Специфічні показники споживання теплової та електричної енергії на одиницю виробництва продуктів харчування характеризуються об'єктно-орієнтованими властивостями, оскільки вони визначаються на основі методів, що підходять лише для конкретного підприємства. Показано, що системний підхід є основним підходом до підвищення ефективності і надійності електрообладнання.

Запропонована концепція підвищення ефективності використання електротехнічного обладнання харчових виробництв за рахунок оптимізації машинного часу. Розроблено методи оптимізації машинного часу для використання обладнання з використанням ресурсо-процесного підходу. Практично доведено, що, комбінуючи послідовні діаграми Ганта по осі часу справа наліво, можна значно скоротити машинний час для передачі сировини. Завдяки ресурсно-процесній оптимізації стало можливим значно скоротити час виконання частини технологічного завдання. Така методика повинна застосовуватися окремо для всіх технологічних одиниць, які є споживачами або джерелами сировини, після чого повинна створюватися інтегрована математична модель з подальшою її оптимізацією.

В результаті апробації запропонованого способу отримано економію енергії шляхом оптимізації часу використання електрообладнання хлібопекарського підприємства. Встановлено, що завдяки зменшенню значного загального холостого ходу електродвигунів, нецільового нагрівання, охолодження печей і роботи компресора, підвищується ефективність використання електроенергії в харчовому виробництві

Ключові слова: електротехнічне обладнання, діаграма Ганта, ресурсно-процесний підхід, машинний час, асортиментне завдання

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DEVELOPMENT OF A RESOURCE-PROCESS APPROACH TO INCREASING THE EFFICIENCY OF ELECTRICAL EQUIPMENT FOR FOOD PRODUCTION

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1. Introduction

Technological complexes (TC) have a complicated structure and consist of a large number of interconnected machines, which are combined through material, informational, thermal and energy flows into sections, workshops and manufactures [1].

The food industry is one of the leading sectors of the agro-industrial complex, which is faced with the tasks of increasing production efficiency, improving product quality and introducing resource-efficient technologies. The functioning of food production enterprises is determined by the efficiency of the electrical complex: electrical equipment, control systems. In connection with the continuous growth of the capabilities of automated control systems, the urgent task is an integrated approach to ensuring the necessary efficiency of the functioning of electrical complexes of food production.

It is possible to solve this problem through the use of modern intelligent production process control systems with simultaneous monitoring of the condition, the need for maintenance and repair of electrical equipment. For this, it is necessary to determine a system of indicators that take into account all aspects of the functioning of electrical complexes of food production. Obviously, the system of indicators should take into account not only economic factors, but also the level of operation and management of equipment. A systematic approach is the main approach to increasing the efficiency and reliability of electrical equipment and depends on the support of technological operating modes and the compliance of technical characteristics of the equipment with the conditions of its operation.

2. Literature review and problem statement

As a result of rapid technological development, traditional systems of automation and standard methods of production (compliance with the technological regulations, reducing intermediate losses through modernization of the production facility, process coordination of the adjacent areas [2]) are not sufficient as the means of receiving high profits. Managers of industrial enterprises are likely to introduce intelligent systems at their production sites [3], which are based on various modern methods and technologies [4–6]. The most popular among them are the use of robust [7, 8], multidimensional optimal regulators [9], diagnostics [10], neural networks [11], fuzzy logic, scenario-target approach [12, 13] and others. However, the use of all the mentioned methods is becoming increasingly insufficient with the aim of ensuring high production efficiency and equipment utilization.

All the alternatives of electricity consumption result in inevitable losses, which are associated with the transportation and transformation of energy resources. In addition, useful work is achieved through preparatory, auxiliary and basic process operations. The violation of process regimes, improper maintenance of electrical equipment as well as renewal failure of the fixed production assets become sources of the other losses [14, 15]: excessive and inexpedient electric power consumption.

The relative factors of heat and electric power consumption per food production facility unit are determined on the basis of the methods that are suitable only for a particular enterprise, meaning, they bear object-oriented characteristics.

The most informative and most suitable for practical application are the methods based on scientific approaches, where the norm of electric power consumption is determined by the following formula, J – energy volume/unit of production [16]:

$$\varepsilon = Q/M, \tag{1}$$

where Q stands for electric power consumption; M stands for quantity (weight) of products.

