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THE DEVELOPMENT OF THEORY CONCERNING OPERATION OF MINING MACHINE SYSTEMS OF CONTINUOUS ENGINEERING STRUCTURES. BASIC RESULTS OF INVESTIGATIONS

Summary. This paper presents examples of currently operating complex multiproduct systems of continuous engineering structures. Principles of synthesis of such systems are given in the sense of reduction of series-structure subsystems as well as series-parallel structure subsystems. The paper provides principles of taking into account the geological structure of mined rocks (mineral, overlay); ways of determining spaces of technically possible operating states of systems are discussed, particular attention being paid to an algorithmic method adapted for a digital computer; and furthermore, the problem of system control in actual time is discussed. On account of the limited length of this paper, some important problems have been omitted, eg: conditions of start-up in the algorithmic method, the principle of system decomposition (Fig. 12), the principle of averaging the mineral properties in stacking yards.

1. INTRODUCTION

Currently, in open pit and underground mines, as well as in raw material processing plants, machine systems with conveyors and wheel transport are used. Figs. 1-5 show examples of machine systems being currently employed in mines. Fig. 1 represents a constructional-functional diagram of a system operating in one of lignite mines. Fig. 2 represents a diagram of the main conveyor transport in one of underground mines with which wheel transport (Fig. 3) cooperates in particular flats, and - possibly - belt transport with heading machines (Fig. 4) or scraper-buckets.

As far as machine systems with belt transport are concerned, until the 60 s there was no theoretically correct method of calculating systems with belt transport of mixed reliability structures. In the case of systems with wheel transport, (1) presents a technique of solving cyclic single systems of bulk handling; another solution in this respect is given in (2), and the applicability to the calculation of this type of systems in mining is presented in [2, 3]. Both solutions did not take into account the fact that exploitation in mines involves hierarchical, multiple (at least duplex) systems of winning and transport. The principles of solving such systems as well as a general method of calculating cyclic systems are given in [32].

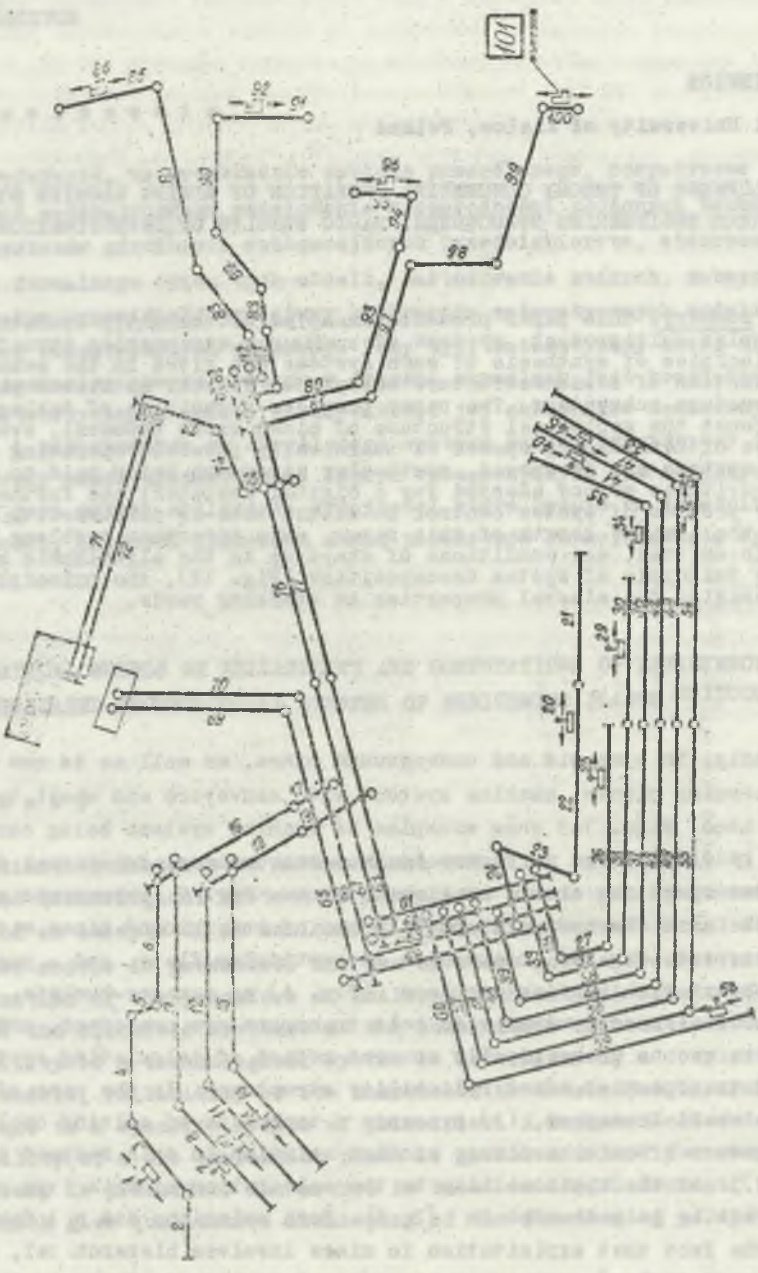


Fig. 1. Constructional-functional diagram of multi-product machine system
Rys. 1. Schemat konstrukcyjno-funkcjonalny wieloproduktowego systemu maszynowego

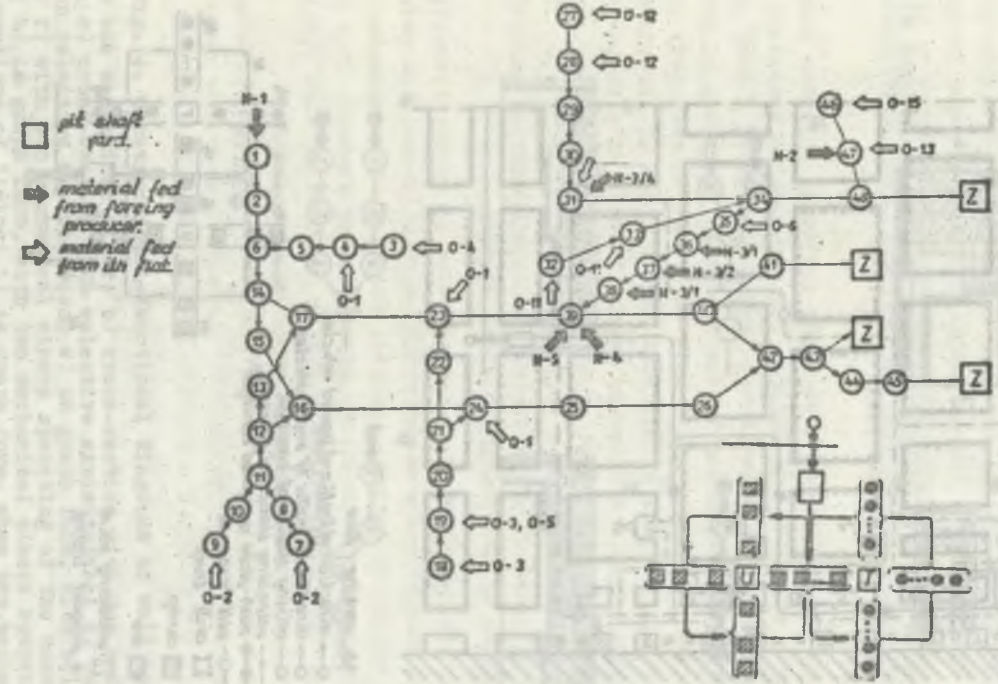


Fig. 2. a) Diagram of main conveyor transport in underground mine; b) calculation diagram of wheel transport in a flat

Rys. 2. Schemat: a) przenośnikowego transportu głównego kopalni podziemnej, b) obliczeniowy oponowego transportu oddziałowego

