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Coordination of serial-parallel manufacturing processes of milk production

Abstract. *The use of spatially distributed technological objects in industry and production systems is an ever-increasing trend. The optimal coordination algorithm is used in the information technology for the control of preparation and packaging of dairy products based on SCADA/HMI. The optimizing task is solved by genetic algorithm. In the process of coordination is carried out resource allocation and synchronization of technological lines. The results obtained ensure reduction of losses from equipment downtime and increase the production efficiency.*

Streszczenie. *Optymalny algorytm koordynacji wykorzystywany jest w technologii informacyjnej do kontroli przygotowania i pakowania produktów mlecznych w oparciu o SCADA / HMI. W procesie koordynacji prowadzona jest alokacja zasobów i synchronizacja linii technologicznych. Uzyskane wyniki zapewniają redukcję strat spowodowanych przestojem sprzętu i zwiększają wydajność produkcji. (**Koordynacja szeregowo-równoległych procesów produkcyjnych w wytwarzaniu mleka**).*

Keywords: Resource Allocation, Synchronization, Genetic algorithms, Local Control Systems
Słowa kluczowe: Alokacja zasobów, synchronizacja, algorytmy genetyczne, lokalne systemy sterowania

Introduction

The use of spatially distributed technological objects in industry and production systems is an ever-increasing trend. One of the first fundamental overview of distributed processes control systems was in the work of Golemanov [1]. The isolated action of these objects often leads to numerous problems and generates a high degree of uncertainty in making managerial decisions. Objects can have different goals and constraints, various parameters of productivity and efficiency, therefore to achieve a common goal it is necessary to organize their complex interaction [2-4].

The problem of decision making coordination in the control of production systems is particularly relevant. Researchers have dedicated a lot of attention to formulation of coordination control in complex systems and methods of their solutions, as evidenced by the significant number of publications that have appeared in recent decades [5-6]. In this work, we consider mainly iterative and non-iterative coordination algorithms. With the non-iterative algorithm, the result of optimal coordination is achieved through a single information exchange between levels of the control hierarchy. The disadvantage of this method is the high complexity of the calculations. In the iterative algorithm, the optimal solution is associated with multiple exchanges of information between the center and the elements. In this case, the drawback consists in a significant number of iterations and, consequently, a long calculation time. The disadvantage of this method is the high complexity of the calculations. In the iterative algorithm, the optimal solution is associated with multiple exchanges of information between the center and the elements. In this case, the drawback consists in a significant number of iterations and, consequently, a long calculation time.

A series of works carried out with the participation of authors [7-9] is devoted to the tasks of model development and coordination algorithms in production processes with a complex structure. However, the variety of coordination tasks (criteria, constraints, structures, systems, etc.), the large dimensionality of the work (the number of coordinate parameters), and the presence of uncertainty in the assessment of coordinated processes determine the need for further research. In particular, the published works have not solved the problem of resource allocation considering the synchronization of series-parallel processes [10-13].

The solution of the problem of resource allocation in connection with the synchronization of parallel technological processes is of particular importance in the control of modern dairy production [14-16] .

Modern dairy enterprises produce a broad range of dairy products simultaneously and use for this purpose a set of automated production lines. However, each technological line is controlled independently of other lines (uncoordinated), which can result in a decrease in overall production efficiency. Therefore, the task of coordinating the control of technological lines is relevant [17].

The scheme for coordinating the control of the dairy plant is shown in Fig. 1.

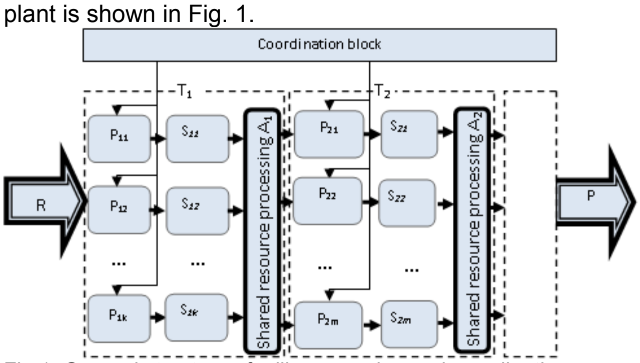

Fig.1. General structure of milk processing and coordination.

Where R: general amount of resource, P: general amount of product, P_{ij} : Processing with model $a_{ij}(r_{ij},p_{ij})$, r_{ij}: processing operation resource, p_{ij}: processing operation productivity, S_{ij}: Storage with amount B_{ij}.