According to the technical approach to improving electric power supply, the activities are divided into two categories [17]:

– the first category reserves are related to the elimination of irrational electric power consumption. The main reasons of which are as follows;

– direct energy source losses;

– excessive heat loss due to radiation and heat conductivity;

– losses due to over- or undervalued transformers power;

– worn technological and electrical equipment;

– violation of electric power supply modes;

– violation of operating modes, electrical equipment operation regulations and rules;

– measures of the second category are related to the improvement of existing and introduction of new electrotechnology and auxiliary equipment.

It is obvious that the implementation of the first category measures depends on the enterprises personnel potential, while the second category measures, which are aimed at saving electric power, need involving third-party organizations [18, 19].

Thus, the system approach proves to be principal for increasing the efficiency and reliability of the electrotechnology equipment operation. Solving individual tasks, selected from the set of measures aimed at improving the operation of electrotechnology equipment, is not associated with any significant electric power savings. Consequently, it is possible to highlight the following ways of improving energy efficiency:

1. Consolidating technological industrial units and increasing the equipment capacity [1, 2]. Despite the overall increase in electric power consumption, an advanced increase in the production of useful products generally reduces the specific electric power consumption. The unit growth of industrial plants allows the reduction of specific losses due to both idling and operating modes per unit of production. Consequently, electric power consumption due to the maintenance of auxiliary power equipment is drastically reduced: water and air supply facilities, loading and unloading, gas outlet facilities, facilities related to cleaning and utilization of secondary heat, etc.

2. Increasing the efficiency of heat energy utilization by means of intensifying the work of technological consumers, which allows reducing electric power consumption dramatically by means of reducing the length of the production process, taking into account the application of higher technological parameters.

3. The aim and objectives of the study

The aim of the study is to increase the efficiency of the use of electrical equipment of food production through the use of a resource-process approach.

To achieve the goal, the following objectives were formed:

– A study of existing measures to improve energy supply. Development of a concept to increase the efficiency of the use of electrical equipment of food production by optimizing the machine time for the implementation of the assortment task.

– Development of models and methods for optimizing machine time for the transfer of raw materials, depending on the number of raw materials transfer sources and end users.

– Testing the proposed concept of increasing the efficiency of using electrical equipment on the example of a real object.

4. Development of a concept to increase the efficiency of the use of electrical equipment of food production

Food industry enterprises operate on the basis of targeted assortment plans for processing products and production capacities of the enterprise, usually for a day or a shift, in accordance with the specifics (Fig. 1). Therefore, the methodological implementation of the resource-process approach at such enterprises is quite acceptable. It is necessary to determine ways to increase the efficiency of equipment use by optimizing the machine time of its operation, taking into account the technological features of enterprises.

It is obvious that the electrotechnical complex of a food production facility is a distributed network, in terms of providing the enterprise production capacity [20]. In this distributed network, the raw materials are gradually transformed into semifinished products as a result of power resources utilization, and at the final stage – into the finished product. This creates the preconditions for using a resource-process approach to minimizing the production tasks implementation machine-time [21]. Machine time refers to the period of time during, which the equipment (plant, unit, apparatus) makes a change in condition, size or shape of a product or semifinished product without any direct involvement of a human.

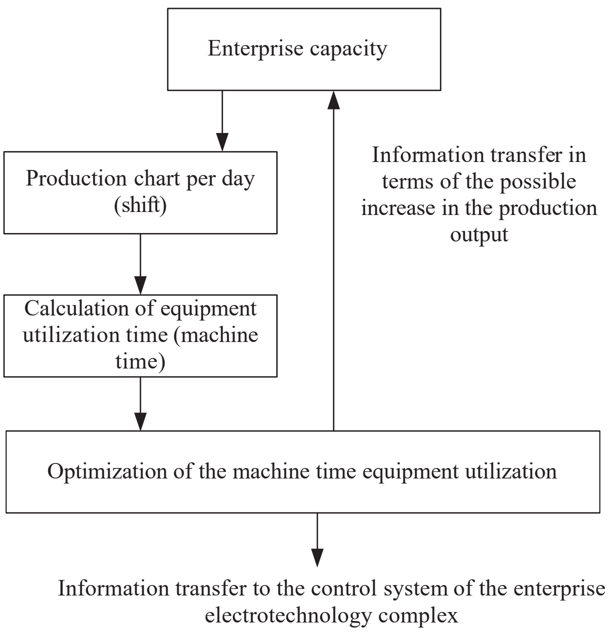

Fig. 1. The concept of increasing the efficiency of the electrotechnical equipment of food production facilities by means of machine time optimization

Additionally, this approach allows determining the influence of the cost of electricity, within different tariff zones, on the end product production cost.

