the participants were included in direct interaction with representatives of government bodies, the solution of social cases. The final events were a competition of short films of the Moscow-Caucasian Club on the topic of interethnic relations, as well as an amateur art festival “One World – a Thousand Voices”.

In conclusion, the organizers of the Mashuk – 2019 Forum in order to assess and reveal the leadership potential of the youth of the North Caucasus Federal District organized the III session “I am the leader!” in the period from August 23 to August 30, 2019.

The grant fund of the North Caucasus Youth Forum "Mashuk" in 2019 amounted to 85.5 million rubles.

To receive grant support, individuals and legal entities submitted applications for the competition.

Let's analyze the question of public organizations participation in the North Caucasus Youth Forum "Mashuk 2019".

Materials and research methods. Let's carry out a comparative study of the development of public organizations in modern Russia on the data collected at the North Caucasian Youth Forum "Mashuk – 2019". The author used a systemic and comparative approach when studying the problems of public organizations in the North Caucasus.

Results. In 2019, 31 non-governmental organizations of the North Caucasus Federal District received grant support totaling 50 million rubles. Of these, 13 organizations represented the Republic of Ingushetia, 3 – Stavropol Territory, 4 – Republic of Alania, 7 – Republic of Dagestan, 2 – Karachay-Cherkess and 2 – Kabardino-Balkarian Republics. If we consider the project component of the representatives of the non-profit sector, then they are mostly aimed at solving social problems and strengthening interethnic relations of the peoples of the North Caucasus Federal District [3].

Social activists and their organizations have certain difficulties and problems on the way of implementing their ideas and carrying out activities.

In order to identify the problems faced by a public organization, we conducted a sociological survey (the questionnaire is presented in Table 1) of the heads (representatives) of non-profit organizations [4].

An analysis of the problems in this sector was made from the data. The study involved 12 public organizations from the regions of the North Caucasus, namely:

– Republic of Ingushetia – 4 organizations;

– Karachay-Cherkess Republic – 1 organization;

– Stavropol Territory – 7 organizations.

Table 1

Questionnaire for public organizations

1) To help what category of the population your organization is focused on (no more than 5 answers)	1) Families (young families) 2) Large families and single mothers 3) Minor children and children at risk 4) Great Patriotic War veterans; labor veterans; disabled veterans; pensioners 5) People with disabilities 6) Youth 7) Cultural and scientific elite; trade union associations 8) National minorities and religious groups 9) Other
2) Indicate the difficulties and problems that your organization faces in the work (no more than 5 answers)	1) Difficulties with the premises 2) Lack of partner organizations 3) Imperfection of the legal framework 4) Insufficient qualification of personnel 5) Financial difficulties 6) Staff turnover 7) Lack of support from local authorities 8) Low activity of the majority of members of the organization 9) Lack of volunteers 10) Other
3) What you need to make your organization work more efficiently (no more than 5 answers)	1) Increase the staff 2) Increase funding 3) Improve the qualifications of employees 4) Solve the issue with the premises 5) Get to know the experience of other NGOs in the region 6) Get acquainted with the experience of NGOs in neighboring regions 7) Get acquainted with the experience of foreign NGOs 8) Develop special programs to support NGOs 9) Create an advisory website for NGOs 10) Receive timely information related to the activities of the NGO 11) Other
4) Indicate how often your organization interacts with other NGOs	1) every week 2) 1-2 times a month

	3) 3-4 times a year 4) once a year or less 5) does not interact
5) Information assistance (provision of information in printed and electronic form)	1) This kind of help is not needed 2) Very rare 3) Sometimes in specific situations 4) Periodically 5) Very often 6) Constantly
6) Advisory and methodological assistance (consultations, assistance in the development of projects, in the conduct of the event, transfer of methodological developments)	1) This kind of help is not needed 2) Very rare 3) Sometimes in specific situations 4) Periodically 5) Very often 6) Constantly
7) Material and financial assistance (monetary and non-monetary)	1) This kind of help is not needed 2) Very rare 3) Sometimes in specific situations 4) Periodically 5) Very often 6) Constantly

The first question was: "Which category of the population does your organization aim to support?" In their activities, 10 organizations put youth in the first place (Ingushetia, Karachay-Cherkess Republic, Stavropol Territory); Public organizations of the Stavropol Territory are involved in national minorities and religious groups; Minors and children at risk are included in the activities of 4 non-profit organizations (Ingushetia, Stavropol Territory); Public organizations of Ingushetia and the Stavropol Territory are engaged in the development of cultural and scientific elites, as well as trade union associations.

It is worth noting that public organizations from Ingushetia and the Stavropol Territory, in view of their activities, are engaged in rendering assistance to Great Patriotic War veterans, labor veterans, invalids of the Great Patriotic War, pensioners, people with disabilities, large families and single mothers.

In the second question: "What difficulties and problems does your organization face in its work?", the heads of 6 public organizations (Ingushetia, Karachay-Cherkess Republic, Stavropol Territory) identified financial difficulties and 5 organizations from the above-mentioned republics face difficulties in premises. Also, 3 organizations of the Stavropol Territory noted the imperfection of the legislative framework, 2 organizations – a lack of volunteers. There are no partner organizations for two organizations from the Karachay-Cherkess Republic and the Stavropol Territory. It is worth noting that for two organizations (Ingushetia, Stavropol Territory), the problematic part of their activities is the lack of support from local authorities, and the Karachay-Cherkess organization notes the low activity of most members of the organization.

The third question was aimed at identifying what is necessary for a public organization to work most effectively. 7 organizations (Ingushetia, Karachay-Cherkess Republic, Stavropol Territory) believe that for effective work they need to increase funding. The priority areas for achieving maximum efficiency are:

– solution of the issue of premises (2 organizations – the Karachay-Cherkess Republic, Stavropol Territory);

– to increase the staff (3 organizations – Stavropol Territory);

– to get acquainted with the experience of NGOs in neighboring regions (5 organizations – Ingushetia, Stavropol Territory);

– improve the qualifications of employees (2 organizations – Ingushetia, Stavropol Territory);

The organizations of the Stavropol Territory, in addition to everything, need to receive timely information, develop special programs to support NGOs, create a consultative website for NPOs, get acquainted with the experience of other NGOs in the region and abroad.

When asked how often your organization interacts with other non-profit organizations, we received the following answers: every week and 1-2 times a month (4 organizations – Ingushetia, Stavropol Territory), 2 organizations from Ingushetia 3-4 times a year and 6 organizations do not interact with other organizations (Karachay-Cherkess Republic, Stavropol Territory). According to these statistics, most public organizations do not interact with each other at all, which in turn is a negative moment, because the success of a public organization needs the exchange of information,

project ideas, problems and ways to solve them, for the functioning of civil society in modern Russia this is an important point.

As for the information assistance, 4 NGOs of the Stavropol Territory sometimes need information in specific situations, 3 organizations need periodic information (Ingushetia, Stavropol Territory), 2 organizations from the Karachay-Cherkess Republic and the Stavropol Territory are interested in very rare information assistance, as well as 2 NGOs need to receive information very often (Ingushetia, Stavropol Territory).

Advisory and methodological assistance, which consists in assistance in consultations, in the development of projects, in holding an event, transfer of methodological developments, etc., 6 organizations from Ingushetia and the Stavropol Territory need help in specific situations, for 3 public organizations (Ingushetia, Karachaevo-Cherkess Republic, Stavropol Territory) periodic assistance is needed. Also, 3 NGOs from the Stavropol Territory do not need this type of assistance.

To the final question: "Material and financial assistance", five respondents answered that they need periodic assistance (Ingushetia, Karachay-Cherkess Republic, Stavropol Territory), in such assistance in a specific situation, 2 public organizations of the Stavropol Territory are constantly interested in. Also, 2 organizations from Ingushetia very often need financial assistance and 1 organization from the Stavropol Territory needs this type of assistance very rarely.

Conclusion. In fact, the North Caucasian Youth Forum "Mashuk – 2019" is a practice-oriented educational platform for public organizations, where, in a favorable environment for communication, cultural exchange and self-development, NGOs can intensify the disclosure of their potential in the context of the country's development. Leading experts of the region were invited to the Forum to implement the ideas of public. The purpose of the expert session of the Forum is to improve the quality of projects by providing methodological advice to NGOs (Forum participants) and evaluating projects as part of the public defense of the youth projects in the North Caucasus Federal District.

Expert advice is provided in the following areas:

– selection of a project idea ("points of growth", focusing on current trends in the development of the district's territories, compliance with the solution of strategic tasks of the North Caucasus Federal District);

– the sustainability of the project (the prospects for the long-term existence of the project without permanent grant support, minimization of financial costs or the search for options for implementing the project without grant funds);

– description of the project application (geography, relevance, goals and objectives, target audience, methods and schedule of implementation, estimate and results of implementation);

– public presentation of the project (project evaluation criteria).

Each project is evaluated according to 10 criteria from 0 to 10 points. The project evaluation criteria correspond to the Federal Agency for Youth Affairs method recommendations:

1. Relevance and social significance of the project;
2. Logical coherence and project feasibility;
3. Innovation and uniqueness of the project;
4. Cost-benefit ratio;
5. Realistic budget and reasonable expenses;
6. The scope of the project;
7. Own input and additional resources;
8. Team work experience;
9. Information transparency and publicity;
10. Compliance with the competencies of the team members.

Thus, public organizations of the North Caucasus Federal District by participating in the Mashuk Forum can solve the problems that we identified in the course of this study, but this area requires systematic support from the state, since this sector is able to solve social problems in society.

It should be noted that the Mashuk Forum is not the only platform for NGOs, there are such forums as the All-Russian Youth Forum “Territory of Meanings on the Klyazma”, the All-Russian Youth Educational Forum “Tavrida”, the International Youth Forum “Baltic Artek” and others. There are also various electronic platforms for project implementation. Thus, we can conclude that Russian public organizations at this stage are going through the path of formation. It is a young sector that requires special attention, since it is an integral component for the functioning of civil society and the state as a whole.

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МЕХАНИЗМЫ ОБЕСПЕЧЕНИЯ ПОЛИТИКИ НАЦИОНАЛЬНОЙ БЕЗОПАСНОСТИ В СИТУАЦИИ НОВЫХ УГРОЗ И ВЫЗОВОВ: КОМПАРАТИВИСТСКИЙ АНАЛИЗ

MECHANISMS OF NATIONAL SECURITY POLICY ENSURING IN A SITUATION OF NEW THREATS AND CHALLENGES: A COMPARATIVIST ANALYSIS

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Аннотация*. Национальная безопасность трактуется в качестве системы способов, средств и институциональных форм реализации национальных интересов во внутренней и внешней политике, защищённости государства, общества и граждан от рисков и угроз.*

Материалы, методы, результаты и обсуждения. *Традиционные направления политики национальной безопасности – защита конституционного строя государства, его суверенитета и территориальной целостности в условиях глобализации дополнены новыми направлениями: антитеррористической и антиэкстремистской политикой, противодействием международной организованной преступности, обеспечением информационной безопасности. В данной статье автор сравнивает механизмы обеспечения политики национальной безопасности двух систем.*

Институциональная подсистема обеспечения политики национальной безопасности РФ становится более разветвленной и организационно рациональной. При сохранении стратегического руководства Президента РФ и Совета безопасности РФ на уровне специализированных органов возросла роль Национального антитеррористического комитета,

антитеррористических комиссий субъектов федерации. Система обеспечения национальной безопасности РФ в силу специфики территориальных политических рисков и угроз включает в себя федеральный, макрорегиональный, региональный и муниципальный уровни. На макрорегиональном (федеральные округа) и региональном (субъекты федерации) уровнях необходимы программы реализации Стратегии национальной безопасности РФ.