Let´s consider the generalized problem of coordination of processes for some successive steps of production (Fig. 1). In the scheme, there is some initial quantity of raw material R, which is divided into k portions. Each portion of raw material r_i, i=1..k arrives at the processing site with performance p_i. Each portion corresponds to a buffer b_i, i=1..k, which has a maximum capacity B_{maxi} . The result of the processing comes to a general block of operations, A, where in a certain sequence it is processed with productivity u. The product of block A arrives at the next group of m parallel blocks and again on the common processing unit, etc. The aim of this work is to develop a model, an algorithm, and an information technology for the coordination of sequential-parallel processes to improve production efficiency [18-21].

Method

As a criterion of production efficiency, we proposed the intensity of profit.

(1) $$E = \frac{P - C}{T},$$

where P is the price of the production lot; C - the production costs of the party; T - duration of the manufacturing process of the party.

This criterion takes into account both technological and economic aspects. For analysis of the relationships of operations, we use a chart (Fig. 2).
The total volume of raw materials is distributed between production lines:

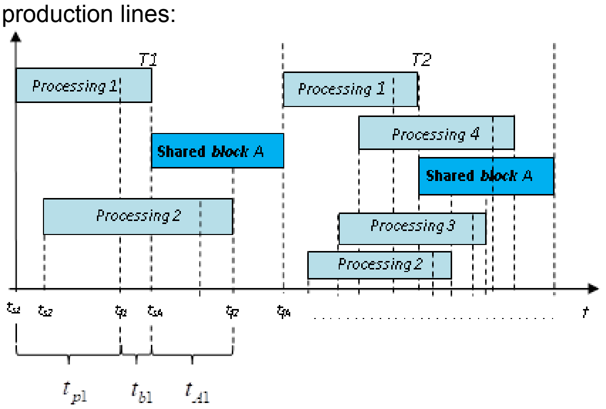

Fig.2. Chart for serial-parallel processing

(2) $$R = \sum_{i=1}^{N} r_i .$$

The processing time depends on the amount of raw material assigned to each line and its technical parameters. Thus, the duration of the technological process t_{pi} of each line is [22-23]:

(3) $$t_{pi} = \frac{r_i}{p_i},$$

where pi is the productivity of the *i-th* line. On the other hand, the duration of the technological process is:

(4) $$t_{pi} = t_{fi} - t_{si},$$

where t_{si} is the start time of the technological process; and t_{fi} is the time of its completion.

As a result of modeling the coordination of processes, we obtain the basic equations.

The system run time will consist of the sum of the execution time of all consecutive steps:

(5) $$T = \sum_{j=1}^{G} T_j .$$

If the order of receipt of the semi-processed products to the joint processing block is determined for the *j-th* step then

(6) $$t_{A_j} = \sum_{i=1}^{N_j} \left(t_{A_j i} + t_{v_j i} \right),$$

Where $t_{v_j i}$ is the downtime of the *j-th* joint processing block awaiting *i-th* portion of the prefabricated. The total execution time of *i-th* technological operations is:

(7) $$t_{ji} = t_{p_{ji}} + t_{b_{ji}},$$

where $t_{b_{ji}}$ - the residence time of the semi-finished product in the buffer.

The time for filling buffer is:

(8) $$t_{b_{ji}} = \frac{B_{ji}}{P_{ji}},$$

and the total time of the j-th sequential step is:

(9) $$T_j = \frac{r_{j1}}{p_{j1}} + \frac{B_{j1}}{p_{j1}} + \sum_{i=1}^{N_j} \left(\frac{r_{ji}}{u_{ji}} + t_{v_j i} \right).$$

Then the total production time is:

(10) $$T = \sum_{j=1}^{G} \left[\frac{r_{j1}}{p_{j1}} + \frac{B_{j1}}{p_{j1}} + \sum_{i=1}^{N_j} \left(\frac{r_{ji}}{u_{ji}} + t_{v_j i} \right) \right].$$

Let's consider optimization of the moments of the beginning of work of parallel processes on each consecutive step.