Let us assume that the mathematical model of an electrotechnology complex being a distributed network includes the following:

– $n\geq 2$ – the sources number of the raw materials (semifinished products) of distributed transfer;

– $p\geq 2$ – the number of raw materials (semifinished products) ultimate consumers;

– $s\geq 2$ – the number of the structured competing flows of raw materials (semifinished products) portions (blocks) from sources;

– $T=[t_{ij}]$, $i=\overline{1,n}$, $j=\overline{1,s}$ – the time period matrix for the transmission of raw materials (semifinished products) by the i source from the j electric power price range;

– $C=[c_{ij}]_{n\times s}$ – the unit of electric power cost matrix from the j price range generated by the i source;

– $\varepsilon>0$ – the parameter characterizing the system time, which is spent on the organization of electric power parallel transfer from n and p sources to ultimate consumers.

We will assume that the interaction of competing sources of raw materials (semifinished products) with ultimate consumers is subject to the following conditions:

1) none of the sources can supply electric power to more than one consumer at a time;

2) none of the ultimate consumers can simultaneously receive more than one portion of electric power from distributed generation sources;

3) each portion of electric power is transmitted (received) without interruptions;

4) the distribution of electric power portions from distributed generation sources to ultimate consumers is carried out by the computer system repeatedly in accordance with the following rule: the block with the number $j=kp+i$, $j=\overline{1,s}$, $i=\overline{1,p}$, $k\geq 0$ is transmitted to the consumer with the number i;

5) there are no interruptions in the electricity supply to ultimate consumers or downtime periods in the electricity transmission upon the availability of ultimate consumers;

6) for each of the n distributed generation sources, the moment of completion of the j portion electric power transmission to the i ultimate consumer coincides with the moment of transmission start of the next $(j+1)$ portion to the $(j+1)$ ultimate consumer, $i=\overline{1,p-1}$, $j=\overline{1,s-1}$;

7) for each ultimate consumer, the moment of completion of receiving the electric power portion from the l source coincides with the moment of the electric power transmission start from the $(l+1)$ source of distributed generation, $l=\overline{1,n-1}$.

If we add conditions 6 and 7 in turn to conditions 1 and 4, respectively, we will obtain two basic synchronous modes of the electrotechnology complex network operation of food industry facilities.

The first synchronous mode, defined by conditions 1–4, 6, ensures continuous transmission to ultimate consumers by all distributed sources. The second synchronous mode, defined by conditions 1–4, 7, ensures continuous reception by all ultimate consumers from the sources.

5. Development of models and methods for optimizing the total transfer time of raw materials

Let us consider the second synchronous mode of interaction between the sources and ultimate consumers, which provides a continuous receipt of raw materials (semifinished products) by all ultimate consumers.

We will consider $n\geq 2$ heterogeneous distributed sources, which compete for the electric power transmission to $n\geq 2$ ultimate consumers, with the transmission of raw materials (semifinished products) being carried out in blocks $Q_1, Q_2,..., Q_s$. The task is to find the minimum total time of $T_n^2(p,n,s,\varepsilon)$ transmission of raw materials (semifinished products) to consumers under the conditions of their continuous supply by electric power. Let us consider the following cases:

a) When the number of blocks of raw materials (semifinished products) of structured flows is equal to the number of ultimate consumers, that is $s=p$. In order to find the value of $T_n^2(p,n,s,\varepsilon)$ we obtain the formula:

$$T_n^2(p,n,s,\varepsilon)=\sum_{j=1}^{p-1}\max_{1\leq v\leq n}\left[\sum_{i=1}^{v}t_{ij}^{\varepsilon}-\sum_{i=1}^{v-1}t_{i,j+1}^{\varepsilon}\right]+\sum_{i=1}^{n}t_{ip}^{\varepsilon}, \qquad (2)$$

where $T^{\varepsilon}=\left[t_{ij}^{\varepsilon}\right]$ – $n\times s$ is the time period matrix of the blocks of raw materials (semifinished products) transmission by the i source from the j electric power price range, taking into account ε overhead costs.