Заключение. *Таким образом, национальная безопасность РФ является многоуровневой по субъектам реализации. В этой связи важно учитывать разграничение предметов ведения и полномочий в сфере национальной безопасности между федеральными и региональными органами власти РФ.*

Ключевые слова: национальная безопасность, государственная безопасность, концепция национальной безопасности, доктрина информационной безопасности, сепаратизм, сецессия, экстремизм, угрозы и риски государства.

Abstract. *National security is interpreted as a system of methods, means and institutional forms for the realization of national interests in domestic and foreign policy, protection of the state, society and citizens from risks and threats.*

Materials, methods, results and discussions. *The traditional directions of national security policy – protection of the constitutional system of the state, its sovereignty and territorial integrity in the context of globalization – have been supplemented with new directions: anti-terrorist and anti-extremist policies, countering international organized crime, ensuring information security. In this article, the author compares the mechanisms for ensuring the national security policy of the two systems. The institutional subsystem for ensuring the national security policy of the Russian Federation is becoming more ramified and organizationally rational. While maintaining the strategic leadership of the President of the Russian Federation and the Security Council of the Russian Federation at the level of specialized bodies, the role of the National Antiterrorist Committee and the antiterrorist commissions of the subjects of the Federation has increased. The system of ensuring the national security of the Russian Federation, due to the specifics of territorial political risks and threats, includes the federal, macro regional, regional and municipal levels. At the macro regional (federal districts) and regional (federal subjects) levels, programs for the implementation of the RF National Security Strategy are required.*

Conclusion. *Thus, the national security of the Russian Federation is multi-level in terms of subjects of implementation. In this regard, it is important to take into account the division of responsibilities and powers in the field of national security between Federal and regional authorities of the Russian Federation.*

Key words: national security, state security, concept of national security, doctrine of information security, separatism, secession, extremism, threats and risks of the state.

Введение. До распада СССР в отечественном законодательстве и научной литературе доминировало использование термина «государственная безопасность», с которым «национальная безопасность» отождествлялась. Тем самым, реализовывался принцип верховенства интересов социалистического государства над интересами личности. В нормативно-правовом аспекте термин стал широко употребляться после создания Главного управления государственной безопасности в структуре Народного комиссариата внутренних дел СССР (1934 г.). Понятие «государственная безопасность» не конкретизировалось, хотя и вошло в ст. 14 п. «и» Конституции СССР 1936 г[4].

Первая попытка разработать концепцию национальной безопасности страны в условиях демократии состоялась в мае 1990 г., когда группа Комитета Верховного Совета СССР по науке, народному образованию, культуре и воспитанию под руководством Ю.А. Рыжова подготовила проект концепции[5]. Он впервые определял национальную безопасность как органическое единство безопасности личности, общества и государства. Причём основой была названа безопасность личности, которая определяет безопасность гражданского общества и легитимность правового государства. Авторы законопроекта обосновывали реализацию безопасности в двух измерениях: общественном и государственном. По источникам угроз, опасностей и рисков для жизненно важных интересов безопасность классифицировалась на внутреннюю и внешнюю. Авторы проекта концепции впервые обращали внимание политического руководства страны на то, что ведущие угрозы безопасности возникают в сфере внутренней политики, и это требует коренного пересмотра целей и механизмов обеспечения безопасности. Увы, «война законов» между союзным и российским центрами власти в 1990–1991 гг., идейно-политическая неготовность правящей элиты, распад СССР не позволили принять концепцию.

Материалы, методы, результаты и обсуждения. С образованием Российской Федерации как независимого государства разрабатывается Закон РФ «О безопасности», введённый в действие Постановлением Верховного Совета страны 5 марта 1992 г.[6] Его ст. 1 определила безопасность как «состояние защищённости жизненно важных интересов личности, общества и государства от внутренних и внешних угроз». Как справедливо оценивает эту формулировку один из тогдашних российских депутатов В.Л. Шейнис, она соответствовала демократическому правосознанию и конституционному принципу – высшей ценности человека, его прав и свобод[7]. Основными принципами обеспечения безопасности впервые были выбраны: законность; соблюдение баланса жизненно важных интересов личности, общества и государства; их взаимная ответственность по обеспечению безопасности; интеграцию национальной системы безопасности с международными. Указанный закон впервые сформулировал и легитимировал правовую систему обеспечения национальной безопасности РФ, установил её функции, субъектов, силы и средства обеспечения. Был определен порядок организации и ресурсов сил обеспечения безопасности, контроля и надзора над законностью их действий.

Вместе с тем, становление российской концепции национальной безопасности шло при острых конфликтах ценностей и интересов. Так, в условиях децентрализованного и этнизированного федерализма 1990-х гг. ряд политиков критиковали сам термин «национальная» безопасность. Разработчики закона вынуждены были пояснять, что речь идёт о синонимах «национально-государственной» и «общей» безопасности России[8]. В.Л. Шейнис признает: закон 1992 г. был «возможно, несколько декларативным, оперировавшим не вполне раскрытыми понятиями и недостаточно детализованным», хотя и прогрессивным[9]. Не удалось и намерение в 1992–1993 гг. принять первую Концепцию национальной безопасности РФ. Она не была утверждена Президентом страны (по сообщению С.В. Кортунова)[10]. До середины 1990-х гг. шли острые дискуссии о применимости самих категорий «национальные интересы» и «национальная безопасность».[11]

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[4] Линдер И. Б., Чуркин С. А. История специальных служб России X–XX веков. М., 2005. С. 717.

[5] Вахрамеев А. В. К вопросу об обеспечении национальной безопасности Российской Федерации // Социально-гуманитарные знания. 2001. №1. С. 14.

[6] Закон РФ «О безопасности» от 5 марта 1992 г. №2446-1 // Российская газета. 1992. 9 марта.

[7] Шейнис В. Л. Национальная безопасность России. Испытание на прочность // Полис. 2009. №5. С. 143.

[8] Казакова М. Н. Эволюция политико-правовых основ национальной безопасности Российской Федерации // Модернизация и политика: традиции и перспективы России. Политическая наука: Ежегодник 2011. М., 2011. С. 411.

[9] Шейнис В. Л. Указ. соч. С. 142.

[10] Стенограмма «круглого стола» «Национальная безопасность России: доктрина и реальность» // Политическая экспертиза. Альманах. СПб., 2005. Вып. 2. С. 277.

[11] Сорокин К. Э. Государственные интересы как обобщение национальных // Полис. 1995. №1. С. 114-120; Капустин Б. Г. «Национальный интерес» как консервативная утопия // Свободная мысль. 1996. №3. С. 13-38; Концепция нацио-

Следующий шаг в институционализации концепции национальной безопасности России был совершён только через три года, в Послании по национальной безопасности Президента Российской Федерации Федеральному Собранию РФ 1996 г[12]. Смысл категории «национальная безопасность» был концептуально расширен: «Обеспечение безопасности должно быть направлено не только на предотвращение угроз, но и на осуществление комплекса мер по развитию и укреплению прав и свобод личности, материальных и духовных ценностей общества, конституционного строя, суверенитета и территориальной целостности государства»[13].

Другой ключевой концепт – национальные интересы России стали трактоваться в двойственном (государственном и общественном) смысле: как «основа формирования стратегических задач внутренней и внешней политики страны» и «интегрированное выражение жизненно важных интересов личности, общества, государства»[14]. В Послании 1996 г. впервые предпринята попытка определить основные долгосрочные интересы страны: «Их суть сводится к тем содержательным блокам: процветание народа, защита и обустройство территории его проживания и развитие национальной культуры»[15].

В 1997 г. принимается Концепция национальной безопасности Российской Федерации. Она более отчётливо, чем предшествующие акты, определила систему национальных интересов РФ в области экономики, во внутриполитической, международной, оборонной и информационной сферах, социальной сфере, духовной жизни и культуре[16]. Концепция добавила к перечислению интересов личности, общества и государства их сбалансированность (в отличие от акцента в начале 1990-х гг. на интересах личности).

Качественно иной этап стратегического проектирования политики национальной безопасности наступил в РФ осенью 1999 г. в контексте курса консолидации государства, усиления его внутри- и внешнеполитических позиций. Реформированная нормативно-правовая основа национальной безопасности России в начале 2000-х гг. определена в следующих документах:

– «Концепции национальной безопасности Российской Федерации» (в редакции Указа Президента РФ от 10 января 2000 г.)[17];

– «Доктрине информационной безопасности Российской Федерации», утвержденной Указом Президента РФ 9 сентября 2000 г[18];

– Военной доктрине 2000 г., утвержденной Указом Президента Российской Федерации от 21 апреля 2000 г.[19];

– «Основах пограничной политики РФ», утвержденных Указом Президента РФ 5 октября 1996 г.[20];

– «Концепции приграничного сотрудничества в Российской Федерации», утвержденной распоряжением Правительства РФ 9 февраля 2001 г.[21]

Сравним основные параметры концептуального проектирования политики национальной безопасности в Концепции 2000 г. и Стратегии 2009 г.

Согласно Концепции национальной безопасности РФ в редакции 2000 г., внутриполитические аспекты национальной безопасности таковы: поддержание единства и целостности государства, обеспечение баланса

нальных интересов: общие параметры и российская специфика (материалы кругл. стола) // Мир. экономика и междунар. отнош. 1996. №7. С. 59-69; №8. С. 78-84; №9. С. 69-82.

[12] Послание по национальной безопасности Президента РФ Федеральному Собранию 13.06.1996 // Независимая газета 1996. 14 июня.

[13] Там же.

[14] Там же.

[15] Там же.

[16] Концепция национальной безопасности Российской Федерации (утверждена Указом Президента РФ 17 декабря 1997 г., №1300) // Российская газета. 1997. 18 дек.

[17] Концепция национальной безопасности Российской Федерации (в редакции Указа Президента РФ от 10 января 2000 г., №24) // Российская газета. 2000. 18 янв.

[18] Доктрина информационной безопасности Российской Федерации (утверждена Указом Президента РФ 9 сентября 2000 г. №1895-Пр) // Российская газета. 2000. 28 сент.

[19] Военная доктрина Российской Федерации: Утверждена Указом Президента Российской Федерации от 21 апреля 2000 г. №706. Режим доступа: http://www.rg.ru/oficial/doc/ykazi/doc_war.htm

[20] Основы пограничной политики Российской Федерации: Утверждены Президентом РФ 5 окт. 1996 г. // Российская газета. 1996. 14 окт.

[21] Концепция приграничного сотрудничества в Российской Федерации: Утверждена распоряжением Правительства РФ от 9 февр. 2001 г. // Российская газета. 2001. 16 февр.

потенциалов и интересов регионов, недопущение сепаратизма и сецессии [22]. Безопасность должна обеспечивать оптимальное сочетание жизненно важных интересов общества, государства и личности на основе принципов законности.

Концепция национальной безопасности РФ трактовала национальные интересы России как совокупность сбалансированных интересов личности, общества и государства в экономической, внутриполитической, социальной, международной, информационной, военной, пограничной, экологической и других сферах. Национальные интересы долгосрочны. Они определяют основные цели, стратегические и текущие задачи внутренней и внешней политики государства.

Специфика национальных интересов России (по Д. В. Кротову)[23] в том, что они определяются базовыми параметрами состояния страны: её обеспечением природными и экономическими ресурсами, социальной структурой населения, политической системой, типом политической культуры и идентичности, характером внешних и внутренних угроз безопасности.

Политический аспект национальных интересов включает в себя обеспечение гарантий конституционного строя страны, её суверенитета и территориальной целостности, гражданского мира и национального согласия, единства правового пространства. Необходимо также нейтрализовать причины и условия политического и религиозного экстремизма, этносепаратизма, последствиями которых становятся насильственные конфликты.