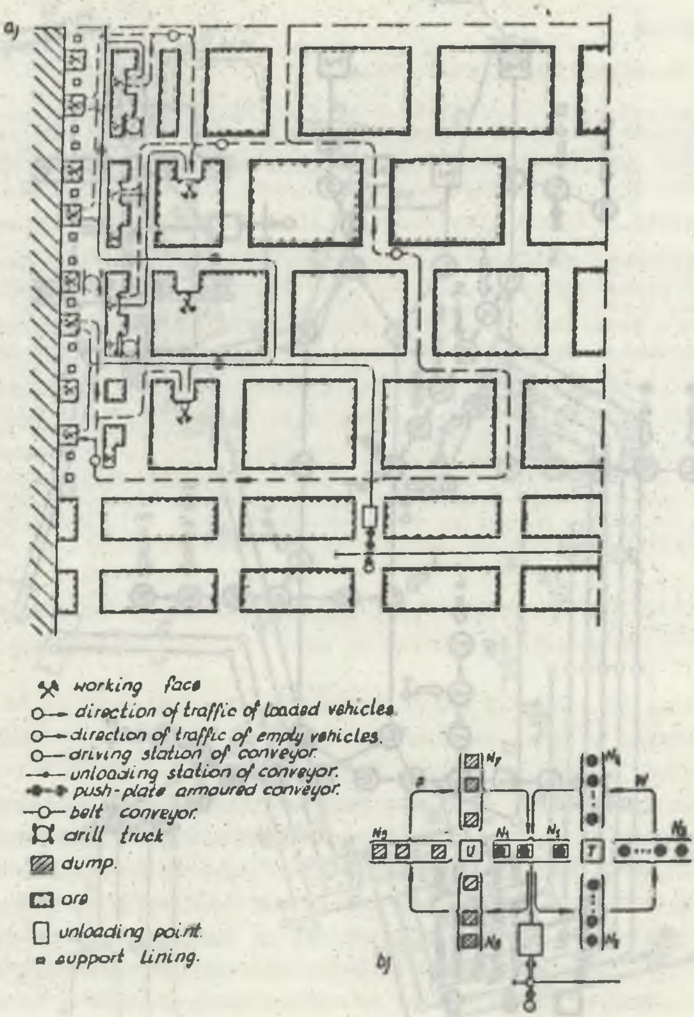


Fig. 3. a) Diagram of breast-and-pillar system with wheel transport in a flat; b) calculation diagram of wheel transport in a flat

Rys. 3. Schemat: a) systemu komorowo-filarowego z oddziałowym transportem oponowym, b) obliczeniowy oponowego transportu oddziałowego

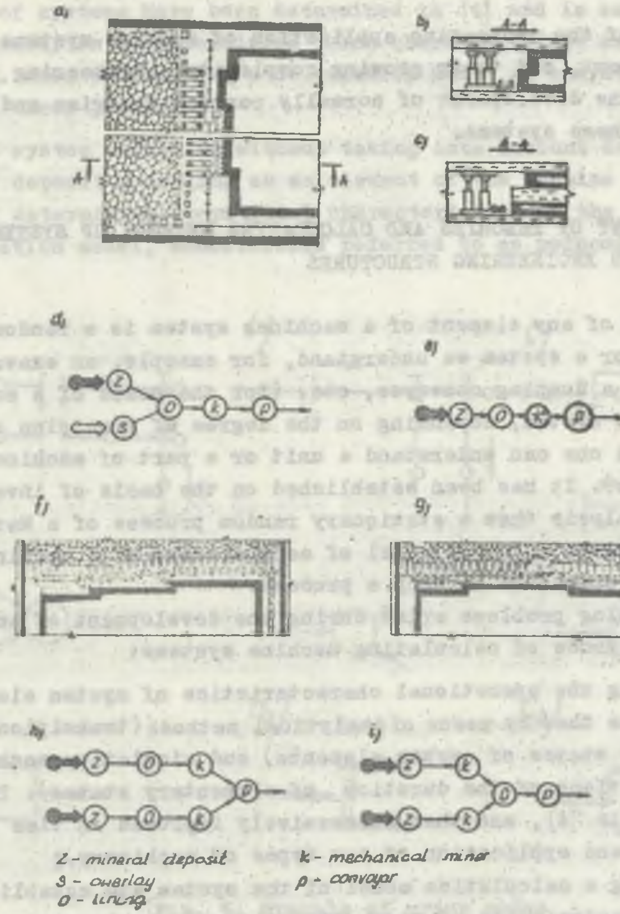


Fig. 4. Constructional-functional diagrams of wall equipment

a) with one mechanical miner; b) cross-section with non selective exploitation; c) cross-section with selective exploitation; d) in graph form, with non selective exploitation; e) in graph form, with selective exploitation; f) with two mechanical miners operating of the same direction of mining; h) in graph form, with two mechanical miners cooperating with different sections of lining; i) in graph form, when two mechanical miners cooperate with the same section of lining

Rys. 4. Schematy konstrukcyjno-funkcjonalne uzbrojenia ściany

a) jednym kombajnem, b) przekrój poprzeczny z eksploatacją nieselektywną, c) przekrój poprzeczny z eksploatacją selektywną, d) w formie grafu z eksploatacją selektywną, e) w formie grafu z eksploatacją nieselektywną, f) z dwoma kombajnami o tym samym kierunku urabiania, g) z dwoma kombajnami o przeciwnych kierunkach urabiania, h) w formie grafu w wypadku pracy dwóch kombajnów współpracujących z różnymi sekcjami obudowy, i) w formie grafu w wypadku pracy dwóch kombajnów współpracujących z tą samą sekcją obudowy

This problem is only mentioned here and it will not be discussed in this paper.

In view of the increasing application of machine systems with belt and wheel transport, and their growing complexity, engineering practice has called for the development of normally correct theories and calculating methods of these systems.

2. DEVELOPMENT OF THEORIES AND CALCULATING METHODS OF SYSTEMS WITH CONTINUOUS ENGINEERING STRUCTURES

Operation of any element of a machines system is a random process. By an element for a system we understand, for example, an exavator, any type of conveyor, a dumping conveyor, etc. (for the needs of a more precise analysis of a system, depending on the degree of precision of analysis, by an element one can understand a unit or a part of machinery included in the system). It has been established on the basis of investigations and their analysis that a stationary random process of a Markov type [4] can be adopted as a formal model of each element of a machine system; hence system operation is such a process.

The following problems arise during the development of analytical and simulation methods of calculating machine systems:

- establishing the operational characteristics of system elements in order to calculate them by means of analytical methods (transition rates between operational states of system elements) and simulation methods (distribution functions of the duration of elementary states). This problem was solved in [4], and then successively improved in time (quality improvements and application of new types of machinery);
- establishing a calculation model of the system and establishing operational characteristics of respective elements taking into consideration the fact that the internal structure of these elements changes in time, and that deposit is one of the elements;
- establishing the way or ways of identifying technically feasible operational states of systems taking into account specificity of deposit winning (selective, non-selective, etc.), as well as the specifity of systems - mainly systems without stacking yards, and with them;
- establishing techniques of deriving equations for boundary probabilities of technically possible operational states of a system in the case of calculating systems by means of simulation methods;
- establishing methods of system control in actual time with simultaneous optimization of utility parameters of mineral (calorific value of coal, composition of ores and their mineralization, etc.).

As already mentioned, the operational characteristics necessary for the calculation of systems have been determined in [4] and in subsequent papers. The principles of determining these characteristics are given in [5, 6, 7, 8]. When determining a calculation model of a system, we have to deal with three problems:

- the way of system modelling without taking into account deposit;
- the way of deposit modelling as an element of the machine system;
- methods of determining operational characteristics of the elements of the calculation model, henceforward referred to as reduced elements.

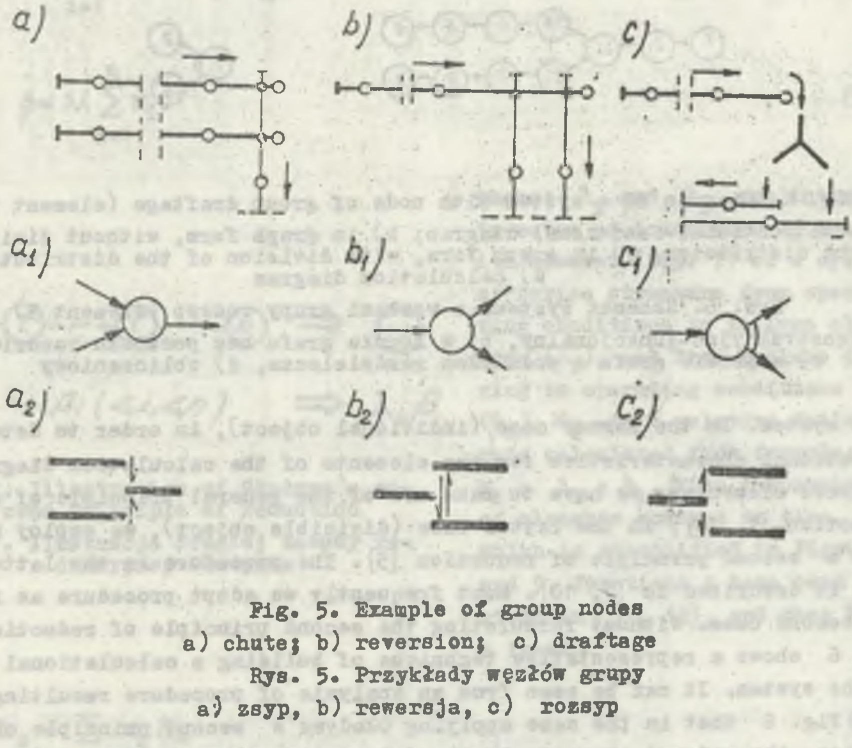


Fig. 5. Example of group nodes
a) chute; b) reversion; c) draftage
Rys. 5. Przykłady węzłów grupy
a) zsyp, b) rewersja, c) rozsyp