The values:

$$\max_{1\leq v\leq n}\left[\sum_{i=1}^{v}t_{ij}^{\varepsilon}-\sum_{i=1}^{v-1}t_{i,j+1}^{\varepsilon}\right],\quad j=\overline{1,p-1},$$

determine the moments of the transmission start of raw materials (semifinished products) to consumers by the sources, commencing from the second, and $\sum_{i=1}^{n} t_{ip}^{\varepsilon}$ is the time of supplying raw materials (semifinished products) to the last p consumer by all the sources.

b) Let us consider the case when the number of ultimate consumers of the system is bigger than the number of blocks of raw materials (semifinished products) of structured flows ($s<p$). In this case, we will split the plurality of consumers $k+1$ into groups of s consumers in each, that is $p=ks+r$, if p is not divisible by s, then the last group will contain only r consumers. The resulting matrix RM of transmission deadlines to ultimate consumers by the sources will consist of $k+1$ T^{ε} matrices, while the matrices will contain only r first columns:

$$RM=\left[t_{ij}^{\varepsilon}\right]_{n\times p}=$$

$$=\begin{bmatrix} t_{11}^{\varepsilon} & t_{12}^{\varepsilon} & \dots & t_{1s}^{\varepsilon} & t_{11}^{\varepsilon} & t_{12}^{\varepsilon} & \dots & t_{1s}^{\varepsilon} & \dots & t_{11}^{\varepsilon} & t_{12}^{\varepsilon} & \dots & t_{1r}^{\varepsilon} \\ t_{21}^{\varepsilon} & t_{22}^{\varepsilon} & \dots & t_{2s}^{\varepsilon} & t_{21}^{\varepsilon} & t_{22}^{\varepsilon} & \dots & t_{2s}^{\varepsilon} & \dots & t_{21}^{\varepsilon} & t_{22}^{\varepsilon} & \dots & t_{2r}^{\varepsilon} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ t_{n1}^{\varepsilon} & t_{n2}^{\varepsilon} & \dots & t_{ns}^{\varepsilon} & t_{n1}^{\varepsilon} & t_{n2}^{\varepsilon} & \dots & t_{ns}^{\varepsilon} & \dots & t_{n1}^{\varepsilon} & t_{n2}^{\varepsilon} & \dots & t_{nr}^{\varepsilon} \end{bmatrix}.$$

Taking into account the formula (2), the n minimum total time for supplying the alternative electric power sources p to ultimate consumers under the condition $s<p$ will be determined from the following formula:

$$T_H^2\left(p=ks+r,n,s,\varepsilon\right)=$$
$$=kT_H^2\left(s,n,s,\varepsilon\right)+kT_H^2\left(1,n,1,\varepsilon\right)+T_H^2\left(r,n,r,\varepsilon\right), \quad (3)$$

where

$$T_H^2\left(s,n,s,\varepsilon\right)=\sum_{j=1}^{s-1}\max_{1\le v\le n}\left[\sum_{i=1}^{v}t_{ij}^{\varepsilon}-\sum_{i=1}^{v-1}t_{i,j+1}^{\varepsilon}\right],$$

$$T_H^2\left(1,n,1,\varepsilon\right)=\max_{1\le v\le n}\left[\sum_{i=1}^{v}t_{is}^{\varepsilon}-\sum_{i=1}^{v-1}t_{i1}^{\varepsilon}\right],$$

$$T_H^2\left(r,n,r,\varepsilon\right)=\sum_{j=1}^{r-1}\max_{1\le v\le n}\left[\sum_{i=1}^{v}t_{ij}^{\varepsilon}-\sum_{i=1}^{v-1}t_{i,j+1}^{\varepsilon}\right]+\sum_{i=1}^{n}t_{ir}^{\varepsilon}. \quad (4)$$

c) Assuming the number of blocks of raw materials (semifinished products) of structured competing flows $s\ge2$ exceeds the number of ultimate consumers $p\ge2$, being limited ($s>p$). In this case, we will split the plurality of blocks into $k+1$ group of p blocks in each, except for the last group, which, if p is not divisible by s, will contain r blocks: $s=kp+r$, $k\gtrsim1$, $1\lesssim r<p$. This is equivalent to the division of the original time matrix of raw materials (semifinished products) transmission by the i source from the j electric power price range, taking into account system consumption $\varepsilon>0$, $T^{\varepsilon}=\left[t_{ij}^{\varepsilon}\right]$, $i=\overline{1,n}$, $j=\overline{1,s}$ on the $k+1$ submatrix containing p columns in each, and the submatrix by $k+1$ times, when s is not divisible by p, will contain r columns.