Основные задачи обеспечения национальной безопасности РФ таковы:

– своевременное прогнозирование и выявление угроз национальной безопасности;

– осуществление тактических и стратегических мер по предупреждению и нейтрализации данных угроз;

– обеспечение суверенитета и территориальной целостности России, безопасности её пограничного пространства;

– обеспечение личной безопасности человека и гражданина, его конституционных прав и свобод в пространственном аспекте (равенства прав на всей территории страны, свобода выбора места жительства и пребывания);

– совершенствование системы государственной власти РФ, федеративных отношений, местного самоуправления и законодательства РФ;

– сохранение социально-политической стабильности общества;

– формирование гармоничных межэтнических отношений;

– подъем и поддержание на необходимом уровне обороноспособности военного потенциала государства.

Концепция национальной безопасности РФ (2000 г.) определяла специализированные направления обеспечения безопасности. В конституционно-правовой сфере направлениями, имеющими политический характер, указывались[24]:

– обеспечение приоритета федерального законодательства;

– разработка организационных и правовых механизмов защиты государственной целостности, обеспечение единства правового пространства;

– выработка и реализация политики, обеспечивающей оптимальный баланс федеральных и региональных интересов;

– пресечение деятельности партий и общественных объединений, имеющих сепаратистские цели;

– правовая защита культурного наследия, исторических традиций и духовных норм жизни всех народов РФ; сохранение роли русского языка как фактора духовной интеграции народов РФ;

– применение военной силы внутри территории страны в строгом соответствии с Конституцией РФ и федеральными законами в случаях возникновения угрозы жизни граждан, территориальной целостности страны, угрозы насильственного изменения конституционного строя.

Основные приоритеты обеспечения национальной безопасности России в сфере её внутренней политики не формулируются в упомянутой Концепции концентрированно. По работам Ю. В. Морозова, К. В. Сивкова, М. Н. Казаковой[25] можно выделить приоритетные направления:

[22] Концепция национальной безопасности Российской Федерации // Российская газета. 2000, 18 янв.

[23] Кротов Д. В. Политическая безопасность России (на материалах Южного федерального округа) // Национальная и региональная безопасность на Юге России: новые вызовы. Ростов н/Д, 2003. С. 102.

[24] Концепция национальной безопасности Российской Федерации // Российская газета. 2000, 18 янв.

– защиту территориальной целостности, противодействие сепаратизму;

– создание и поддержание устойчивых эффективных отношений между центром и регионами на основе комплекса экономических, правовых и политических мер;

– предупреждение насильственных форм межэтнических и межконфессиональных конфликтов, управление существующими конфликтами в целях их урегулирования;

– проведение информационной и, шире, символической политики, направленной на укрепление общероссийской идентичности и толерантности;

– восстановление ресурсов Вооруженных сил и правоохранительных органов, необходимых для реализации задач национальной безопасности;

– курс «территориальной справедливости» в политике, призванный обеспечить равенство возможностей граждан РФ независимо от места их жительства, этничности, конфессии и иных социально значимых различий;

– пограничное взаимовыгодное сотрудничество на равноправной основе с зарубежными странами и транснациональным организациями.

В политической науке разработан ряд важных терминов, которые недостаточно отражены в федеральных правовых актах. К ним относится категория «источник опасности». А. А. Сергунин определяет источники в качестве условий и факторов, которые обнаруживают свои вредоносные свойства. Опасность – «осознаваемая, но не фатальная вероятность причинения вреда..., определяемая наличием неких объективных и субъективных факторов» [26]. По степени вероятности опасность подразделяется на реальную и потенциальную. Меньшими по масштабам негативного воздействия на страну являются риски и вызовы. Риск безопасности трактуется международниками А. А. Сергуниным и А. С. Макарычевым узко – как возможность неблагоприятных и нежелательных последствий деятельности именно субъекта безопасности (государства либо отдельного органа власти).[27] Напротив, специалисты по внутриполитическим аспектам расширяют понятие «риск безопасности». С. А. Красиков определяет его как коллективный риск, связанный со столкновением множества групповых политических интересов, с рядом затронутых последствиями субъектов, имеющий системный характер, затрагивающий все сферы общества. Это вынужденный, некалькулируемый риск с неопределенным временем последствий[28].

Вызов безопасности обычно трактуется в качестве совокупности обстоятельств, воздействующих на государство извне, не обязательно угрожающего характера, но требующих ответной реакции субъекта безопасности.

В 2000 г. впервые была концептуально выделена сфера информационной безопасности, которая стала пониматься отныне не в узком смысле защиты личности, общества и государства от информационных угроз, а в широком: политико-идеологическом. Характерно упоминание в тексте «Доктрины информационной безопасности РФ» 2000 г. таких угроз, как «монополизация информационного рынка России, его отдельных секторов отечественными и зарубежными информационными структурами». Справедливо подчеркнута опасность «девальвации духовных ценностей, пропаганды образцов массовой культуры, основанных на культе насилия, на духовных и нравственных ценностях, противоречащих ценностям, принятым в российском обществе»[29].

Субъекты политики России и их функции, согласно Концепции национальной безопасности 2000 г., выполняют следующие законные функции[30].

Президент РФ руководит в пределах конституционных полномочий государственными органами обеспечения национальной безопасности, возглавляет Совет безопасности РФ и руководит его повседневной дея-

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тельностью, определяет стратегию обеспечения безопасности, санкционирует действия по её реализации. Он формирует, реорганизует и упраздняет подчиненные органы и силы обеспечения безопасности. В ежегодных посланиях Федеральному Собранию Президент страны уточняет положения Концепции (с 2009 г. – Стратегии) национальной безопасности РФ, определяет направления текущей внутренней и внешней политики в данной сфере.

Федеральное собрание РФ по представлению Президента РФ Правительства страны формирует законодательную базу в области обеспечения национальной безопасности.

Правительство РФ в пределах своих полномочий и с учетом приоритетов обеспечения национальной безопасности координирует деятельность федеральных органов исполнительной власти, органов исполнительной власти субъектов РФ. Оно формирует статьи федерального бюджета для реализации целевых программ в данной сфере.

Совет Безопасности РФ проводит упреждающее выявление и оценивает угрозы национальной безопасности, готовит проекты решений по их предотвращению и предложения в области обеспечения национальной безопасности. Координирует реализацию федеральными и региональными органами исполнительной власти данных решений.

Федеральные органы исполнительной власти исполняют законодательство РФ, решения Президента РФ и Правительства РФ в области национальной безопасности, разрабатывают законопроекты и представляют их на голосование законодательным органам.

Органы исполнительной власти субъектов РФ взаимодействуют по вопросам исполнения законодательства РФ, решений Президента РФ и Правительства страны, федеральных программ и планов, директив Верховного Главнокомандующего Вооруженными силами РФ с федеральными органами исполнительной власти. Совместно с органами местного самоуправления привлекают граждан, общественные объединения и организации к содействию в решении задач национальной безопасности. Они вносят в федеральные органы исполнительной власти предложения по совершенствованию системы обеспечения национальной безопасности РФ.

Заключение. Таким образом, национальная безопасность РФ является многоуровневой по субъектам реализации. В этой связи важно учитывать разграничение предметов ведения и полномочий в сфере национальной безопасности между федеральными и региональными органами власти РФ[31].

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ СОДЕРЖАНИЯ ФЛАВОНОИДОВ В ИЗВЛЕЧЕНИИ ИЗ КОМПЛЕКСНОГО ЛЕКАРСТВЕННОГО РАСТИТЕЛЬНОГО СЫРЬЯ ПРИ РАЗЛИЧНЫХ МЕТОДАХ ЭКСТРАКЦИИ

COMPARATIVE ANALYSIS OF FLAVONOID CONTENT IN EXTRACTION FROM COMPLEX MEDICINAL PLANT RAW MATERIALS USING VARIOUS EXTRACTION METHODS

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Аннотация. *В наше время древнейшая лекарственная категория – препараты на основе лекарственного растительного сырья (ЛРС), не потеряли актуальности, постоянно развивается и, как следствие, во многих государствах они имеют фармакопейный статус. Тенденции развития медицинской науки проявляются не только в усложнении новейших фармацевтических технологий, но и в глубоком познании механизмов воздействия средств природного происхождения, особенно при длительных и хронических заболеваниях различного генеза. В общей структуре заболеваемости патология опорно-двигательного аппарата занимает одно из лидирующих мест. Болезни позвоночника, костей и суставов одинаково свойственны и молодым, и пожилым людям. Практически каждый десятый взрослый имеет ту или иную патологию костно-мышечной системы. В процессе многочисленного подбора и исследования комбинаций разнообразного ЛРС с противовоспалительной, регенерирующей и как следствие, противоартритной и противоартрозной активностью и скрининга на Parametium caudatum, была выбрана комбинация из 13 объектов. Все они содержат флавоноиды, которые и являются основными «носителями» фармакологической активности. Оптимальным экстрагентом, для извлечения флавоноидов (основных «носителей» интересующего фармакологического эффекта) является этанол 70%. Для выбора метода экстракции были исследованы следующие: мацерации (Метод 1), перколяции (Метод 2). Значения соизмеримы, но учитывая, что первая методика не требует длительного экстрагирования как в перколяции и является более «облегченной» в аппаратурном исполнении, мы остановили свой выбор на мацерации.*

Ключевые слова: флавоноиды, лекарственное растительное сырье, артриты, артрозы, мацерация, перколяция.

Abstract. *The ancient medicinal category-drugs based on medicinal plant raw materials (MPRM), has not lost relevance today. The production of such drugs is constantly developing and they have a pharmacopoeial status in many states. Trends in the devel-*

opment of medical science are manifested not only in the complexity of the latest pharmaceutical technologies, but also in a deep knowledge of the mechanisms of action of natural products, especially in long-term and chronic diseases of various genesis. In the general structure of morbidity, pathology of the musculoskeletal system occupies one of the leading places. Diseases of the spine, bones and joints are equally characteristic of both young and old people. Almost every tenth adult has one or another pathology of the musculoskeletal system. In the process of numerous selection and research of combinations of various medicinal plant raw materials with anti-inflammatory, regenerative and consequently anti-arthritic and anti-arthrotic activity and screening for Parametium caudatum, a combination of 13 objects was selected. All of them contain flavonoids, which are the main "carriers" of pharmacological activity. The optimal extractant for the flavonoids extracting is 70% ethanol. To select the extraction method, the maceration (Method 1) and percolation (Method 2) were studied. The values are comparable, but taking to account that the first method is more common and does not require a long extraction as in percolation, maceration was chosen.

Key words: flavonoids, medicinal plant raw materials, arthritis, arthrosis, maceration, percolation.

Introduction. Trends in the development of medical science are not only in the complication of the latest pharmaceutical technologies, but also in a deep understanding of the mechanisms of effect of natural products, especially in treatment of long-term and chronic diseases. Medicinal plants are in demand for the production of plant-based preparation that do not cause those side effects that are observed with the use of synthetic drugs [9]. The growing popularity of herbal medicines, which have proven their effectiveness and safety, requires constant expansion of their arsenal. Phytopreparations have advantages due to the presence of complexes of basic substances that enhance their biological activity. Herbal preparations (total preparations) – tinctures, extracts are among the oldest dosage forms of official medicine. In our time, these ancient medicinal categories have not lost their relevance, they are constantly developing and, as a result, in many countries they have a pharmacopoeial status [2, 3, 4, 6].

In practice, several plants are usually used at once (collection of medicinal herbs). This makes it possible to expand the range of applications, enhance the effect of certain medicinal herbs, introducing into the collection plant objects that affect various pathological processes in the lungs, liver, kidneys, heart, spleen, stomach, pancreas, intestines, joints and many other organs and tissues [3, 9, 11, 12].