From the diagram (Fig. 2) we find the recursive formula for the time of the beginning of the next parallel operation with the known time parameters of the previous one is:

(11) $$t_{S_{j(i+1)}} = t_{S_{ji}} + \left[\frac{r_{ji}}{p_{ji}} + \frac{B_{ji}}{p_{ji}} + \left(\frac{r_{ji}}{u_{ji}} + t_{v_j i} \right) \right]. - \left(\frac{r_{j(i+1)}}{p_{j(i+1)}} + \frac{B_{j(i+1)}}{p_{j(i+1)}} \right)$$

The price of lot P depends on the duration of storage of raw materials for processing and can be approximated by the function:

(12) $$P = r_{ji} \left[\left(P_0 - \lambda \right) \exp \left(-k \frac{\sum_{j=1}^{G} \max_i \left(t_{b_{ji}} \right)}{2} \right) + \lambda \right],$$

where r_{ji} is the amount of raw materials (resource*) i-th* line at the *j-th* step; P_{0ji} is the initial price of a raw material unit; is the sale price of expired raw materials.

The optimization criterion (1) is given by the set of explicit relations (10) and (12) and implicit (11) for □(*j,i*).
Based on the developed model, an algorithm for optimal coordination is proposed:
1. Input of the initial characteristics of the system (the number of successive steps *G*, the number of parallel lines at each step m_j, the productivity of each parallel line P_{ji}, the productivity of each common unit u_j, P_{0ji} - the initial price of a unit of raw materials; λ_{ji} – the selling price of the expired raw materials, kji - the proportionality coefficient);
2. Input the quantity of raw materials *R*;
3. Set the initial matrix for the distribution of the amount of raw materials $\{r_{ji}\}$ for all parallel lines at each step;
4. Run the optimization algorithm of distribution of raw materials:
4.1. For each successive step *j*=1..*G* ;
4.1.1. We generate a variant of the termination sequence of parallel processes by a permutation method;
4.1.2. We calculate the start time of each operation;
4.1.2.1. $t_{s11} = 0$;
4.1.2.2. for *j*=1 to *G* ;
4.1.2.2.1. for *i*=1 to m_j ;
4.1.2.2.1.1. Calculate $t_{Sj(i+1)}$ according to (12);
4.1.2.2.1.2. Calculate the shift in the beginning of the next process relative to the previous one $\Delta t_{S\,j(i+1)} = t_{S\,j(i+1)} - t_{Sj}$;
4.1.2.2.1.3. End;
4.1.2.2.2. End;
4.1.2.3. End

Due to the non-linearity of the objective function and a large number of optimization parameters, either a genetic algorithm [10] or a random search algorithm [11] is chosen to solve the problem.
The optimal coordination algorithm is used in the information technology for the control of preparation and packaging of dairy products based on SCADA / HMI.

The automated milk preparation and packaging management system is designed to control the technological process of milk production. The system monitors the stages of the technological process: separation and normalization; homogenization; pasteurization; packing.

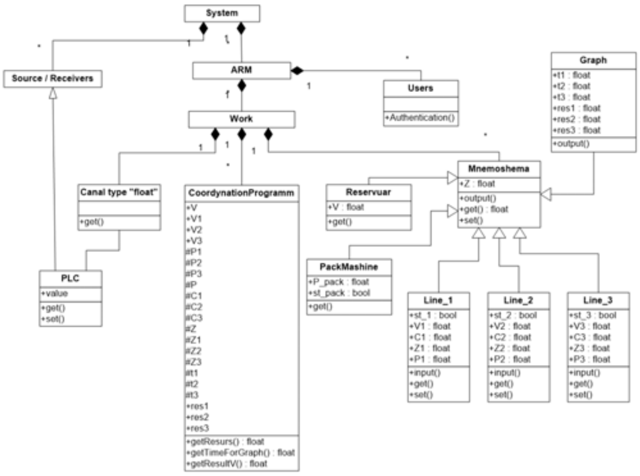

Fig.3. The UML diagram of the classes of the information technology of the control of the preparation and packaging of dairy products

Results

The interface of the coordination control system is shown in Fig.4. The interface has 3 zones: the mnemonic zone, the parameter area and the visualization area of coordination control results in the form of work lines schedules. The display of the mnemonic diagram is formed from standard SCADA graphic objects. To verify the adequacy of the model, we construct the following dependencies $t_a=f(r)$, $t_a=f(p)$, $t_b=f(B_{max})$, $t_b=f(p)$, $t_b=f(u)$. Parameters are normalized in the range from 0 to 100.