6. Results of optimization of the transfer time of raw materials

The proposed approach was tested at the bakery in the dough preparation department. Let us consider a separate case when p is divisible by s, that is $s=kp$, $k>1$. Given the fact that the number of blocks is k times bigger than the number of consumers, we will split the plurality of blocks into k groups with p blocks in each. Consequently, the original time period matrix for the transmission of raw materials (semifinished products) T^{ε} will be split into k sub-matrices with p columns in each. The interaction of the competing sources of raw materials (semifinished products) of distributed generation with ultimate consumers, taking into account the periods of transmission for the l group, $l=\overline{1,k}$, can be represented as linear Gantt charts.

Thus, assuming that for 3 nodes of dough kneading 4 kinds of ingredients are supplied in portions of 9, we get nonaligned Gantt charts (Fig. 2) for the following case: $T_n^2\left(p,n,s,\varepsilon\right)$. Production parameters for the use of the resource-process mathematical apparatus at the bakery – kneading unit. The volume of loading in one unit is 200 liters.

$$T^{\varepsilon}=\left[t_{ij}^{\varepsilon}\right]_{4\times9}=\begin{bmatrix} t_{11}^{\varepsilon} & t_{12}^{\varepsilon} & \dots & t_{19}^{\varepsilon} \\ t_{21}^{\varepsilon} & t_{22}^{\varepsilon} & \dots & t_{29}^{\varepsilon} \\ t_{31}^{\varepsilon} & t_{32}^{\varepsilon} & \dots & t_{39}^{\varepsilon} \\ t_{41}^{\varepsilon} & t_{42}^{\varepsilon} & \dots & t_{49}^{\varepsilon} \end{bmatrix}=$$

$$=\begin{bmatrix} 3 & 1 & 2 & 1 & 1 & 3 & 2 & 3 & 1 \\ 2 & 3 & 1 & 3 & 2 & 1 & 4 & 2 & 2 \\ 4 & 2 & 1 & 1 & 3 & 2 & 3 & 1 & 2 \\ 1 & 1 & 2 & 2 & 2 & 1 & 2 & 1 & 1 \end{bmatrix}.$$

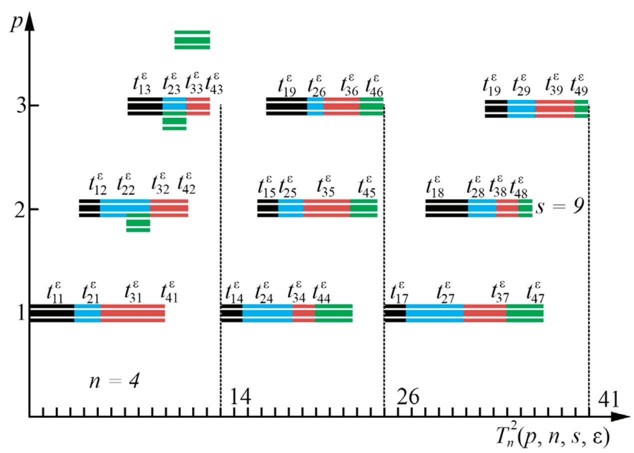

Fig. 2. Nonaligned Gantt chart

Then the machine time of raw materials transmission: $T_n^2\left(p=3,n=4,s=9,\varepsilon\right)=41$ can be reduced (Table 1) significantly if we use the method of alignment of successive Gantt charts along the time axis from right to left (Fig. 3).

Table 1

Comprehensive indicators of the total machine time of operation of the kneading unit in the production of wheat bread (timed at the enterprise for the same type of product in assortment and volume)

Direct kneading time, full machine time	Inter-operational time (inter-unit transportation, temporary pause), total machine time	Total batch operation time, total machine time
Before using the resource-process approach		
28	13	41
After the implementation of the resource-process approach		
28	5	33

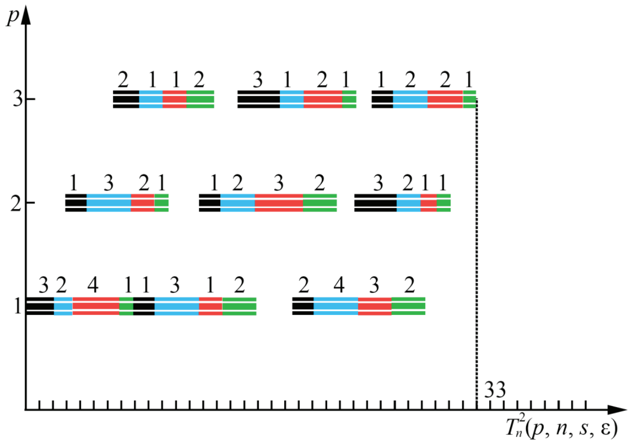

Fig. 3. Aligned Gantt chart

Hereafter we will need the following notations:

– $t_{ij}^{\varepsilon,l} = t_{ij}^{l} + \varepsilon = t_{i,(l-1)p+j} + \varepsilon$ – time period for the transmission of a raw material portion from the j range by the i source in the l group of blocks with account of the parameter ε, $i = \overline{1,n}$, $j = \overline{1,s}$, $l = \overline{1,k}$;

– T_l^{ε} – the total time for the transmission of the l group of raw material blocks p to consumers by all the sources $l = \overline{1,k}$;

– $E_{ij}^{\varepsilon,l}$ – the completion time of the transmission of the j block by the i source in the l group of blocks, $l = \overline{1,k}$.

On the basis of formula (2) for calculating T_l^{ε} and $E_{ij}^{\varepsilon,l}$ we get the following formula:

$$T_l^{\varepsilon} = \sum_{j=1}^{p-1} \max_{1 \le v \le n} \left[\sum_{i=1}^{v} t_{ij}^{\varepsilon,l} - \sum_{i=1}^{v-1} t_{i,j+1}^{\varepsilon,l} \right] + \sum_{i=1}^{n} t_{ip}^{\varepsilon,l}, \qquad (5)$$

$$E_{ij}^{\varepsilon,l} = \sum_{w=1}^{j-1} \max_{1 \le v \le n} \left[\sum_{q=1}^{v} t_{qw}^{\varepsilon,l} - \sum_{q=1}^{v-1} t_{q,w+1}^{\varepsilon,l} \right] + \sum_{q=1}^{i} t_{qj}^{\varepsilon,l},$$

$$i = \overline{1,n}, \quad j = \overline{1,p}, \quad l = \overline{1,k}.$$

In addition, we use $B_{1j}^{\varepsilon,l}$ to denote the transmission start time of the j block in the l group as the first source:

$$B_{1j}^{\varepsilon,l} = \sum_{w=1}^{j-1} \max_{1 \le v \le n} \left[\sum_{q=1}^{v} t_{qw}^{\varepsilon,l} - \sum_{q=1}^{v-1} t_{q,w+1}^{\varepsilon,l} \right], \quad j = \overline{1,p}. \qquad (6)$$

It follows from the analysis of the successive Gantt charts (Fig. 2, 3) that:

$$T_n^2(p,n,s,\varepsilon) = T_n^2(p,n,kp,\varepsilon) = \sum_{l=1}^{k} T_l^{\varepsilon} - \Omega, \qquad (7)$$

where T_l^{ε} is behind the formulas (4), and the value Ω is the criterion of the maximum permissible sum of combinations of the neighboring charts along the time axis. The following lemma takes place.

The value Ω of the maximum permissible sum of alignment of the neighboring Gantt charts along the time axis is determined by:

$$\Omega \ge \sum_{l=1}^{k-1} \min\left\{ \omega_l', \omega_l'' \right\}, \qquad (8)$$

where

$$\omega_l' = \min_{1 \le j \le p} \left\{ T_l^{\varepsilon} - E_{nj}^{\varepsilon,l} + B_{1j}^{\varepsilon,l+1} \right\},$$

$$\omega_l'' = \min_{1 \le i \le n} \left\{ \sum_{q=1}^{i-1} t_{q1}^{\varepsilon,l+1} + \sum_{q=i+1}^{n} t_{qp}^{\varepsilon,l} \right\}, \quad l = \overline{1,k-1}, \qquad (9)$$

here ω_l' and ω_l'' are the intervals of the maximum permissible alignment of the l and (l+1) charts along the time axis.

In formula (8) we have used the symbol of slack inequality, since each value of $\min\left\{ \omega_l', \omega_l'' \right\}$, $l = \overline{1,k-1}$ takes into account only the value of the maximum and minimum permissible combination along the time axis between the pairs of the neighboring Gantt charts, but does not always take into account the possible combinations between the adjacent groups of blocks, which are transmitted to the same consumer in two neighboring charts. Fig. 2, 3 show an example of equality while Fig. 4, 5 show the presence of inequality.