An analysis of complex machine systems shows that each of these systems consists of a finite set of subsystems with a series structure. The division of the system into subsystems is determined by engineering and constructional reasons, and it is accomplished by the nodes of the system. We can distinguish three basic kinds of nodes [9] (Fig. 5). Nodes are logical categories [7], two of them, namely nodes of the group "chute" and "reversion" are non-material objects, whereas nodes of the group "draftage" are material objects (Fig. 5c).

In determining a calculation model of a system, a node of the group "draftage" can be treated as formally indivisible or divisible element

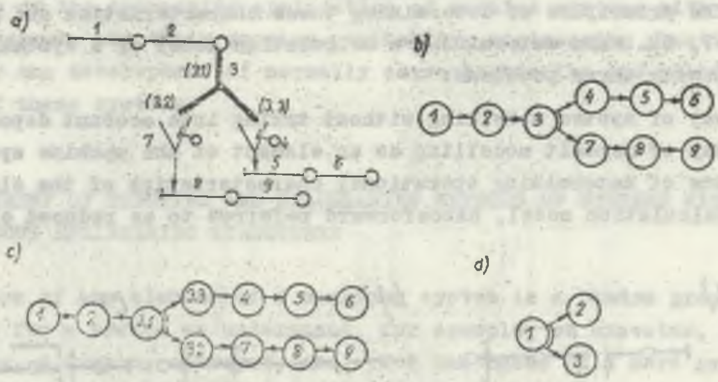


Fig. 6. Diagram of a system with node of group draftage (element 3)
a) constructional-functional diagram; b) in graph form, without division of the distributor, c) in graph form, with division of the distributor; d) calculation diagram

Rys. 6. Schemat systemu z węzłami grupy rozsyp (element 3)
a) konstrukcyjno-funkcjonalny, b) w formie grafu bez podziału rozdzielacza, c) w formie grafu z podziałem rozdzielacza, d) obliczeniowy

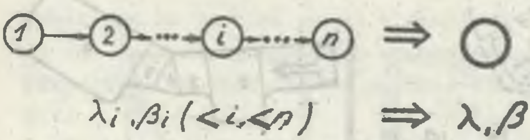
of a system. In the former case (individual object), in order to determine operational characteristics for the elements of the calculation diagram (reduced elements), we have to make use of the general principle of system reduction [7, 10]; in the latter case (divisible object), we employ Gładysz's second principle of reduction [5]. The procedure in the latter case is described in [7, 10]. Most frequently we adopt procedure as in the second case. Without formulating the second principle of reduction, Fig. 6 shows a representative technique of building a calculational model of the system. It can be seen from an analysis of procedure resulting from Fig. 6 that in the case applying Gładysz's second principle of reduction, the reduced elements of the calculational model (Fig. 6d) are made up of the following elements, respectively (including part of element 3), namely: $1 \Rightarrow \{1;2;3.1\}$, $2 \Rightarrow \{3.3;\ 4;5;6\}$, $3 \Rightarrow \{3.2;7;8;9\}$, whereas when applying a general principle of reduction, we shall have, respectively: $1 \Rightarrow \{1,2,3\}$, $2 \Rightarrow \{4,5,6\}$, $3 \Rightarrow \{7,8,9\}$. The aim of Gładysz's second principle of reduction is to transform the operational characteristics of elements included in the subsystem of series structure into the operational characteristics of a respective reduced element. Therefore, let M be a set of charasteristics (corresponding to this system) of a reduced element, then

$$A : M \rightarrow L \tag{1}$$

where A is a set of functions or algorithms that transform M into L. Dependence (1) holds for the application of either analytical or simulation methods. Functions A for analytical methods, when the number of elements in a system of series structure does not change in time, have been derived in [5] and they have the form:

$$\lambda = \sum_{i=1}^{n} \lambda_i \tag{2}$$

$$\beta = \lambda \left(\sum_{i=1}^{n} \varkappa_i \right)^{-1} \tag{3}$$



Rys. 7. Illustration of Gładysz's second principle of reduction

Rys. 7. Ilustracja drugiej zasady redukcyjnej Gładysza

where: λ_i and β_i are intensity rates of transition of the ith element (Fig. 7) of a system of series structure from operating conditions to failure clearing (λ_i), and from failure clearing to operating conditions (β_i), $\varkappa_i$ is a relative failure rate calculated from formula: $\varkappa_i = \lambda_i : \beta_i$. When the number of elements changes in time, which is exemplified in Figs. 8 and 9, functions A have been derived in [11, 12], and they have a form:

$$\lambda_z = \sum_{k=1}^{m} m_k \lambda_k \tag{4}$$

$$\beta_z = \lambda_z \left(\sum_{k=1}^{m} m_k \varkappa_k \right)^{-1} \tag{5}$$

in which: k is an identifier of changes in the number of operating elements in a system of series structure, eg in the case as shown in Fig. 8b and c, $1 \leqslant k \leqslant r-1$; λ_k and β_k are intensity rates of changes in operational states calculated from formulae (2) and (3); m_k is a relative worktime rate in the kth situation of a series structure system, therefore:

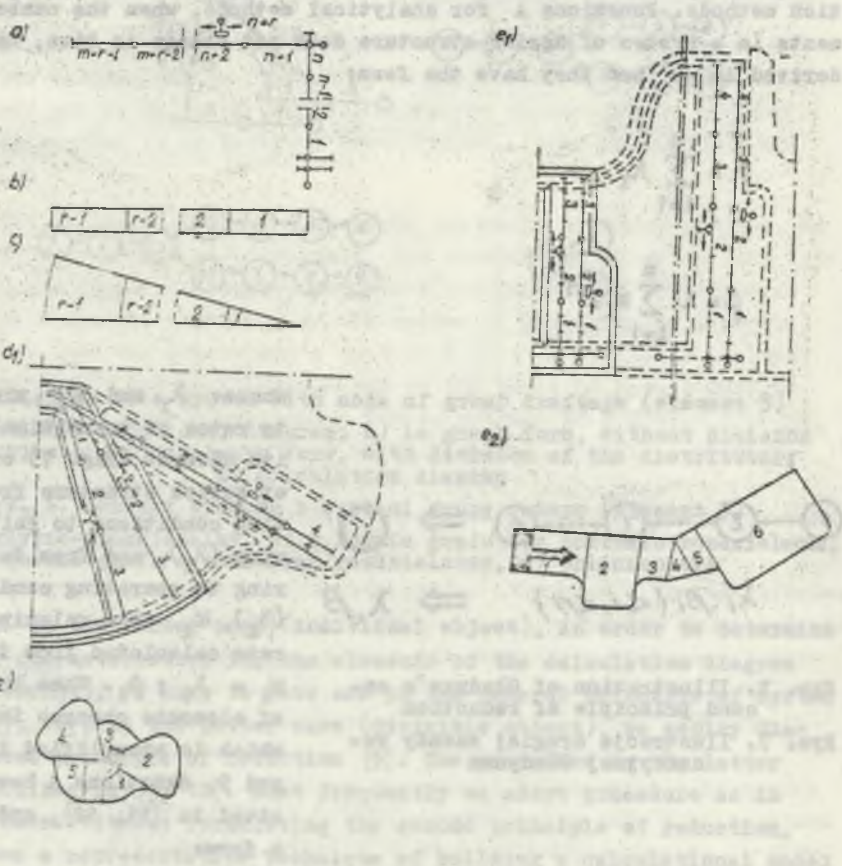


Fig. 8. Diagrams representing changes in the number of elements in time in a system of series structure in the case

a) changes of position of stock-feeding device in relation to collecting (conveyors) devices; b) exploitation of deposit in a parallel way; c) exploitation of deposit in a fan-like way; d_1, d_2) changes in the number of belt conveyors in time in exploitation fields; in the fan-like way; e_1,e_2) changes in the number of belt conveyors on lateral haulage levels and in the exploitation fields in the parallel and fan-like ways