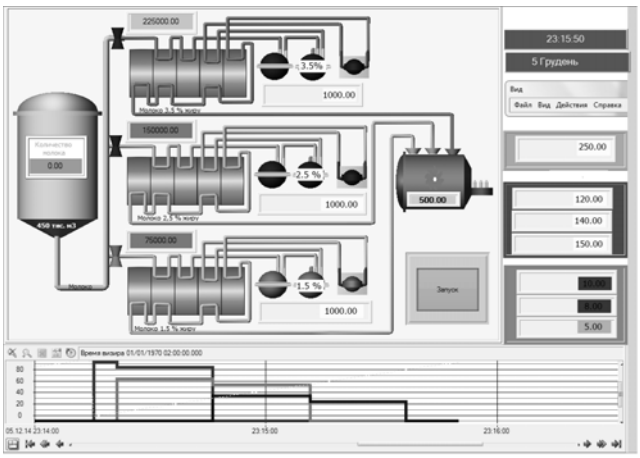

Fig.4. The UML diagram of the classes of the information technology of the control of the preparation and packaging of dairy products

Result of simulation of the coordination control process: in Fig. 5a), the inverse proportional dependence of the unit's operating time on the block's performance is displayed. Fig. 5b) shows a direct proportional dependence of the unit's operating time on the amount of raw material. In Fig.5 c) shows the direct dependence of the residence time of the raw material in the buffer on the size of the buffer. Fig. 5d) displays the parabolic dependence of the residence time of the raw material in the buffer on the block's performance for the range (0,u_{max}) that satisfies the condition $u_n > p_n$. Fig. 5e) is the hyperbolic dependence of the residence time of the raw material in the buffer, which also satisfies the condition. Dependency analysis shows the adequacy of the model.

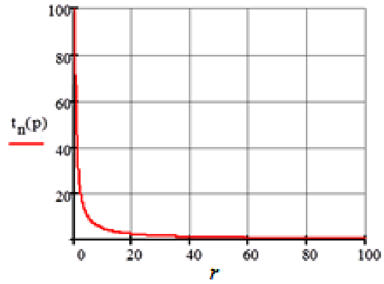

Fig.5a. Dependence of the operating time of the t_n block on the productivity of the block to the amount of the raw material by the block r=50

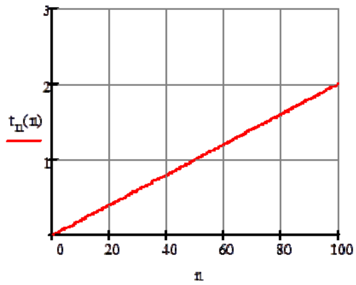

Fig.5b. Dependence of the time of operation of the block with respect to the quantity of raw material in the capacity of the block p_n=50 , $t_n = f(n)$, p = 50

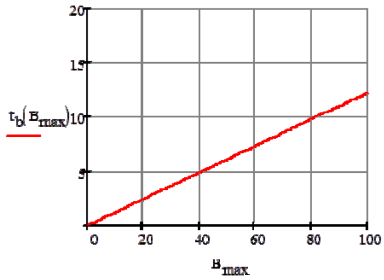

Fig.5c. Dependence of the time of permanence on buffer size for the performance of the block p=45 and the productivities of the general block u_n=55

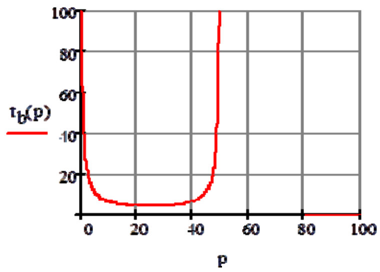

Fig.5d. Dependence of the time of permanence on buffer t_b from the performance of the block p_n and the productivities of the general block u_n=55

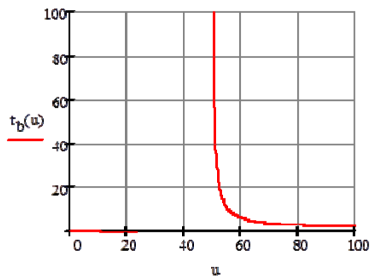

Fig.5e. Dependence of the block operating time t_b from the productivity of the general block u_n=55 with respect to the size buffer B_{max}=50 of the general block p_n=50

Conclusions

The model, algorithm and information technology for effective coordination of local control systems of serial-parallel production lines for the preparation and packaging of milk was developed. These results ensure reduction of losses from equipment downtime and increases the production efficiency. Genetic optimization of coordination parameters is fast enough for control the preparation of technological process and packaging of the milk in real time. Further research should be directed to development of model and coordination algorithm under conditions of random variations of the parameters of process from calculated ones.

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