Taking into account the initial data shown in Fig. 4, 5 (Table 2), as well as formulas (8) and (9), the value Ω assumes an exact amount equal to:

$$\Omega = \sum_{l=1}^{2} \min\left\{ \omega_l', \omega_l'' \right\} = \min\{4,4\} + \min\{5,4\} = 8,$$

$$\omega_1' = \min_{1 \le j \le 3}\{4,5,5\} = 4, \quad \omega_1'' = \min_{1 \le i \le 4}\{4,4,6,5\} = 4,$$

$$\omega_2' = \min_{1 \le j \le 3}\{5,6,9\} = 5, \quad \omega_2'' = \min_{1 \le i \le 4}\{4,5,7,9\} = 4.$$

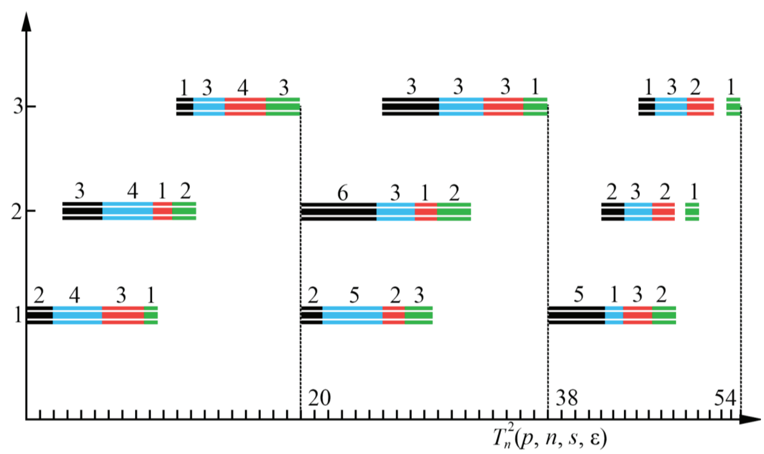

Fig. 4. Nonaligned Gantt chart T

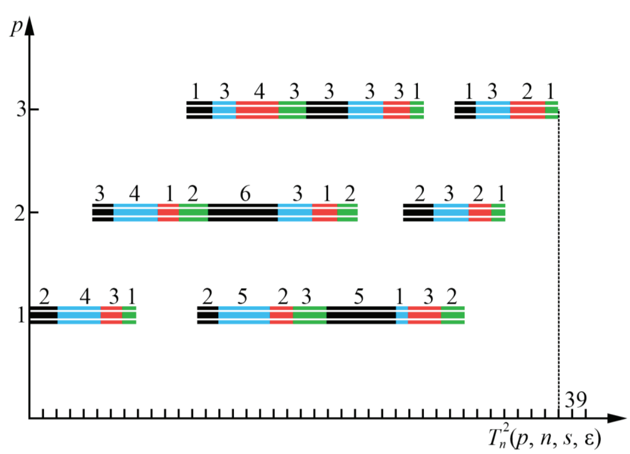

Fig. 5. Aligned Gantt chart

Table 2

Comprehensive indicators of the total machine operating time of the kneading unit in the production of «Ukrainian» bread (timed at the enterprise for the same type of product in assortment and volume)

Direct kneading time, full machine time	Inter-operational time (inter-unit transportation, temporary pause), total machine time	Total batch operation time, total machine time
Before using the resource-process approach		
32	22	54
After the implementation of the resource-process approach		
32	7	39

Taking into account the initial data shown in Fig. 4, 5, the value Ω can also be determined from the inequality (8) and is equal to 14 time units. But, given the possible alignment of the groups of blocks of the second and first charts, which are transmitted to the first consumer, an additional time reserve of 1 unit appears for the following alignment of the third and second charts. As a result, the value Ω of the total sum of the maximum permissible combination will make 15 time units.

7. Discussion of the results of applying the resource-process approach

Due to resource-process optimization, we managed to significantly reduce the time (in terms of machine time) of performing a part of the technological task. The slug supply of raw materials to the technological line of dough kneading and processing in accordance with the accepted initial conditions from 41 to 33 – by 19.5 %.

Hence, the method of practical implementation of the resource-process approach in food production facilities will contain a number of successive stages (Fig. 6, 7). Such method should be applied separately for all the technological nodes, which are either consumers or sources of raw materials (semifinished products), later creating an integrated mathematical model with its further optimization.