In the general structure of morbidity, pathology of the musculoskeletal system ranks fourth after diseases of the respiratory system, blood circulation and digestion. Diseases of the spine, bones and joints are equally common in young and old people. Men suffer from them almost twice as often as women. Almost every tenth adult has one or another pathology of the musculoskeletal system. Arthritis and arthrosis is observed in every fifth patient between the ages of 30 and 40, and in every second – at the age of 50 to 60. Among people over the age of 65, the incidence of arthritis and arthrosis is 70-85%. In recent years, the proportion of diseases of the musculoskeletal system has been constantly growing: the number of new cases is increasing annually by about 25%. In addition to the threatening morbidity rates, information on the consequences are even more alarming – primary disability due to diseases of the musculoskeletal system ranks third after diseases of the circulatory system and malignant neoplasms. The constant progress of medicine provides a significant extension of life, while the percentage of chronic diseases is increasing. This tendency is most noticeable in diseases of the musculoskeletal system, and such pathologies as arthritis and arthrosis are the most urgent. An important problem of the modern approach to the treating arthrosis and arthritis is the search for external remedies based on medicinal plants that can be used for a long time, without side effects in different age groups. The objective of this study is to create a product based on medicinal plant raw materials (MPRM), which has an increased pharmacological effect, as well as to develop a method for its production [12].

In the process of numerous selection and research of combinations of various medicinal products with anti-inflammatory, regenerating and, as a consequence, antiarthritic activity and screening for Parametium caudatum, a combination of 13 objects was chosen. All of them contain flavonoids, which are the main carriers of pharmacological activity.

The optimal extractant for the extraction of flavonoids is 70% ethanol.

To select the extraction method, the maceration (Method 1) and percolation (Method 2) were studied.

Research methods

Method 1 – the technology for obtaining complex extraction by the maceration method.

Complex extraction was obtained in a maceration tank. The technological process consisted of the following main stages: preparation of medicinal plant raw materials and extractant, obtaining a complex alcohol-water extraction, packing and packaging.

The method of remaceration was used in the ratio of medicinal product: extractant – 1: 8. The crushed raw material was placed in a maceration tank and filled with a 5-fold amount of the extractant (70% ethyl alcohol + 10% methylene chloride). The addition of methylene chloride significantly increased the yield of flavonoids compared with extraction with pure 70% ethanol. The combination of polar (alcohol) and non-polar (methylene chloride) solvents made it possible not only to increase the yield of flavonoids, but also to ensure efficient extraction of lipids. This is due to the low dielectric constant of methylene chloride (about 9). Extraction was carried out at room temperature for 24 hours. Then the raw material was squeezed out, the extract was filtered, and the meal was re-poured with a 3-fold amount of the extractant, and the process was repeated for 12 hours at room temperature. Then the meal was squeezed out, and the resulting extract was filtered. Periodic change of the extractant is necessary for a more complete depletion of the raw material and to reduce the loss during diffusion. After the completion of the extraction, the resulting extracts were combined.

The combined alcohol-water extract was precipitated for 24 hours and filtered. Next, the extract was evaporated under vacuum at a temperature of 50-60. 0C and a residual pressure of 50-60 inches of mercury with water jet vacuum pump for methylene chloride removal.

In the selected complex of medicinal products, terpene compounds are also contained in addition to flavonoids. Volatile compounds – essential oils are having been lost during storage and processing. Significant losses also occur during the roll milling of crushed plant materials. In this connection, impregnation of a blended mixture of raw materials with a solution of castor oil and ethanol was tested. It has been determined that the optimal is the addition of a 7-8 wt.% alcohol solution per unit mass of raw material.The studies have shown that the impregnation of the raw material before roll milling allows to increase the content of essential oils in the product (phytoconcentrate) by 5-7% compared to the control process without impregnation. The yield of essential oils without impregnation is 4-8%.

The combination of solvents also allows additional extraction of such a valuable product as chlorophyll from medicinal plant raw materials. Chlorophyll is the "green blood" of the plant world, which acts as a protein. Being the basis of the entire plant world, it is the very first product of sunlight, carries out photosynthesis. Regular consumption of chlorophyll can improve the body's resistance to many diseases, such as arthritis, rheumatoid arthritis, rhinitis, diabetes mellitus, high blood pressure, etc. Thus, the maintenance of chlorophyll in the extract is an important link in obtaining the extract.

Method 2 – extract preparation by percolation method. The extraction of complex raw materials was carried out in a battery of six diffusers according to the counterflow principle, in which the extract obtained from the first diffuser is sent to the second, the extract obtained from the second diffuser is sent to the third, etc. All six doses of the extractant with this extraction method are supplied into the first diffuser. After putting into operation all the diffusers of the battery, all six portions of the extract are taken from the head, sixth diffuser, and the tail diffusers are taken out alternately, with the start of the selection of finished products.

Quantification of the amount of flavonoids in the extract. Alcohol-water extraction was obtained from standardized raw materials [7].

The quantitative determination of flavonoids in terms of narutin was carried out traditionally. The optical density of the resulting solution was measured on a spectrophotometer at a wavelength of 415 ± 2 nm in a cuvette with a layer thickness of 10 mm. In parallel, the optical density of the rutin working standard solution was measured.

Research results. The final combination of MPRs was matched by studying the increase in the lifespan of Paramecia with the addition of extracts (pre-thickened to remove ethanol). Among all the variety of microorganisms, paramecia are one of the most convenient test objects for medico-ecological, pharmacokinetic and toxicological studies, as they are well studied, have large sizes that allow working with individual organisms [1, 5, 8, 10]. Cultivation methods have been developed for them that provide the necessary culture standardization with relatively inexpensive methods. There are no pathogenic forms among them. Paramecia in pharmacology, as a biological model, is used to screen antioxidant (regulating lipid peroxidation) and membrane-stabilizing drugs. Paramecia, as living self-regulating structures, are characterized by a high degree of adaptability, that is, they are able to develop protective reactions aimed at weakening the damaging effects of various stimulant, and resistance to stimulant remains for some time after its removal. There are various modifications of microscopic counting in medical and microbiological research. To conduct an experiment, a few drops are taken from a suspension with organisms and the number of ciliates is counted under a microscope [1, 10]. The microscopical method allows visual observation of changes in the functional and structural parameters of Paramecia under the influence of substances of various natures in both acute and long-term experiments. As a pharmacological indicator (toxicant), predominantly damaging the lipid part of the membrane, hydrogen peroxide 1% is used,

which is broken down to peroxide radicals in vivo, initiating the process of lipid peroxidation (LPO) of membranes; a pharmacological indicator that predominantly damages the structure of the protein biomembrane is 14% ethyl alcohol, leading to denaturation of both enzymatic and membrane proteins [1, 8, 10].

Table 1

The composition of the optimal combination of medicinal products

№ п/п	Optimal combination of alcohol-water extraction from medicinal plant raw materials	The optimal ratio of medicinal products
1.	Chamomile (flowers)	0,04
2.	Calendula (flowers)	0,05
3.	Cumin (fruit)	0,03
4.	Pine (buds)	0,50
5.	Yarrow (herb)	0,05
6.	Mint (leaf)	0,10
7.	Rosehip (fruit)	0,06
8.	Fennel (fruit)	0,30
9.	Licorice (root)	0,25
10.	Wormwood (herb)	0,40
11.	Thyme (herb)	0,15
12.	St. John's wort (herb)	0,05
13.	Celandine (herb)	0,02
Итого:	13 ingredients	2,00

The choice of the medicinal plant was based on the analysis of researches on raw materials that have anti-inflammatory, regenerating effects and indirectly affect pathological links in degenerative-inflammatory processes of the musculoskeletal system.

The results of determining the degree of protection of the paramecia cell wall when the developed combination is added to them in relation to cell poisons (14% ethanol and 1% hydrogen peroxide solution) are shown in Table 2.

Table 2

Study of the degree of protection of paramecium from the action of toxicants by the time of stopping (acute experience)

Object name	Stop time of paramecium in 14% ethanol, min	Stopping time of paramecium in 1% hydrogen peroxide solution, min
Control	0,2 ± 0,01	0,09 ± 0,01
Medicinal product combination	11,0 ± 0,30	5,9 ± 0,20

The developed combination significantly extended the stopping time of paramecium by a factor of 55 and 65 under the influence of cellular poisons – ethyl alcohol and hydrogen peroxide, respectively. The lengthening of the stopping time of the movement of paramecium under the influence of ethyl alcohol, characterizes the membrane-stabilizing activity of the developed combination, selected components, which in a qualitative and quantitative ratio prevent damage to the protein part of the biomembrane. Antioxidant activity was tested by extending the time of movement of paramecium under the influence of a solution of hydrogen peroxide, which is associated with the ability of the components of the developed combination to inhibit membrane lipid peroxidation.

Quantification of the amount of flavonoids in the extract

Method 1 (maceration)

The metrological characteristics of the developed methodology are shown in Table 3.

Table 3 – Metrological characteristics of the method for determining the content of the sum of flavonoids in the complex extract (Method 1)

n	**$X_{ср}$**	**ΔX**	**S**	**S^2**	**S_x**	**t (p,f)**	**ε,%**
10	2,850	0,025	0,035	0,0013	0,011	2,26	0.90

Thus, in the extract obtained by Method 1, the content of flavonoids in terms of rutin is 2,850±0,025 ($X_{ср}$± ΔX).

To confirm the correctness of the method, a calibration curve was plotted, the dependence of the optical density of the solution on the concentration of rutin and is shown in Figure 1.

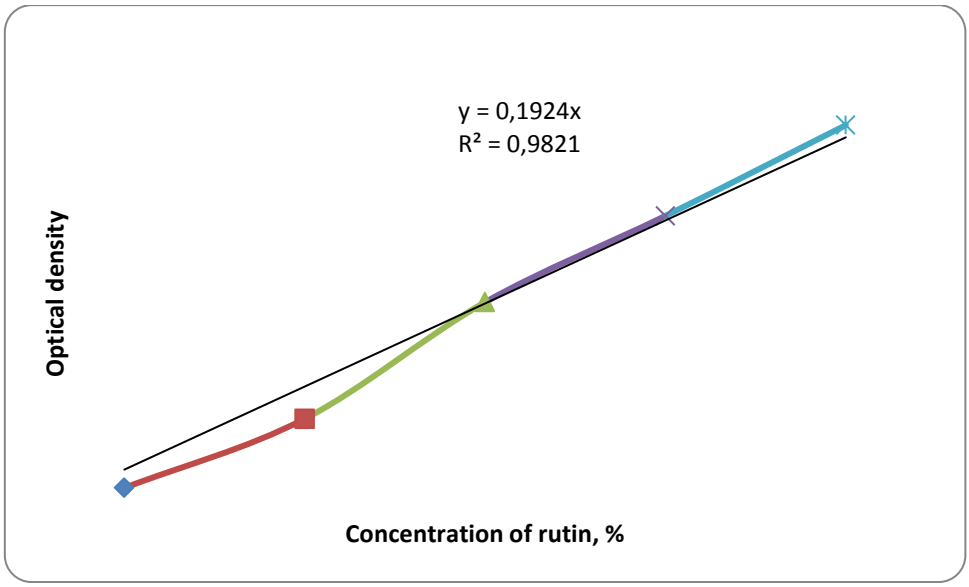

Fig. 1. Calibration dependence for determining the amount of flavonoids in a complex extract

The graph shows a direct dependence of the increase in optical density on the concentration of rutin.

Method 2 (percolation)

The metrological characteristics of the developed methodology are shown in Table 4.