Rys. 8. Schematy ilustrujące zmiany ilości elementów w czasie w systemie o strukturze szeregowej w przypadku

a) zmian położenia urządzenia podającego w stosunku do urządzeń (przenośników) odbierających, b) eksploatacji złoża sposobem wachlarzowym, d_1,d_2 zmian liczby przenośników taśmowych w czasie w polach eksploatowanych sposobem wachlarzowym, e_1,e_2) zmian liczby przenośników taśmowych na bocznych poziomach transportowych i w polach eksploatowanych sposobami równoległym i wachlarzowym

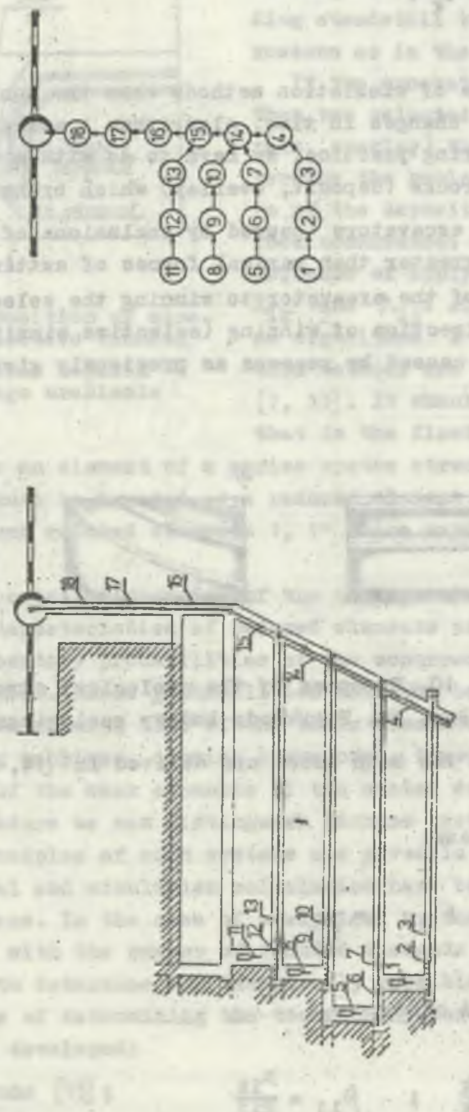


Fig. 9. Diagram representing changes in the number of elements in time in underground mining
Rys. 9. Schemat ilustrujący zmiany ilości elementów w czasie w górnictwie podziemnym

$$m_k = \frac{t_k}{T} \qquad (6)$$

where:

$$T = \sum_{k=1}^{m} t_k .$$

In the case of simulation methods when the number of elements does not change and/or changes in time, algorithms A are given in [7, 13].

In engineering practice, we have to do with a definite lithological structure of rocks (deposit, overlay) which brings out:

- shutdown of excavators (caused by inclusions of rocks, with exavation resistance greater than maximal forces of cutting; rock slices, etc);
- transition of the excavator to winning the solected kinds of rocks along the direction of winning (selective winning, Figs. 10, 11) with simulations caused by reasons as previously given.

Fig. 10. Examples of the geological structure of deposite
Rys. 10. Przykłady budowy geologicznej złóż

Functions A for both cases are derived in [14, 7], and have a simplified form:

in the first case:

$$\lambda = \frac{1}{\bar{T}_k} \quad ; \quad \beta = \frac{1}{\bar{T}_p} \qquad (7)$$

- in the second case:

$$\lambda_{ik} = \frac{n_{ik}}{Tik} \quad ; \quad \beta_{ij} = \frac{n_{ik}}{Tij} \qquad (8)$$

where: Tik + Tij is a joint time of rock winning by the excavator in the ith area including stanstill times caused by reasons as in the first case;

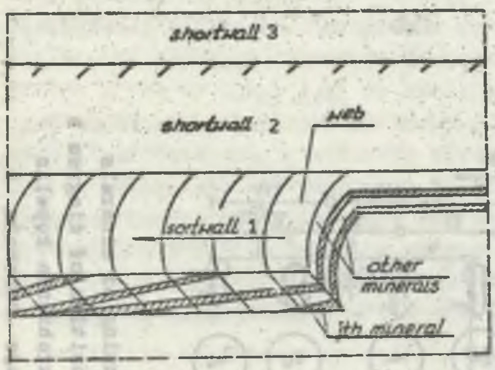


Fig. 11. Diagram of deposition of minerals in the case of selective winning
Rys. 11. Schemat zalegania kopalin w przypadku selektywnego urabianie

Tik is the time of winning of a particular mineral including standstill times caused by reasons as in the first case in the ith area; Tij is the time of winning of other minerals including standstill times caused by reasons as in the first case.

If the excavator mines more than two selected rocks (minerals, overlay) then we must determine the geological structure of the deposit, sequence of rock occurrence: therefore, the sequence of applying quantities λ_{ik} and λ_{ij}. Also in this case algorithms A for simulation methods are given in [7, 13]. It should be noted that in the first case the deposit can be treated as an element of a series system structure, whereas in the second case it must be treated as a reduced element of the system (Fig. 12). In this figure reduced elements 1, 1' 2 are mapping the deposit.

Having a determined calculation model of the machine system and knowing the operational characteristics of reduced elements of the system, we can determine the boundary probabilities of the occurrence of the operational states of systems. These probabilities make the basis for the calculation of effective running time of the basic elements of the system (eg excavators, heading machines, dumping conveyors), throughput, etc, and for the determination of the weak elements of the system due to a specific feature. In this procedure we can distinguish machine systems without and with stacking yards. Examples of such systems are given in Figs. 1 and 13.

Methods of analytical and simulation calculation have been developed for both kinds of systems. In the case of analytical systems, particularly in the case of systems with the number of reduced elements greater than four, it is essential to determine the technically possible states of operation. Four techniques of determining the technically possible states of operation have been developed:

- diagrams of transitions [15];
- graphs [16, 7];
- positional systems of digital numeration and symbolism [18, 19, 20, 7];

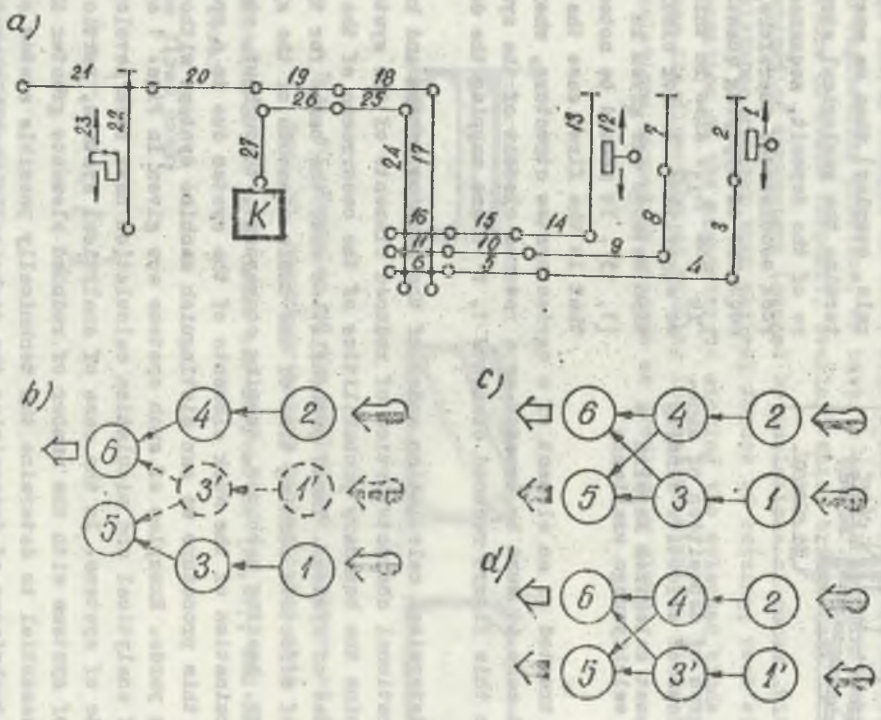


Fig. 12. Diagrams of machine system in the case of selective winning of minerals a) constructional-functional diagram; b) calculation diagram; c) d) decomposition of diagram b