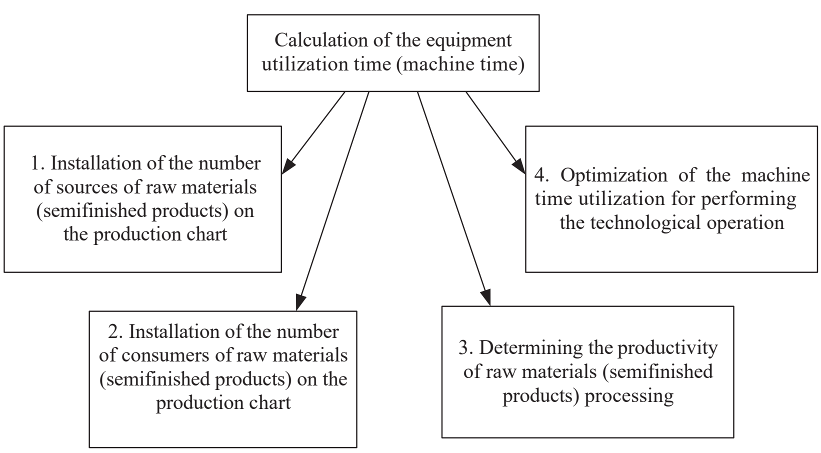

Fig. 6. Methods of implementation of the computing unit block of equipment (machine time) utilization on the basis of optimization resource-process approach

The application of the proposed methods in relation to the actual data of the real-life bread-baking complex has shown that this approach provides an adequate description of the electrical equipment utilization efficiency (mean square error being in the range of 1.9–5.2 %).

The use of resource-process optimization of machine time for using equipment for food production is complicated by the following features of control objects:

– the structure of food production is hierarchical in nature (the products of one production process are raw materials for other production processes);

– large dimensionality of data, a high degree of uncertainty of work and secrecy of the quality indicators of raw materials and semi-finished products;

– multi-purpose behavior of the object, when the priority of the goals of each subsystem depends on the general situation at the control object.

Therefore, when implementing the proposed method for food production, it is necessary to take into account the indicated features.

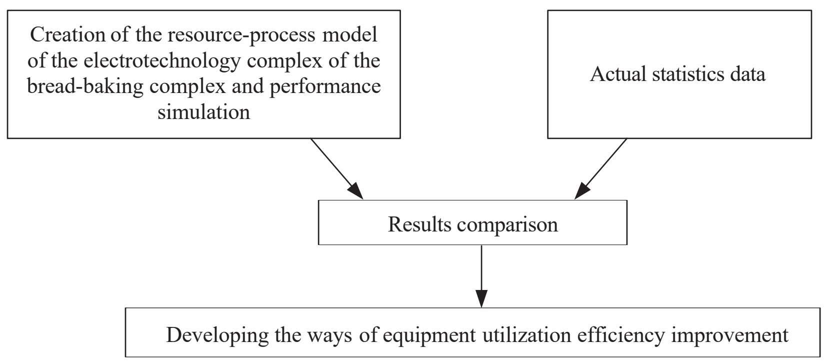

Fig. 7. Implementation structure of the resource-process approach at the bread-baking complex

8. Conclusions

1. The method of resource-process optimization in the direction of minimization of machine time of realization of industrial tasks for the food enterprises of continuous type is developed. The feature of such innovation in terms of improving resource-process optimization is the use of Gantt diagrams to determine the optimum technological map of realization of industrial capacity of the enterprise. Thanks to this improvement, it has become possible to develop a concept for increasing the efficiency of the use of electrotechnological equipment by optimizing the machine time for the implementation of assortment tasks. In particular, it is shown that the essence of the concept can be expressed by determining the maximum allowable total combination of neighboring diagrams along the time axis. The characteristic difference of this concept, therefore, is the account of interrelation of the electrotechnical equipment, industrial capacity of the enterprise and quantity of the structured streams of raw materials and end users. This makes it possible to

increase the efficiency of energy use in the food processing industry by reducing the time spent by machines on the realization of assortment tasks.

2. Methods have been developed to optimize machine time for the use of equipment, which differs from modern ones using a resource-process approach. The features of the proposed method take into account the relationship of electrical equipment and production facilities of the enterprise. As a result of testing the proposed method, energy savings were obtained by optimizing the time of using the electrical equipment of the baking enterprise. Also, the application of the resource-process approach in relation to the actual data of the bakery has demonstrated that such a simulation adequately describes the efficiency of using electrical equipment (standard error of 1.9–5.2 %).

3. As a result of testing, it turned out that the company meets unjustified idle times of electric motors, heating and cooling furnaces, compressor operation (simple with a non-optimal technological scheme). As a result, the monthly irrational energy consumption reached 6.8 % of the nominal capacity, which is 4.3 % of the actual profit of the enterprise. Consequently, reducing the duration of the machine time of the daily production capacity of the enterprise allows increasing the efficiency of energy use in food production enterprises.

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