Table 4

Metrological characteristics of the method for determining the content of the sum of flavonoids in the complex extract (Method 2)

n	$X_{ср}$	ΔX	S	S^2	S_x	t (p,f)	ε,%
10	2,950	0,035	0,035	0,0013	0,011	2,26	0,75

Thus, in the extract obtained according to Method 2, the flavonoid content in terms of rutin is 2,950±0,035 ($X_{ср}$±ΔX).

Conclusions. Flavonoids – substances of a polyphenolic nature that protect plants from adverse environmental factors, perform similar functions in animals, whose body does not produce these substances, but consumes them with food. Although the concentration of flavonoids in the body of animals is significantly lower than that of plants, these substances retain their protective functions and are normally constantly present in the blood, lymph and intercellular fluids, acting on the receptors of the signaling system of cells. Flavonoids also enter the cytoplasm, having a direct effect on the work of some enzymes. Currently, there is a lot of evidence of changes in the expression and functioning of various proteins in the cytoplasm and nucleus, although the molecular mechanisms explaining the mechanisms of the effect of flavonoids on the functioning of proteins are poorly understood. In addition, in the body of animals, flavonoids undergo a variety of chemical modifications. Flavonoid metabolism products also have biological activity. However, the pharmacokinetics of flavonoids is still in its infancy and there is still relatively few research in this area [12, 13, 14, 15].

Medicinal plant preparations containing flavonoids, the release and quantitative analysis of flavonoids are of particular interest. Studies of the action of flavonoids show their ability to influence various vital processes, both of individual cells and the body as a whole. Epidemiological studies of the relationship between the spread of various diseases (cardiovascular, oncological, neurological, diseases of the musculoskeletal system) with the consumption of flavonoids under experimental conditions on animals convincingly indicate the prospects of using some flavonoids in the prevention and even in the treatment of various diseases. Flavonoids are powerful antioxidants that prevent the development of oxidative stress in cells where metabolism is impaired by toxic prooxidants, UV radiation, and other damaging factors. The antioxidant properties of flavonoids are determined both by the ability of these molecules to capture free radicals and by the ability to chelate cations of variable valence metals involved in oxidation processes. The antioxidant effect of flavonoids is not limited to the direct effect of these substances on the processes of peroxidation. Flavonoids are sometimes a subtle, but necessary link in the assembly and functioning of proteins, in the formation of biological membranes, in the transmission of information in the cell. Always available, they serve as helpers in many processes. This is a

kind of "lubricant" in the complex mechanism of the cell. It can be hoped that further research of flavonoids will make it possible to make many interesting discoveries, and the creation of artificial derivatives of flavonoids will make it possible to obtain new effective medicinal substances [12, 13, 14, 15].

Comparative analysis of the methods of extraction – maceration and percolation, based on the analysis of the transition of flavonoids, in terms of rutin, in alcohol-water extraction showed that in the extract obtained by Method 1, the content of flavonoids was 2.850 ± 0.025, according to Method 2, the content of flavonoids was 2.950 ± 0.035. The values are comparable, but taking to account that the first method is more common and does not require a long extraction as in percolation, maceration was chosen.

The resulting alcohol-water extraction is an intermediate product for the design of a soft dosage form - a gel with roughly antiarthritic and antiarthrosique activity.

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СОВЕРШЕНСТВОВАНИЕ МЕТОДОВ ОЦЕНКИ УСТОЙЧИВОСТИ ПРЕДПРИЯТИЙ ТУРИСТИЧЕСКОЙ ИНДУСТРИИ НА РЕГИОНАЛЬНОМ УРОВНЕ

IMPROVEMENT OF METHODS FOR ASSESSING THE FINANCIAL STABILITY OF TOURISM INDUSTRY ENTERPRISES AT THE REGIONAL LEVEL

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Аннотация. *Статья посвящена применению методов стресс-тестирования для оценки риска возможного банкротства для туристических компаний на уровне региона. При сценариях изменения турпотока от 100% до 50% и 30%, динамика корреляций исследуемых показателей показывает не критичную динамику ослабления тесноты связи. Стресс-тест показал некоторый запас прочности санаторно-курортного комплекса региона Кавказских Минеральных Вод.*

Ключевые слова: туризм, рекреационный потенциал, риск-менеджмент, конкурентные преимущества, туристические услуги.

Abstract. *The article is devoted to the application of stress testing methods to assess the risk of possible bankruptcy of tourist companies at the regional level. In the scenarios of changes in the tourist flow from 100% to 50% and 30%, the dynamics of correlations of the studied indicators shows a non-critical dynamics of weakening the tightness of the connection. There are probably hidden nonlinear dependencies of the studied indicators. The stress test showed a certain margin of safety of the health resort complex of the Caucasus Mineral Waters region.*

Key words: tourism, recreation potential, risk-management, competitive advantages, travel services.

Introduction. Risk is an integral part of a person and society life. At the organizational level, economic risk is more significant, it regulates the microeconomic relations of companies when making management decisions. In this case, it is necessary to take into account the resulting influence of external and internal factors, which in turn are subject to constant qualitative and quantitative changes [4].

A potential hazard can be viewed as an uncertain event or condition that, when realized, has a positive or negative impact on the company's reputation, leads to monetary gains or losses [12].

The concept of "force majeure" is defined in accordance with paragraph 3 of Article 401 of the Civil Code of the Russian Federation. In particular, force majeure circumstances include: natural disasters (earthquake, flood, hurricane), fire, epidemics, strikes, hostilities, terrorist acts, sabotage, restrictions on traffic, prohibitive measures of states, prohibition of trade operations, including with certain countries due to the adoption of international sanctions, and other circumstances beyond the control of the parties to the agreement (contract). The epidemic of coronavirus can be attributed to force majeure circumstances, but the lack of clarity and confusion of domestic legislation does not allow this to be done unambiguously.

Today, the Russian economy is facing the most serious crisis in the past two decades. This crisis was caused by extreme measures to combat the pandemic and changes in commodity markets, leading to a significant drop in the income of the Russian economy. Measures of the governments of all countries to combat the pandemic are mandatory for society and lead to a sharp contraction in demand, a reduction in the activity of the service sector (passenger transportation, tourism, hotel, restaurant, recreational businesses). Support programs include: fiscal measures (reducing the actual tax burden), replacing shortfalls in budget revenues, maintaining the availability of lending to businesses and the population, budget support for companies and the population in order to maintain employment and effective demand. These measures will prevent the transition of the recession into depression and ensure its V-shaped development [6] .

As of early April of this year, the World Tourism Organization (UNWTO) predicted a 20-30% decrease in tourist activity in 2020, as a result of which the world economy will receive less from $ 30 billion to $ 50 billion (from 2.2

to 3.7 trillion rubles). According to UNWTO forecasts, the decrease in the number of tourists will continue in the coming years. Lost profits of the global aviation industry in 2020 compared to last year will amount to 38%, or $ 252 billion (1.9 thousand trillion rubles). Sales in the field of tourism in Russia fell to almost minimal values, according to the results of the first half of the year, the total volume of lost revenue by the Russian tourism business will be about 1.5 trillion rubles. According to estimates, there are 1,800 sanatorium-resort institutions in Russia in total, of which 700 are state-owned, the rest are private. The sharp decline in tourism industry revenues increased the risks of non-payment of wages to employees, rent and utility payments, taxes and loan repayment. More than 1.6 million people were under threat of dismissal or sending on unpaid leave. The total number of workers in the tourism industry is 2.5 million, taking into account related industries about 7 million people [11].

The onset of risk in the economic activity of a tourism organization leads to the disruption of plans, in the form of unplanned expenses, losses or a decrease in expected income [5,12]. Risk classification should be understood as the distribution of risk into specific groups according to certain criteria to achieve the set goals [9]:

- operational (violation of the internal business processes of the organization;
- environmental, (external threat of environmental degradation);
–A security risk (the threat of reducing the attractiveness of a tourist destination from a safety point of view);
- political (threat of deterioration of the political situation);
- marketing (threat of an unfavorable situation in the markets);
- economic (threat of deterioration of the economic situation);
- infrastructural, (decrease in the quality of tourism infrastructure).

There are also two main categories of risks in tourism:

1) risks that directly threaten tourists when planning and implementing a tour (tourist risks);

2) the risks of the activities of tourism enterprises from the provision of services to tourists, during the formation and promotion of the tour (economic and economic risks) [8] .

The tourism industry can have a multiplier effect on the development of other sectors of the region's national economy (agriculture, transport, construction, trade, services, etc.) and can ensure sustainable growth of the regional economy. However, it is associated with the risks of the industries entering the tourism industry, which also enhance or compress the multiplier effect, adding to the overall level of tourism risk.

The variety of tourist resources of the North Caucasus Federal District contributes to the development of various types of inbound and domestic tourism: recreational, cultural, educational, extreme, ski, business, ecological, rural, fishing and hunting.

The Government of the Russian Federation pays significant attention to the development of the region: the state program "Development of the North Caucasian Federal District for the period up to 2025 (the volume of budget allocations is 305 billion rubles)" and a number of subprograms ("Development of the tourist cluster in the North Caucasian Federal District") have been adopted.

Tasks of these subprograms: creation of conditions for attracting investments; infrastructure development; creation and promotion of local tourism products in the domestic and foreign markets; a significant increase in the tourist flow; development of industry and agriculture on the territory of the federal district. JSC "Resorts of the North Caucasus" assessed the tourist and recreational potential of the North Caucasus Federal District. The region was supposed to develop all-season tourist and recreational complexes in the following territories: (Karachay-Cherkess Republic "Arkhyz"), (Kabardino-Balkarian Republic "Elbrus") (Chechen Republic "Veduchi"), (Republic of Ingushetia "Tsori", "Armkhi »), (Republic of Dagestan – Caspian coastal cluster) [10].

It was planned that by 2025:

– 12.8 thousand jobs would be created,

– the proceeds from the sale of goods and services would reach 19.5 billion rubles.

Over the past five years, more than 2 trillion rubles have been allocated to solve social and economic problems in the region. In 2019, the subjects of the North Caucasus Federal District received 70 billion from the budget for the implementation of national projects, and 200 billion rubles for state programs. However, not all targets were met. At the same time, the values of socio-economic indicators there still lag behind the national average. Unemployment is 11%, and in the country – 4.6%. The average monthly salary is 61% of the national average [10].

In 2019, the resorts of the republics of the North Caucasus Federal District were visited by about 4 million people, the Stavropol Territory – about 1.6 million people. The ski tourism cluster will be able to accommodate up to 100

thousand vacationers at a time. Paid travel services amounted to more than 6 billion rubles, sanatorium and health services more than 3 billion rubles.

As a result of anti-epidemic measures, the regional tourism and hospitality industry (hotel business, catering enterprises, transport, cultural and entertainment services) will be seriously affected. The introduction of a self-isolation regime for Russian regions in order to reduce the spread of coronavirus in the short term will seriously affect the financial condition of the health resorts of the Caucasian Mineral Waters region, the hotel business of the all-season resorts Arkhyz, Elbrus, Veduchi and others. According to the press service of the Ministry of Tourism of the Stavropol Territory, tourist flow in the region in March 2020 fell by 34% against last year. Sanatoriums are loaded by 65%, in hotels there are fewer guests by 28%. By the Decree of the Governor of the Stavropol Territory dated 04/31/2020. No. 123, the reception and placement of citizens in collective accommodation facilities from April 31 to June 01, 2020 was restricted.

The **purpose** of our research is to qualitatively analyze the risks of the impact of economic, infrastructural, market factors on the local market of tourist and recreational services in the North Caucasus Federal District.