Rys. 12. Schematy systemu maszynowego w przypadku selektywnego urabiania kopalin a) konstrukcyjno-funkcjonalny, b) obliczeniowy, c) d) dekompozycja schematu b

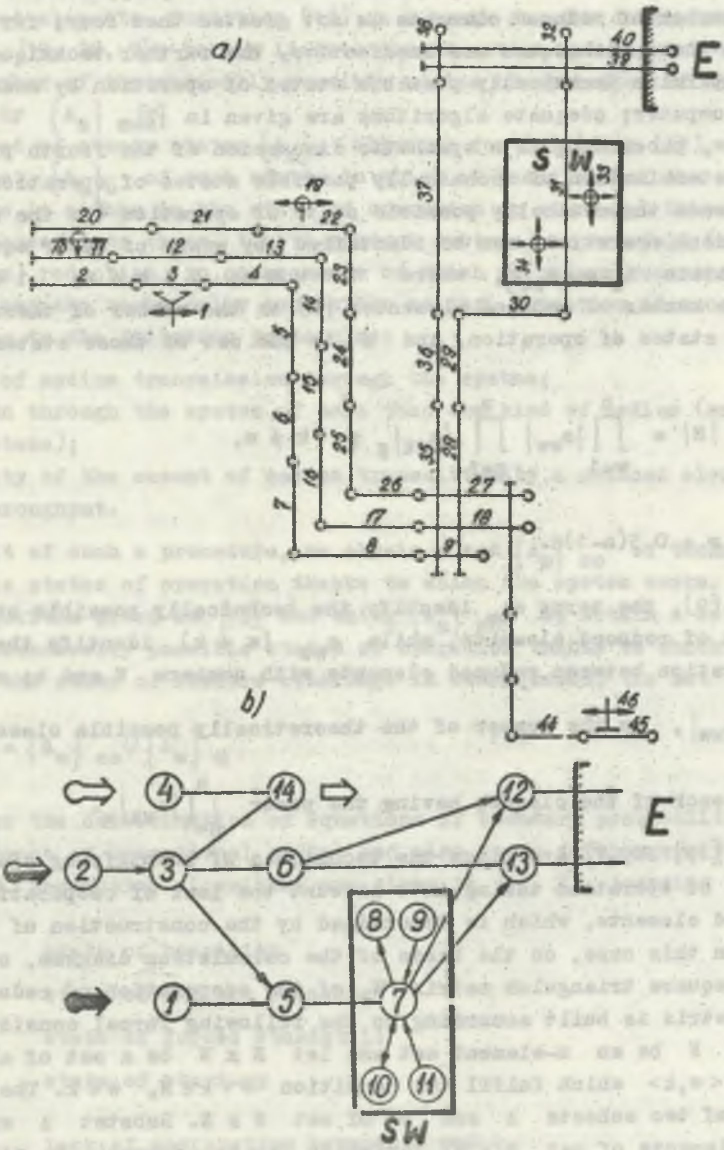


Fig. 13. Diagram of machine system with stacking yard
a) constructional-functional diagram; b) calculation diagram (SW) coal stacking-yard, (E) area of power plant

Rys. 13. Schemat systemu maszynowego ze składowiskiem
a) konstrukcyjno-funkcjonalny, b) obliczeniowy, (SW) składowisko węgla, (E) teren elektrowni

The first three techniques can be effectively applied in the case when the number of reduced elements is not greater than four; for greater systems these techniques are ineffective. The further technique is adjusted to determine technically possible states of operation by means of a digital computer; adequate algorithms are given in [7].

Now, proceeding to a synthetic discussion of the fourth procedure for the determination of technically possible states of operation, let's note that each theoretically possible state of operation (in the system of independent operation) can be identified by means of upper square triangular matric $A_m = \{a_{wk}\}$, where $1 \leqslant w \leqslant n$; $1 \leqslant k \leqslant n$; $1 \leqslant m \leqslant |M|$; n is the number of reduced elements; $|M|$ is the number of theoretically possible states of operation, and M is the set of those states in which

$$|M| = \prod_{w=1}^{n} |a_{ww}| \prod_{g=1}^{r} |a_{wk}|_g \; ; \quad k \neq w, \tag{9}$$

$$r = 0{,}5(n-1)n. \tag{10}$$

In (9), the terms a_{ww} identify the technically possible states of operation of reduced elements, while a_{wk} $(w \neq k)$ identify the states of cooperation between reduced elements with numbers W and k; moreover, $\prod_{w=1}^{n} |a_{ww}|$, is the number of the theoretically possible classes of operation, each of the classes having the power $\prod_{g=1}^{n} |a_{wk}|_g$.

In [19, 20, 7] are given the techniques of identifying classes of the states of operation taking into account the lack of cooperation between reduced elements, which is determined by the construction of the system [7]. In this case, on the basis of the calculation diagram, one builds upper square triangular matrix W of the cooperation of reduced elements. This matrix is built according to the following formal considerations:

Let N be an n-element set and let N x N be a set of all ordered pairs $\langle w,k \rangle$ which fulfil the condition $w \vee k \in N$, $w \leqslant k$. Then let's think of two subsets A and B of set N x N. Substet A will include such elements of set N x N for which $w < k$; subset B will include such elements of set N x N for which $w = k$; now let subset A, which is a binary relation, identify the transmitted medium (solid, liquid or gaseous matter, electric or thermal energy, signals, and so on) between the elements of set N. Therefore, if pair $\langle w,k \rangle \in A$, then dependence w A k holds. On the other hand, if $\langle w,k \rangle \notin A$, then $\{A_m\}_{m \in M}$, $a_{wk} = 0$, hence

$$\langle i,j \rangle \notin A \Rightarrow a_{ij} \in \{A_m\}_{m \in M} = 0 \tag{11}$$

B is a subset of reverse relations which identify the states of operation of reduced elements. Condition (11) is a basis for the construction of matrix W [19, 20, 7]; taking it into consideration reduces substantially the number of theoretically possible states of operation of the system given by $\{A_m\}_{m\in M}$.

From the set of steady states $\{A_m\}$, allowing for condition (11), we separate subset $\{A_m\}_{\bar{o}}$ of such states in which at least one of the reduced elements is either in the state of operation or start-up. Subset $\{A_m\}_o$ is subjected to three- (multi-product systems) or two-fold (one-product system) reduction, in consequence of which we remove successively, from this subset the technically impossible states. Reduction is accomplished according to the following principles:

- continuity of medium transmission through the system;
- transmission through the system of more than one kind of medium (multi-product systems);
- compatibility of the amount of medium transmitted by a reduced element with its throughput.

As a result of such a procedure, we obtain a set $\{A_m\}_{so}$ of technically possible states of operation thanks to which the system works. Using the algorithm given in [19] and using $\{A_m\}_{so}$, we obtain a set $\{A_m\}_{s1}$ of technically possible states of operation thanks to which the system is in the state of failure clearing. In consequence, the set

$$\{A_m\}_t = \{A_m\}_{so} \cup \{A_m\}_{s1}$$

is a basis for the determination of equations of boundary probabilities of the occurrence of operational states and also for a further analysis of the system. Respective algorithms are given in [19, 7]. Assuming that:

$$a_{ww} = \begin{cases} 0 & \text{state of operation} \\ 1 & \text{state of failure clearing} \\ 2 & \text{state of forced standstill} \\ 3 & \text{state of start-up} \end{cases} \tag{12}$$

$$a_{wk} = \begin{cases} 0 & \text{lack of cooperation between } w \text{ and } k \\ 1 & \text{cooperation} \end{cases} \tag{13}$$

and also that: $N_z \subset N$ is a subset of sources; $N_w \cup N$ is a s bset of internal elements; $N_u \subset N$ is a subset of outlets, we obtain th following conditions of continuity of medium haulage through the system

$$\left[w \in N \wedge a_{ww} = (1 \vee 2)\right] \Longrightarrow$$

$$\Longrightarrow \left[\sum_{w} a_{wk} = \sum_{j} a_{wk} = 0\right] \quad \text{for } w < k, \tag{14}$$

$$\left[w \in N_z \wedge a_{ww} = (0 \vee 3)\right] \Longrightarrow$$

$$\Longrightarrow \left[\sum_{w} a_{wk} = 0 \wedge \sum_{k} a_{wk} \geqslant 1\right] \quad \text{for } w < k, \tag{15}$$

$$\left[w \in N_w \wedge a_{ww} = 0\right] \Longrightarrow$$

$$\Longrightarrow \left[\sum_{w} a_{wk} = \sum_{k} a_{wk} \geqslant 1\right] \quad \text{for } w < k, \tag{16}$$

$$\left[w \in N_w \wedge a_{ww} = 3\right] \Longrightarrow$$

$$\Longrightarrow \left[\sum_{w} a_{wk} = 0 \wedge \sum_{k} a_{wk} > 1\right] \quad \text{for } w < k, \tag{17}$$

$$\left[w \in N_u \wedge a_{ww} = 0\right] \Longrightarrow$$

$$\Longrightarrow \left[\sum_{w} a_{wk} \geqslant 1 \wedge \sum_{k} a_{wk} = 0\right] \quad \text{for } w < k, \tag{18}$$

$$\left[w \in N_u \wedge a_{ww} = 3\right] \Longrightarrow$$

$$\Longrightarrow \left[\sum_{w} a_{wk} = \sum_{k} a_{wk} = 0\right] \quad \text{for } w < k, \tag{19}$$

Using conditions (14)-(19) and the algorithm given in [19, 7], as a result of an analysis of the set of states $\{A_m\}_{ko}$, we obtain set $\{A_m\}_{do}$ for further analysis.