When analyzing risks, a qualitative analysis is carried out in order to identify risks, which includes the following tasks: identifying risks; classification and description of risks, analysis. Quantitative analysis aims at determining the size of the risk, calculating risks and assessing them.

In world practice, these methods of analysis are used to obtain the most effective analysis of risks [1,7]:

– method of reliable equivalents (reliability factors)

– method of adjusting the discount rate;

– sensitivity analysis of indicators (univariate stress test);

– scenario method (multivariate stress test);

– analysis of probable distributions;

– Monte Carlo method (simulated distribution).

Sensitivity analysis of indicators is widely used in the practice of financial management. In the general case, it boils down to the study of the dependence of a certain resulting indicator on the variation in the values of indicators involved in its determination. (analysis of "what if"). The problem is that in stressful situations, other risk factors change, if only one is considered, the measurements may be inaccurate. Hypothetical scenarios may consider worst-case outcomes when the considered risk factors have worst-case values. This method does not account for correlations between other risk factors. There are points of view on how the correlations between risk factors should change [1]:

– in stressful situations, the relationships between factors remain the same as in the norm;

– in stressful situations, the relationships between the factors change.

In the previous study, we carried out a cluster analysis of the distribution of tourist and recreational resources within the North Caucasus Federal District, which made it possible to differentiate the distribution of these resources by the subjects of the region. Critical indicators for assessing the sensitivity (competitiveness) of the region's tourism industry to changes in external factors (changes in tourist traffic) have been identified [2.3].

Methodology. The competitiveness of a territory is the basis for its stability in the case of adverse events. To accomplish this task, it is necessary to identify indicators characterizing the development of the tourist and recreational complex in the region. The indicators of regional development of the industry were calculated on the basis of primary indicators.

The sources of information are official statistical data, as well as mass media, scientific publications, sociological surveys (questionnaires, interviews), methods of expert assessments ("focus groups") and others.

Indicators can be presented in nominal or structural indexes, using content analysis, as well as comparison and grouping methods.

We have grouped the indicators into blocks that were used to determine the competitiveness of the regional tourism market and can be applied as scenario criteria [3]:

1. Socio-economic situation;

2. Business conditions;

3. Environment;

5. Infrastructure and economy of the tourism industry.

We settled on a scenario where several risk factors are subjected to stress testing, while the rest can change only in accordance with their historical values. The scenario assumes measuring the sensitivity of the regional tourism market indicators depending on changes in tourist traffic: 100% (column 1), 50% (column 2), 30% (column 3). Tourist flow of 30% from 2019 approximately coincides with the health resort contingent. Other indicators were also adjusted: pas-

senger transportation, collective accommodation facilities, sanatoriums, places and number of people. The number of scenario parameters can be minimized using correlation analysis.

Pearson's correlation coefficient indicates that either one of the two identified phenomena is a partial cause of the other, or both phenomena are a consequence of common causes. The correlation coefficient can range from –1 to +1. At the same time, a negative correlation coefficient indicates that an increase in the value of one variable corresponds to a decrease in the value of another variable correlating with it. A positive correlation coefficient indicates that an increase in one variable corresponds to an increase in another. The main hypothesis is that there is no linear feedback between variables. At p <0.05, the hypothesis is rejected. Correlation strength classification: strong: ± 0.7 to ± 1; average: ± 0.3 to ± 0.699; weak: 0 to ± 0.299.

Table 1

Indicators of the block " Socio-economic situation "

Indicators	Average per capita income population per month, rub			Level of unemployment,%			Number of doctors			Number of hospital beds			Number of crimes		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Amount of tourists	0,22	0,23	0,22	– 0,59	– 0,58	– 0,58	0,23	0,17	0,16	0,81	0,92	0,9	0,86	0,77	0,75

Indicator "Average per capita income of the population per month, rubles." Table 1 has a weak positive correlation with the number of tourists + 0.22, which reflects the irregular development of the subjects of the region and the presence of other incomes not related to the tourism industry. Despite the insignificant share of the tourism industry in the sectoral gross value added of about 3% in the federal district, the tourist flow has an average positive feedback with the indicator "GRP(Gross regional product) per capita" 0.67-0.65.

The "Level of unemployment" indicator has an average negative correlation with the number of tourists – 0.59-0.58. The decrease in tourist flow contributes to the growth of unemployment. The indicator "The number of doctors" has a weakly expressed positive feedback with the number of tourists + 0.23 to 0.16. This can be explained by the fact that not a large part of tourists go to continue their treatment, focusing on the sanatorium-resort complex. Therefore, the indicator "Number of hospital beds" has a strong positive correlation + 0.9 to 0.81. In case of exacerbation of chronic diseases and injuries, hospitalization of tourists is carried out by local health care institutions. The indicator "Number of crimes" has a strong feedback +0.86 +0.77 with the number of tourists who themselves may commit crimes and be subject to criminal acts.

Table 2

Indicators of the "Business conditions"

Indicators	GRP per capita, rubles			Fixed capital investments per capita, rubles			Share of the tourism industry in the sectoral gross value added%			Share of investments in fixed assets from the budget%		
	1	2	3	1	2	3	1	2	3	1	2	3
Amount of tourists	0,67	0,67	0,65	0,27	0,31	0,31	0,08	0,16	0,18	-0,75	-0,72	-0,72

The indicator "Fixed capital investments per capita, rubles" has an average correlation with the indicator under study. Table 2. The indicator of tourist flow has a strong negative feedback to indicator "Share of investments in fixed assets from the budget", which characterizes the significant role of the state in the development of infrastructure (-0, 75-0.72). The indicator "Share of the tourism industry in the sectoral gross value added" has a weakly expressed positive feedback with tourist flow.

Table 3

Indicators of the block "Environment"

Indicators	Atmospheric emissions from stationary sources, thousand tons			Atmospheric emissions from mobile sources, thousand tons			Discharge of waste water into surface water bodies, mln.m3			Production and consumption waste, thousand tons			Population density		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Amount of tourists	0,71	0,7	0,7	0,71	0,58	0,58	0,75	0,68	0,68	0,84	0,75	0,75	-0,78	-0,87	-0,87

Table 3 shows a strong positive feedback between the main indicators of anthropogenic load and tourist flow, the more tourists, the more pollution:

– "Atmospheric emissions from stationary sources" (+ 0.71 + 0.7);

– " Discharge of waste water into surface water bodies" (+ 0.75 + 0.68),

– "Production and consumption waste" (+ 0.84 + 0.75).

– "Atmospheric emissions from mobile sources" (0.71 + 0.58). A decrease in tourist flow has a slight effect on environmental pollution. The tourist flow has the opposite effect on the "Population density" (-0.78-0.87): in one place the population density temporarily increases, while in another it decreases.

Table 4

Indicators of the block "Infrastructure and economy of the tourism industry"

Indicators	Rail transportation, thous. passengers			Automobile (buses) transportation, thous. passengers			Air transportation, thous. passengers			Collective facilities placement, places			Collective facilities accommodation, thous. people		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Amount of tourists	0,86	0,73	0,72	0,79	0,68	0,67	0,78	0,67	0,67	0,92	0,73	0,72	0,95	0,8	0,79

In table 4, the indicators "Infrastructure and economy of the tourism industry" show a positive feedback with tourist flow. Developed transport infrastructure ("Railroad transportation" (+ 0.86 + 0.72), "Automobile transportation" (+ 0.79 + 0.67), "Air transportation" (+ 0.78 + 0.67), has a positive effect on the number of tourists. The first place in transportation is traditionally kept by railway transport, the second place – by road transport and the third place – by aviation. Road transport and aviation have a tendency to decrease to an average positive correlation. Local residents and residents of neighboring regions arrive in road transport.

Table 4.1

Indicators of the block "Infrastructure and economy of the tourism industry"

Indicators	Health resort facilities, places			Health resort facilities, accommodated thous. people			Paid travel services, thous. rubles			Health resort services, thous. rubles			Services of collective accommodation facilities, thous. rubles			Number of people, employed in the tourism industry		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Amount of tourists	0,86	0,77	0,75	0,86	0,73	0,7	0,4	0,49	0,5	0,86	0,74	0,71	0,85	0,7	0,66	0,65	0,6	0,57

The next significant group of indicators in Tables 4 and 4.1 characterizes collective accommodation facilities: hotels, camp sites, campgrounds, rest houses, boarding houses and, separately, sanatoriums. This group also shows a strong positive feedback with the number of tourists:

– "Collective accommodation facilities, places" (+ 0.92 + 0.72),

– "Collective accommodation facilities, thousands of people accommodated" (+ 0.95 + 79),

– "Health resort facilities " (+ 0.86 + 0.75),

– "Health resort facilities, thousands of people accommodated" (+ 0.86 + 0.7),

According to the indicators "Collective accommodation facilities, beds", "Collective accommodation facilities, thousands of people accommodated", the differences in the correlation coefficients can be explained by uneven loading of the bed fund. The downward trend in communication density can be traced as the tourist flow changes.

According to the indicators "Health resort institutions, beds", "Health resort institutions, accommodated thousands of people", the difference in the correlation coefficients is explained by the lower load of the bed fund.

The third group of indicators characterizes the volume of paid services and employment in the region's tourism industry. In this group, there is also a positive feedback with the number of tourists:

– "Paid travel services" (+ 0.4 + 0.5),

– "Health resort services" (+ 0.86 + 0.71),

– "Services of collective accommodation facilities" (+ 0.85 + 0.66),

– "Number of people employed in the tourism industry" (+ 0.65 + 0.57).

The growth of the "Paid tourist services" indicator with an average correlation coefficient of up to 0.5 +0.4 reflects the fact that vacationers will attend excursions and entertainment events.

The downward trend in the positive feedback of the indicators "Health resort services" from +0.86 to + 0.71 and "Services of collective accommodation facilities" from +0.85 to average + 0.66 with a change in tourist flow is characterized by a lower volume of spa and cosmetic procedures, therapeutic massage.

A decrease in the correlation of the indicator "Number of employed in the tourism industry" from +0.65 to an average of + 0.57 is also characterized by a positive feedback with tourist flow and reflects a decrease in employment and the seasonality of the provision of travel services.

Table 5

Influence of the "Business conditions" indicators on the indicators of the "Infrastructure and economy of the tourism industry"

Indicators	GRP per capita, rubles			Fixed capital investments per capita, rubles			Share of investments in fixed assets at the expense of the budget		
	1	2	3	1	2	3	1	2	3
Collective accommodation facilities, places	0,63	0,56	0,54	0,17	0,17	0,13	-0,74	-0,67	-0,63
Collective accommodation facilities, thousands of people accommodated	0,6	0,6	0,6	0,2	0,2	0,2	-0,74	-0,71	-0,68
Health resort facilities, places	0,56	0,6	0,61	0,06	0,2	0,2	-0,68	-0,67	-0,67
Health resort facilities, accommodated thous. people	0,54	0,54	0,54	0,06	0,1	0,1	-0,68	-0,67	-0,65
Health resort services, thous. rubles	0,54	0,54	0,54	0,13	0,12	0,1	-0,66	-0,66	-0,66
Services of collective accommodation facilities, thous. rubles	0,65	0,63	0,6	0,58	0,82	0,84	-0,77	-0,58	-0,55
Number of employees in the tourism industry, thous. people	0,8	0,8	0,8	0,79	0,79	0,79	-0,26	-0,41	-0,45

Our research has revealed a medium and strong feedback between "GRP per capita" and indicators of the section "Infrastructure and economy of the tourism industry". In Table 5, the indicator " Number of employees in the tourism industry " showed a strong positive feedback with the indicator "GRP per capita" +0.8, which will directly affect employment in the region as a whole.

The indicators of the block “Infrastructure and economy of the tourism industry” has a weak dependence on the indicator “Fixed capital investments per capita”, with the exception of “Services of collective accommodation facilities” and “Number of employees in the tourism industry” which showed a strong positive feedback of 0.8. The indicator “Share of investments in fixed assets at the expense of the budget” did not have an average negative impact on the indicators of the section “Infrastructure and economy of the tourism industry”. This situation is explained by the fact that most of the collective accommodation facilities and sanatoriums were built during the Soviet era and additional private investments in the 2000s did not have a significant impact on the industry. The regional tourism infrastructure still depends on public investment.

In our previous study, we carried out a cluster analysis of the subjects of the North Caucasus Federal District from the point of view of the tourism industry infrastructure using the "Ward's" method: the distance between objects was measured using the "City-Block" method. First, in both clusters, for all available observations, the average values of individual variables are calculated. Then, the squared Euclidean distances from individual observations of each cluster to that cluster mean are calculated. These distances are summed up. Then, into one new cluster those clusters that give the smallest increase in the total amount of distances are combined [2, 3].

As a result of the procedures, 2 clusters were created:

– first cluster – 28.6% (Stavropol Territory, Republic of Dagestan);

– the second cluster – 71.4% (Republic of Ingushetia, Chechen Republic, Kabardino-Balkarian Republic, Karachai-Cherkes Republic, North Ossetia);

The best results in the first cluster on the state of infrastructure and the economy of the tourism industry were shown by the Stavropol Territory and the Republic of Dagestan. The second cluster contains the rest of the regions of the North Caucasus Federal District (Ingushetia, Chechen Republic, Kabardino-Balkarian Republic, Karachai-Cherkes Republic, North Ossetia-Alania), which have similar socio-economic and infrastructural resources.

The majority of balneological resources (58%) of the recreational region of the Caucasian Mineral Waters are concentrated in the area of the Stavropol Territory, in the Karachay-Cherkess Republic – 33%, in the Kabardino-Balkarian Republic – 9%. The combination of natural factors, the geographical proximity of the Stavropol Territory with a historically developed tourist infrastructure has a significant impact on the tourism industry of the Kabardino-Balkarian Republic, Karachai-Cherkes Republic.

Results. The influence of tourist flow on the indicators of the "Socio-economic environment" block is ambiguous: the average positive feedback with "GRP per capita", which does not have a noticeable effect on the "Average per capita income of the population per month". This may be due to the insignificant share of the tourism industry in the sectoral gross value added of about 3%. At the same time, the indicator "Unemployment rate" (–0.59–0.58) shows an inverse feedback with changes in the number of tourists, ie reduction in tourist flow contributes to the growth of unemployment. All this will affect the economic situation of the single-industry towns – resorts of the Caucasian Mineral Waters group (Stavropol segment).

The amount of tourist traffic, accomodation capacity and services of sanatorium-resort institutions have a strong negative feedback to indicator "Share of investments in fixed assets from the budget", which characterizes the significant role of the budget in the development of infrastructure. As most of the health resort institutions are in departmental, trade union and municipal property.

When the tourist flow changes, there remains a negative impact on the environment (due to the use of utilities) and safety indicators (there is a likelihood of committing crimes, both by tourists and local residents against them). In connection with the economic crisis, the role of rail and road transport is increasing.

Thus, under scenarios of decreases in tourist flow from 100% to 50% and 30%, the dynamics of correlations of the studied indicators shows a non-critical dynamics of weakening the tightness of connection. Probably, there are hidden nonlinear dependencies of the studied indicators. The stress test showed a certain margin of safety for the health resort complex of the Caucasian Mineral Waters region (with a time lag): 30% of the tourist flow roughly corresponds to the contingent of health resort institutions, i.e. major consumers of medical and recreational services. Government support is needed to maintain the foundation of the recreational industry. Of the 124 sanatoriums in the Stavropol Territory, only 16% are privately owned. It is necessary to ensure the fulfillment of all the tasks set in the subprogram "Development of the tourist cluster in the North Caucasus Federal District."

Local authorities offer a standard set of support measures that partially cover the conditionally fixed costs: property tax benefits (up to 1%), land tax benefits, government guarantees for obtaining interest-free loans, and lease payments deferral. It is necessary to further stimulate the demand for Health resort and recreational services through the development of domestic tourism, the provision of preferential vouchers to the population at the expense of social funds, and subsidies for travel to the vacation spot.

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АНАЛИЗ ОТКРЫТОГО БЛОКЧЕЙНА В РАМКАХ КОМПЛЕКСНОЙ КЛАССИФИКАЦИИ ТЕХНОЛОГИИ РАСПРЕДЕЛЕННОГО РЕЕСТРА

ANALYSIS OF PUBLIC BLOCKCHAIN UNDER THE COMPLEX CLASSIFICATION OF SHARED LEDGER TECHNOLOGY

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Аннотация. *В статье ставится задача произвести анализ открытого блокчейна в рамках предложенной автором комплексной классификации технологии распределенного реестра. В ходе решения указанной задачи автор определяет ключевые свойства, присущие публичным блокчейнам, описывает характерные открытым реестрам алгоритмы консенсуса, а также определяет основные достоинства и недостатки таких систем. В заключении предложены рекомендуемые области применения открытых распределенных реестров.*

Ключевые слова: блокчейн, распределенный реестр, прозрачность, логистика, децентрализация, криптовалюта, биткоин, цифровизация.

Abstract. *The object of the article is an analysis of public blockchain under the complex classification of* shared *ledger technology suggested by the author. The author defines the key properties of the public blockchains, the consensus algorithms and he finally determines the advantages and disadvantages of the open shared ledgers in the course of task performance. The recommended fields of application are suggested in the conclusion.*

Key words: blockchain, shared ledger, transparency, logistics, decentralization, cryptocurrency, bitcoin, digitization.

Introduction. According to the complex classification of the shared ledger technology proposed by the author, there are four types of blockchain systems, each of which has unique properties (Fig. 1). An important role in the process of data transmission and storage is played by public blockchains, which ensured the successful integration of shared ledger technology into modern business processes.

Materials and methods, results and discussions. Currently, there are public & open blockchains, which have the most free level of access and provide users with ample opportunities for organizing operations performed within the network, and public & closed blockchains, where, with free access, user rights are limited by solving some of the problems of open blockchain systems.

Public & open blockchains are immutable, pseudo-anonymous (or anonymous), and decentralized systems. This means that anyone can become part of the network and take part in the consensus process. These systems have the properties of resistance to censorship and protection of transactions from retrospective changes, which makes it possible to ensure the reliability of the content of the blockchain even in the absence of trust between the participating objects. In addition, thanks to the public access to the platform, all processes occurring within the network are completely transparent.

The main advantage of public & open blockchains is an increased level of system security due to the use of the Proof-of-Work consensus algorithm. Thus, the process of confirming transactions when using the specified algorithm is as follows[32]: miners (persons who verify and confirm user transactions) observe the transactions broadcast to the network and add them to their pool. Due to the large number of unconfirmed transactions and the limited block size[33], miners are forced to select the most priority ones, primarily focusing on the size of the commission offered by the user for adding to the block. As soon as the transactions are collected, the computing power of all miners automatically starts

[32] On an example of the Bitcoin blockchain

[33] Each block in the Bitcoin blockchain has a size limit of 1 megabyte to protect the blockchain from malicious attempts to disable the blockchain using DDos attacks.

performing the most complex mathematical tasks in order to determine the hash value of the new block.[34] First of all, the validity of each transaction of the block is checked for the presence of the funds specified for the transfer by the senders, after which a "Merkle tree" is formed with correct transactions. To build a "Merkle tree", each transaction located in the miner's pool is hashed. The resulting hash values are then combined in pairs and re-hashed. This algorithm runs until the resulting hash value is determined, also known as the "Merkle root" (Figure 2).

public & open blockchain	**public & closed blockchain**
• Anyone can join • Anyone can read, write and confirm transactions • Hosted on public servers • Low scalability	• Anyone can join • Anyone can read • Only authorized participants can write and confirm transactions • Medium scalability
privite& open blockchain	**privite & closed blockchain**
• Only authorized participants can join • Only authorized members can read and write • Hosted on private servers • High scalability	• Only authorized participants can join • Only authorized members can read • Only the network operator can write and confirm transactions • Very high scalability

Fig. 1. Types of blockchain networks

The next piece of mathematical calculations is the process of finding a nonce – a random number given by the system. In connection with security issues, the blockchain automatically sets the complexity of the cryptographic task of finding a hash in such a way that the average time to determine it is 10 minutes. For example, the system can set the following condition: the hash function of the new block must start with three zeros in a row. Depending on the set complexity, the number of zeros at the beginning of the function can vary in different directions.

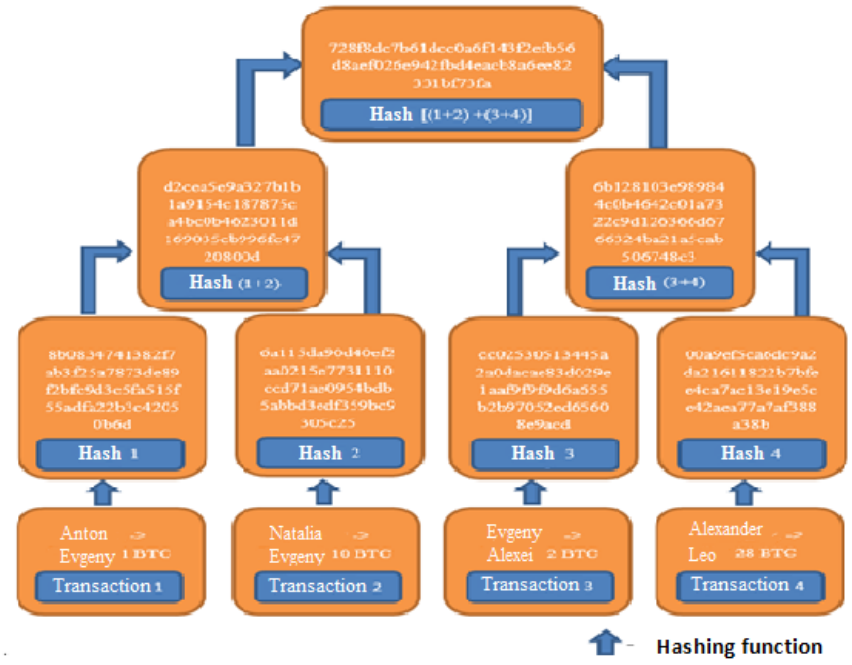

Fig. 2. "Merkle tree" in the presence of 4 transactions in the block

[34] Hashing is the process of converting input information into a fixed-length encrypted code. Accordingly, the hash value is information contained in a block, encrypted with the SHA-256 cryptographic function in order to be able to determine the integrity of the information and uniquely identify the specified block.