When we deal with multi-product systems, we build a matrix of multi-productivity for each $\{A_m\} \in \{A_m\}_{do}$. Let U be a set for discriminated media; $u = |U|$ power of set U, and let u_i, $1 \leqslant i \leqslant u$, be a code that will identify a concrete medium, then we determine the matrix of multi-productivity K_m of a definite state of operation of the system using the following dependences:

$$\left[w \in N \wedge a_{ww} = (1 \vee 2)\right] \Longrightarrow u_{ww} = 0 \tag{20}$$

$$\left[w \in N \wedge a_{wk} = 0\right] \Longrightarrow u_{wk} = 0, \tag{21}$$

$$\left[w \in N_z \wedge a_{ww} = (0 \vee 3)\right] \Longrightarrow u_{kk} = u_i, \tag{22}$$

$$\left[w \in (N_z \vee N_w) \wedge u_{ww} = u_i\right] \Longrightarrow$$

$$\Longrightarrow \left[(u_{wk} = u_i) \Longleftrightarrow (a_{wk} \neq 0)\right] \quad \text{for} \quad w < k, \tag{23}$$

$$\left[w \in (N_w \vee N_u)\right] \Longrightarrow \left[U_{ww} = \bigcup_{w=1}^{k-1} (u_{wk} \neq 0)\right] \quad \text{for } w < k, \tag{24}$$

The sets of states $\left\{A_m\right\}_{go}$, which are taken for further analysis, do not include those for which $|U_{ww}| > 1$, therefore

$$\left[(\bigvee_{w} |U_{ww}| > 1) \in A_m\right] = A_m \in \left\{A_m\right\}_{go}. \tag{25}$$

On account of transfer capacity of reduced elements, we go on to analyze sets of states $\left\{A_m\right\}_{do}$ in the case of one-product systems and sets of states $\left\{A_m\right\}_{go}$ in the case of multi-product systems. For that purpose we build matrix of capacity A_m for each of states S_m which belongs to one of the given sets. The principles of construction of these matrices are slightly different for a system with nodes of the group "draftage" and without those nodes; they are described for both cases in [7, 19]. Here, we shall synthetically present only the principles of building matrix S_m for systems without nodes of the group "draftage". Let q_w be a nominal throughput of a reduced element $w \in N$, then, for $w < k$:

$$s_{wk} = \begin{cases} 1 \Longleftrightarrow a_{wk} = 1 \\ 0 \Longleftrightarrow a_{wk} = 0. \end{cases} \tag{26}$$

$$\left[w \in N_z\right] \Longrightarrow s_{ww} = \begin{cases} q_w \Longleftrightarrow a_{ww} = (0 \vee 3) \\ \emptyset \Longleftrightarrow a_{ww} = (1 \vee 2). \end{cases} \tag{27}$$

$$\left[w \in (N_w \vee N_u)\right] \Longleftrightarrow s_{ww} = \begin{cases} \sum\limits_{w=1}^{k-1} s_{ww}\, s_{wk} \Longleftrightarrow a_{ww} = 0 \\ q_w \qquad \Longleftrightarrow a_{ww} = 3 \\ \emptyset \qquad \Longleftrightarrow a_{ww} = (1 \vee 2) \end{cases} \tag{28}$$

States for which s_{ww} (28) fulfils the condition

$$s_{ww} \leqslant q_w \; . \tag{29}$$

proceed to the set of technically possible states of operation $\{A_m\}_{so}$ thanks to which the system works.

For known $\{A_m\}_{so}$, using the algorithms given in [19], set $\{A_m\}_{s1}$ of the technically possible states of operation, in concequence of the occurrence of states in which the system does not work, we obtain set $\{A_m\}_t$ of the technically possible states of operation of the system

$$\{A_m\}_t = \{A_m\}_{so} \cup \{A_m\}_{s1}.$$

Proceeding to systems with stacking yards, let's note that in practice we deal with systems with direct and indirect stacking yards (Fig. 14), and with systems in which both cases occur simultaneously. The formal fundations of calculating systems with stacking yards are given by Gładysz in [21, 22] and are subsequently developed in [23, 24, 25].

In view of the fact that analytical solution of the system is reduced to the solution of the system of differential-integral equations, it is essential to minimize the number of those equations, and hence the states of operation of the systems. This problem is thus reduced to the substitution of subsystems of complex series-parallel structures (Fig. 14a and b) by reduced elements (Fig. 14a$_1$, b$_1$), which is possible by using a general principle of system reduction [10, 16,7]. The idea of this procedure is illustrated in Fig. 15 where are represented two stages of reduction in Fig. 15b and 15c, respectively. Stage one consists in reducing series-structure subsystems, and thus the following sets of the system elements (Fig. 15a) correspond to the reduced elements: $1 \Rightarrow \{12.2;\ 15\}$, $2 \Rightarrow \{12.2;\ 16\}$, $3 \Rightarrow \{17;\ 18\}$, $4 \Rightarrow \{1;2;3\}$, $5 \Rightarrow \{4;5;6;11;12.1\}$, $6 \Rightarrow \{7;8;9;13;14;1\}$, $7 \Rightarrow \{10;28.1\}$. Stage two consists in reducing series-parallel structure subsystems (Fig. 15c) and thus the following sets of the system elements (Fig. 15a) correspond to the reduced elements; $1 \Rightarrow \{12.2;15\}$, $2 \Rightarrow \{14.2;16\}$, $3 \Rightarrow \{17;18\}$, 4 $\{1;2;3;4;5;6;7;8;9;10;11;12.1;13;14.1;28.1\}$. In order to determine the operational characteristics of reduced elements obtained

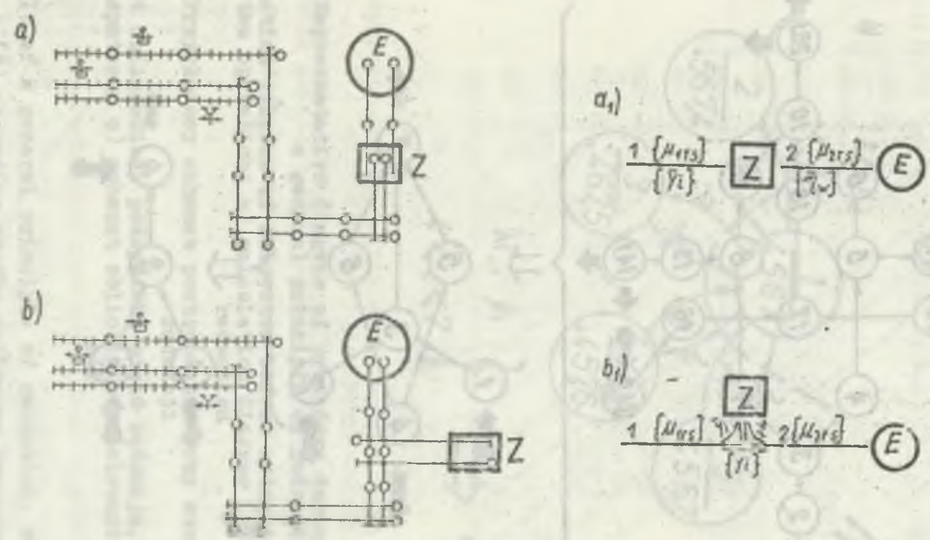


Fig. 14. Constructional-functional diagrams of systems with a) direct, b) indirect stacking yard; calculation diagrams with: a_1) direct, b_1) indirect stacking yard