The nonce search process does not have a mathematical algorithm, therefore, it is performed by iterating over the values. The *miner*, whose computer power is the first to detect the specified *nonce* and determine the hash function of the new block, automatically sends the received response to all network nodes in order to confirm the work done. Thus, the generated block joins the existing blockchain, and *miners* proceed to create the next block [1]. The blockchain structure in the blockchain is shown in Figure 3

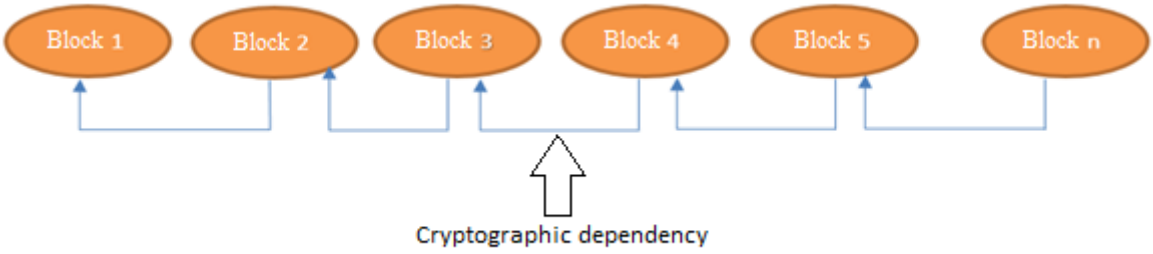

Fig. 3. Block sequence in the blockchain

Each subsequent block in the shared ledger is cryptographically linked to the previous block, thus creating a secure chain. If an attacker tries to change the transaction data contained in a block (for example, the amount of money transfer), the cryptographic relationship of the specified block with the rest of the chain will be broken, which will lead to the sequential destruction of all further blocks (Fig. 4)

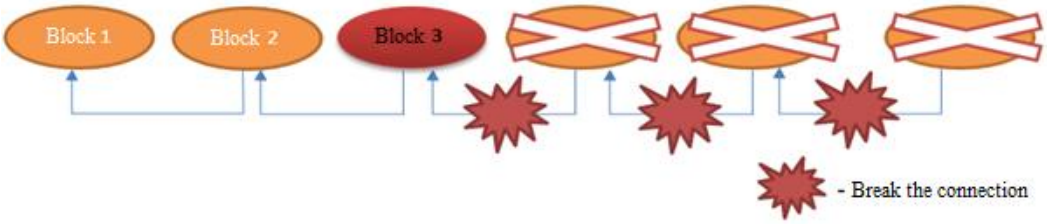

Fig. 4. An attempt to change the data in block 3

It should be mentioned that the blockchain has a "long chain" rule. Namely, the chain of blocks, which is the longest, is taken as the only correct version of the existing system, and, accordingly, all further generated blocks will be added to this chain. Thus, in order for the community to recognize the changes of the attackers as true, the attackers need to determine the hash values of all subsequent blocks and continue creating new blocks in their chain faster than all the miners of the network working in the original version of the blockchain will do (Figure 5).

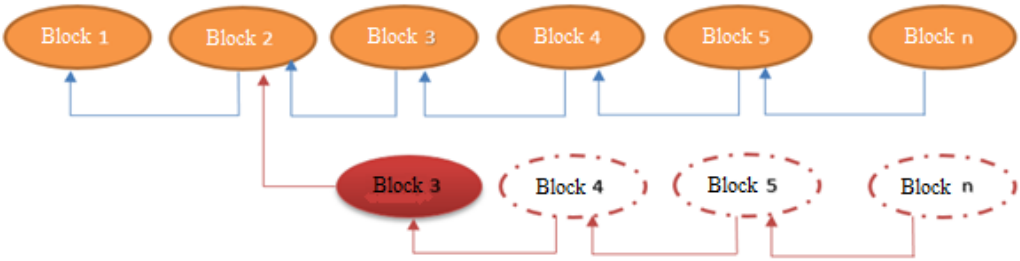

Fig. 5. Creation of an alternative chain as a result of the attack on block 3[35]

This task is practically impossible due to the need for more than 50% of all existing computer power in the hands of attackers. Even if the specified condition is met, such an attack would be inappropriate due to the high monetary costs associated with increased power consumption in the mining process. In addition to financial costs, there are significant time costs. The older the transaction, the more computing it will take to successfully attack it. A

[35] In fact, one block can contain not 4, but 4000 transactions.

transaction with an age of 1 year will require an attacker about 1 year of computation, provided that the attacker's hash[36] rate is twice the hash rate of all other *miners*. Thus, this algorithm successfully ensures the security of the system. The disadvantages of the proof-of-work consensus algorithm include low bandwidth. Due to the need to confirm all transactions by each node in the network, scalability problems arise for such blockchains. Thus, the throughput of the Bitcoin blockchain is 7 transactions per second, while the Visa payment system processes up to 24,000 transactions per second[37] [3]. There is also a problem of increased power consumption arising from the need to perform computer calculations to confirm transactions and reach consensus. According to a report by the British agency *PowerCompare*, the total amount of electricity spent on mining exceeds the energy consumption of 159 countries around the world. Every year, as a result of the mining process in Russia, 1.065 trillion. kW / year, which negatively affects the country's ecology [4].

In addition to enhanced security, public & open blockchains offer no infrastructure costs to build and run decentralized applications (dApps). Such systems are completely open and transparent for all network participants, and transactions in them are unchanged. Confirmed transactions are replicated to each participating node, while consensus takes care of validating and synchronizing them, allowing users to transact with trust in the system. Although transactions can be read by anyone, user identities are protected to ensure their anonymity. Among the main disadvantages of an public & open blockchain, the following properties should be highlighted:

1) Limited scalability (there is a limit on the number of transactions that can be created during periods of increased network load).

2) Slowness (consensus is reached only on condition that each network node has completed the task – a smart contract or transaction verification. Due to the large number of nodes, the task processing time increases).

3) High cost (as the number of transactions increases, the cost of executing these transactions increases).

4) dentity data (anonymous participants can be intruders)

5) Immutability (although the immutability of transactions is an advantage of the public blockchain, it is at the same time its disadvantage. The blockchain considers a smart contract as a transaction. Any error inherent in the conditions of a smart contract cannot be corrected. Before creating a smart contract, programmable conditions must be carefully checked and tested before deployment).

6) Possibility of carrying out "51% attack"

7) Chance of centralization (to realize the benefits of public blockchains, standard nodes operate as full nodes. Full nodes are participants holding a complete copy of the blockchain. As the blockchain network grows in size, it becomes costly for small players and individual nodes to operate in only large players will be able to function as full nodes, which could lead to network centralization).

Public & closed blockchains, like open ones, are anonymous (pseudo-anonymous) immutable systems. Anyone can join the network by gaining access to read the available information, however, unlike open blockchains, the functions of confirming transactions lie with authorized users. Public Exclusive Shared Systems are intended for cases where certain people or authorities (for example, a designated employee or institution) confirm transactions that contain data that is available to the public for viewing. Public exclusive blockchains should not rely on such expensive consensus algorithms as Proof-of-Work, in the absence of the need to validate transactions by all network nodes. The most common consensus algorithm on an public & closed blockchain is Proof-of-Stake. The key feature of this algorithm is the absence of a mining process, and, accordingly, a large number of mathematical calculations that consume significant energy. People who confirm new transactions and create new blocks are called validators, and the process of confirming transactions is called *minting* (or *forging*). If in the Proof-of-Work algorithm the probability of successful mining depended on the presence of a large amount of computer power, then in Proof-of-Stake the cryptocurrency coin of this blockchain acts as the “weight” of the node's vote. Simply put, in order to become a validator, it is necessary to deposit a certain proportion of coins into the specified blockchain. Each holder of the cryptocurrency will receive interest for storage (analogous to a deposit in a bank) and will be able to confirm transactions. The higher the balance of the validator, the higher the probability of block generation. For example, Figure 6 shows four validators with token shares equal to 50, 30, 5 and 15%, respectively. Since validator № 1 has the most coins, he has a higher chance of signing a block than the rest. The determination of the user who signs the block is

[36] Hashrate - the number of attempts per second to find the correct nonce value [2]

[37] It should be noted that scientists are actively working on solving the problem by introducing «sharding» и «lightningnetwork» technologies into the blockchain, but the final results have not yet been presented.

carried out according to the theory of probability, where the chance of signing the block is directly proportional to the number of coins deposited by the user.

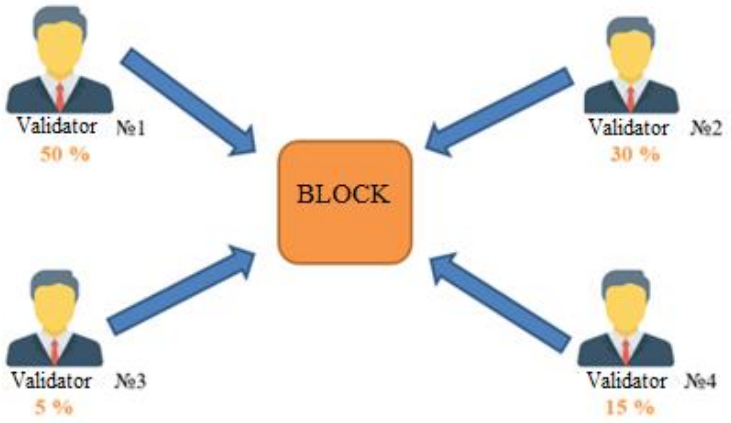

Fig. 6. The process of making consensus using the Proof-of-Stake algorithm

The Proof-of-stake algorithm is one of the most accessible types of consensus, that is, it has a low "entry threshold" due to the absence of the need to purchase expensive mining equipment. All you need for *forging* is a computer and a selected cryptocurrency. This algorithm solves the "environmental issue", which consists in increased energy consumption due to the most complex calculations. When using the consensus proof of ownership stake, the problem of the "arms race" inherent in the Proof-of-Work algorithm disappears, due to the direct dependence of the user's hashrate on the number of coins in the wallets of stakeholders, and not on computer power. It should be noted that the system is secure at the same time. So, to carry out a 51% attack, an attacker must acquire more than 50% of tokens and deposit them into the attacked blockchain. Thus, such attacks become financially impractical. As a result of an imbalance in the network and the stability of the attacked currency, the attacker will suffer himself.

The main disadvantage of the algorithm is the tendency towards centralization. Consensus encourages stakeholders to accumulate and retain funds on the balance sheet of the network, which contradicts the principles of decentralization originally laid down in the public blockchain.

Public exclusive blockchains retain the key advantages of open blockchains, such as the absence of the need for infrastructure costs to create and run decentralized applications (dApps), network transparency and immutability of transactions, and also solve the problem of low scalability by increasing the network bandwidth arising from the use of proof-of-stake consensus algorithm. However, such networks are less open and not fully decentralized. In addition, the disadvantages inherent in public open networks, such as immutability, the possibility of a 51% attack, identity and the chance of centralization, are also common to public & closed blockchains.

Conclusion. In conclusion, it should be noted the high importance of public blockchains in the modern world. A theoretical analysis of the existing literature shows that issues related to shared ledger technology have not been adequately studied. Thus, the results of this analysis allow us to draw conclusions that are of interest for research in the field of shared ledgers. First of all, the high importance of the proposed classification of blockchain systems into four categories is noted, each of which has a unique set of properties characteristic of a specific type of network. In the presented article, within the framework of a comprehensive classification, the category of public blockchains is separately distinguished. As a result of the analysis, the technical aspects of public shared ledgers are considered, where special attention is paid to consensus algorithms inherent in the category of public blockchains. In addition to technical aspects, the key advantages and disadvantages of such systems have been formed, which makes it possible to determine the possibilities of the practical use of shared ledger technology in various fields of activity. Thus, due to the transparency and immutability of the transactions made, the key properties of public blockchains, these categories find their application in the field of cryptocurrency circulation, electronic elections, copyright, as well as information management and audit.

However, the peculiarities of public blockchains impede the use of public shared networks in the field of commercial activities, and in particular in the field of transport and logistics services due to the need to provide free access to corporate information of the participating companies. In addition to confidentiality, public blockchains have scalability limitations that prevent the successful use of open ledgers in the freight and commercial space. To solve these problems, one should pay attention to closed blockchains, which are allocated as an element of further scientific research of shared ledger technology.

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рисунки должны читаться отдельно от текста, поэтому оси должны иметь название и единицы измерения;

рисунки нумеруются снизу (Рисунок 1 – Название) и выполняются в графическом редакторе **10 кеглем** (шрифтом).

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