Rys. 14. Schematy: konstrukcyjno-funkcjonalne systemów ze składowiskiem a) bezpośrednim, b) pośrednim: obliczeniowe ze składowiskiem a_1) bezpośrednim, b_1) pośrednim

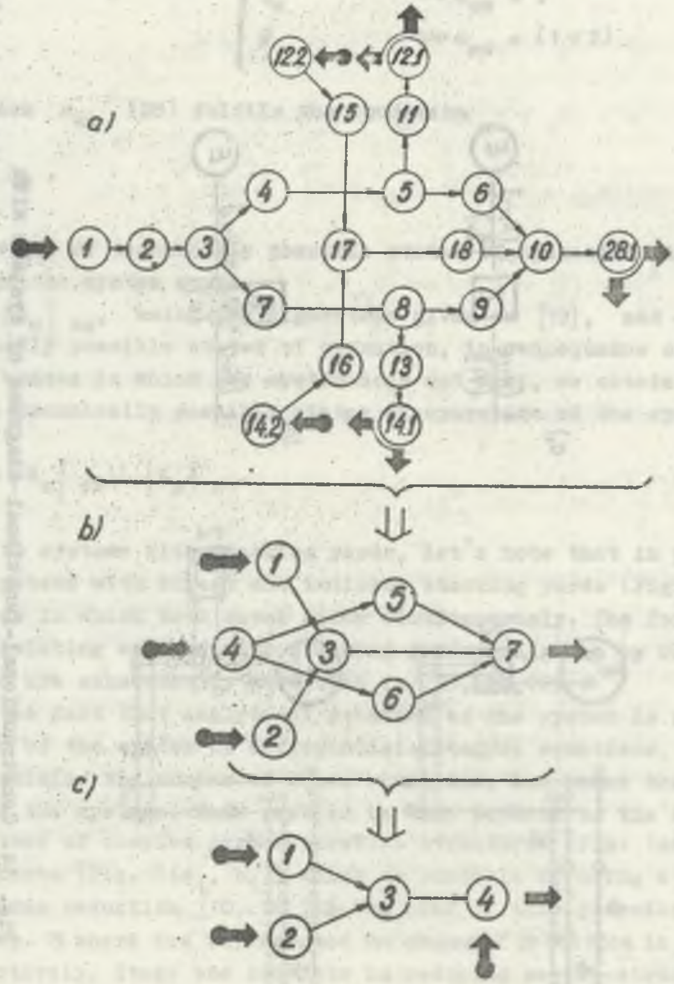


Fig. 15. Diagrams of subsystems of preparing power coal in processing plant

a) constructional-functional diagram, b) first calculation variant; c) second calculation variant

Rys. 15. Schematy podsystemu przygotowania węgla energetycznego w zakładzie przeróbczym

a) konstrukcyjno-funkcjonalny, b) obliczeniowy pierwszy wariant, c) obliczeniowy drugi wariant

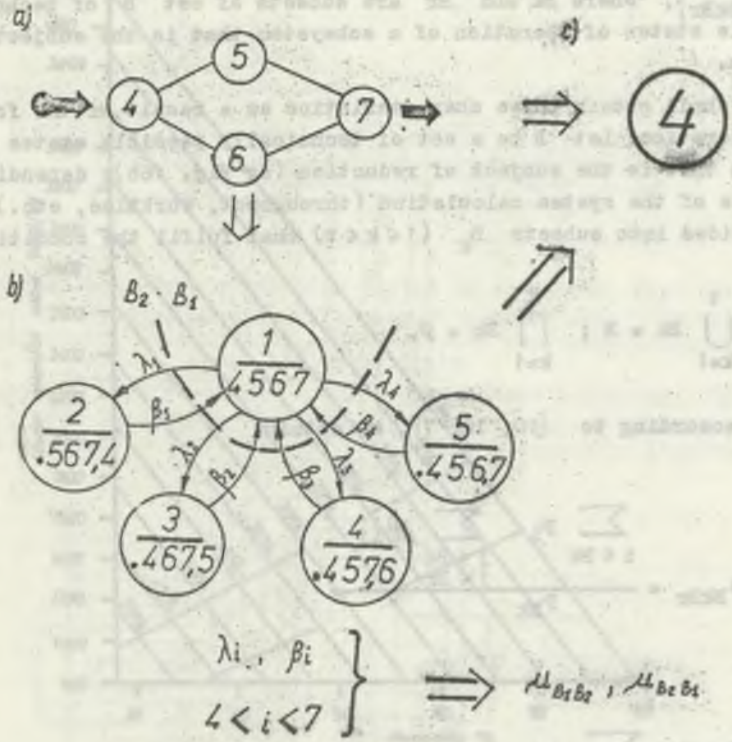


Fig. 16. Representative diagram of procedure during the application of a general principle of reduction

a) calculation diagram of subsystem before reduction; b) graph of process of subsystem operation; c) calculation diagram (reduced element) after reduction

Rys. 16. Przykładowy schemat postępowania przy stosowaniu ogólnej zasady redukcji

a) schemat obliczeniowy podsystemu przed redukcją, b) graf procesu eksploatacji podsystemu, c) schemat obliczeniowy (element zredukowany) po redukcji

as a result of a general principle of reduction, we establish a set of functions A (1) according to the following procedure:

- we exclude from the calculation diagram of the system (eg Fig. 15b) a subsystem (eg Fig. 16a) which is to be reduced;
- by means of the known methods we establish for this subsystem (eg Fig. 16a) the operational characteristics of the reduced elements of the subsystem and boundary probabilities of technically possible states of operation of the subsystem (Fig. 16b);

- we establish the operational characteristics of a reduced element $\{\mu_{BkBr}\}$, where Bk and Br are subsets of set B of technically possible states of operation of a subsystem that is the subject of reduction.

We shall obtain these characteristics as a result of the following consideration: Let B be a set of technically possible states of a subsystem that is the subject of reduction (eg Fig. 16b); depending on the purpose of the system calculation (throughput, worktime, etc.) this set is divided into subsets B_k $(1 \leqslant k \leqslant t)$ that fulfil the conditions:

$$\bigcup_{k=1}^{t} Bk = B \; ; \quad \bigcap_{k=1}^{t} Bk = \emptyset, \tag{30}$$

then, according to [10, 16, 7], we obtain

$$\mu_{BkBr} = \frac{\sum\limits_{i \in Bk} p_i \sum\limits_{\substack{j \in Bk \\ j \in Br}} \mu_{ij}}{p_{Bk}} \tag{31}$$

where

$$p_{Bk} = \sum_{i \in Bk} p_i \tag{32}$$

Simulation methods of calculating systems with stacking yards have also been developed, and the interested Reader is referred to [7, 24, 25, 26, 27, 28].

3. CONTROL OF ENGINEERING SYSTEMS IN ACTUAL TIME

In engineering practice we most often deal with the exploitation of deposits whose geological structure is as shown in Fig. 10, with minerals of high variability of relevant properties, (eg calorific value of lignite in one of the mines varies from 800 kcal/kg to 2800 kcal/kg, which is due to mineral ballast (Fig. 17). Converters of coal into secondary energy (power plants, heat and power plants) work most economically if coal (or generally - mineral) is supplied with a definite value of a relevant property ($Q^r_{i\ opt}$), otherwise considerable losses of primary energy (Fig. 18) may result.

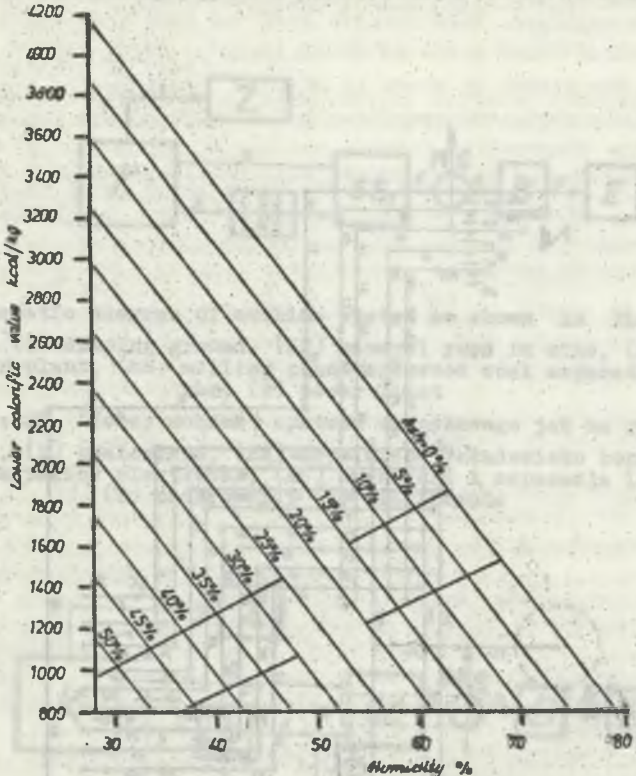


Fig. 17. Dependence of calorific value of coal upon the content of ballast according to F.W. Lautenschlager

Rys. 17. Zależność wartości opałowej węgla od zawartości balastu wg F.W. Lautenschlagera

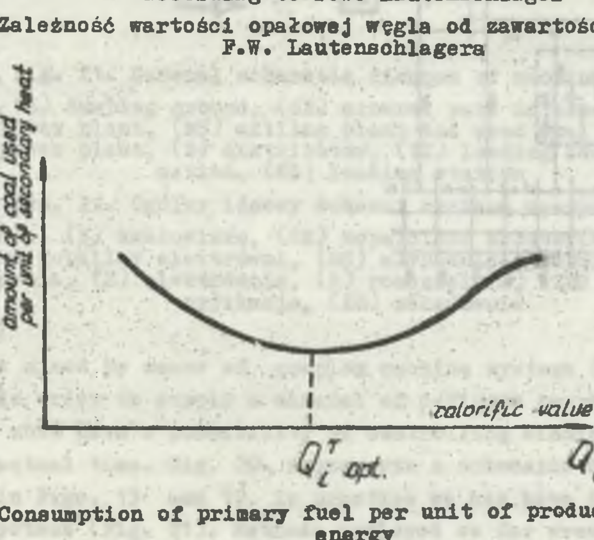


Fig. 18. Consumption of primary fuel per unit of produced secondary energy

Rys. 18. Zużycie paliwa pierwotnego na jednostkę wyprodukowanej energii wtórnej

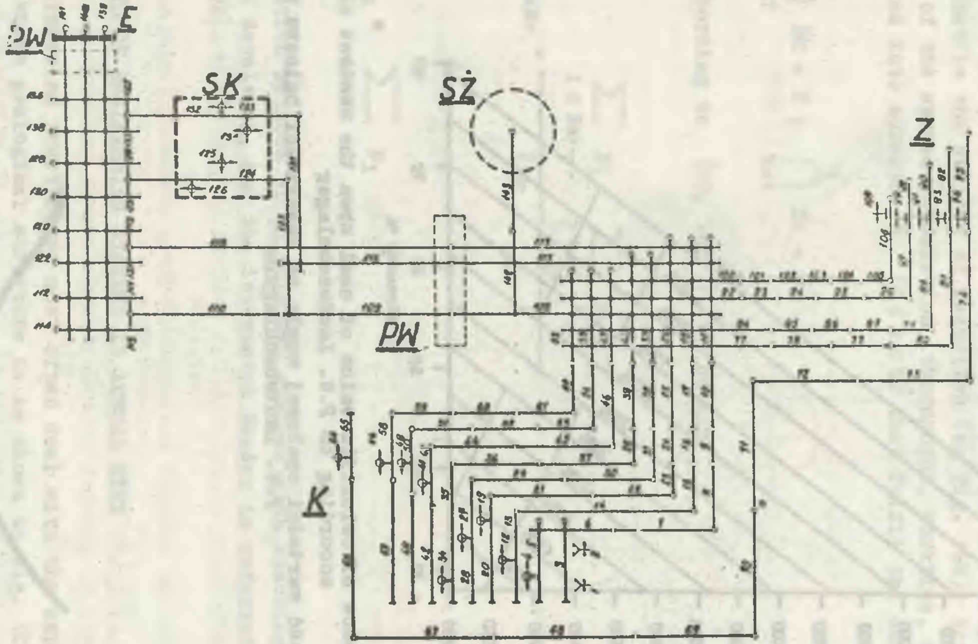


Fig. 19. Constructional-functional diagram of machine system of opencast mine (K) mine, (Z) dumping ground; (SŻ) gravel yard; (PW) measurement of quantity and quality of mineral; (SK) mineral yard

Rys. 19. Schemat konstrukcyjno-funkcjonalny systemu maszynowego kopalni odkrywkowej (K) kopalnia, (Z) zwałowisko, (SŻ) składowisko żwiru, (PW) pomiar ilości i jakości kopaliny, (SK) składowisko kopaliny

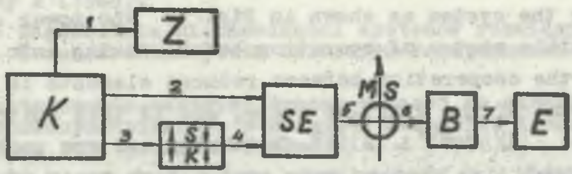


Fig. 20. Schematic diagram of machine system as shown in Fig. 13; (K) mineral, (Z) dumping ground, (SK) mineral yard in mine, (SE) mineral yard in power plant, (MS) milling plant and wood coal separation, (B) bunker, (E) power plant

Rys. 20. Ideowy schemat systemu maszynowego jak na rys. 13 (K) kopalnia, (Z) zwałowisko, (SK) kopalniane składowisko kopaliny, (SE) składowisko kopaliny elektrowni, (MS) młynownia i seperacja lignitów, (B) bunkrownia, (E) elektrownia

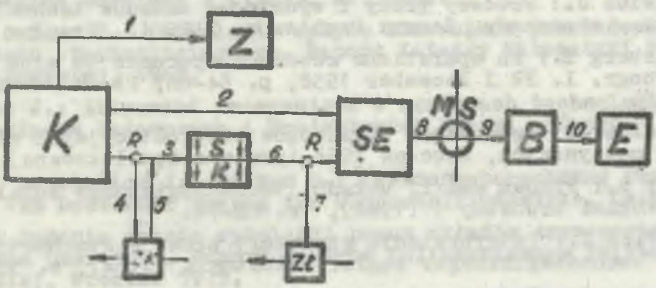


Fig. 21. General schematic diagram of machine system (K) mine, (Z) dumping ground, (SE) mineral yard in mine, (SE) mineral yard in power plant, (MS) milling plant and wood coal separation (B) bunker, (E) power plant, (R) distributor, (ZK) loading station and classification, (ZŁ) loading station

Rys. 21. Ogólny ideowy schemat systemu maszynowego (K) kopalnia, (Z) zwałowisko, (SK) kopalniane składowisko kopaliny, (SE) składowisko kopaliny elektrowni, (MS) młynownia i separacja lignitów, (B) bunkrownia, (E) elektrownia, (R) rozdzielnia, (ZK) zakładownia i klasyfikacja, (ZŁ) załadownia

Mineral is mined by means of complex machine systems (Fig. 19). In view of that, in order to supply a mineral of definite properties to the receivers, one must have a possibility of controlling winning and haulage systems in actual time. Fig. 20 represents a schematic diagram of systems as shown in Figs. 13 and 19. In practice we may have to deal with more complex systems (Fig. 21). Methods employed so far even with the help of modern automation and computer techniques prove to be ineffective as far as systems in Fig. 19 are concerned, even when the methods discussed in section 2 are employed. This results from the fact that the methods discussed in section 2 are based on an analysis of state space, and for example, for the system as shown in Fig. 19 the power of space of theoretically possible states of operation before taking into consideration matrix W of the cooperation between reduced elements is $|M| = 3^{49}.2^{1176}$ without account of the start-up state, and if this state is taken into account, then $|M| = 4^{49} \cdot 2^{1176}$. Naturally, we are unable to control the system in actual time when we have such a high power of state space even though it can be significantly reduced by using matrix W. Solution to this problem is sought in [29, 30, 31] and other papers. Its practical application, as can be seen in Fig. 18, may substantially cut down primary energy consumption.

REFERENCES

[1] Koenigsberg E.: Cyclic qu eues. Opl. Res. Quart. 9 (1958) s. 22-35.

[2] Sajkiewicz J.: Procesy pracy i wydajność układów technologicznych koparki - samochody. Zeszyt Problemowy DBPG 42, Wrocław 1965.

[3] Koenigsberg E.: An operations research approach to mine haulage. Min. Congr. I. Pł I December 1958, p. 64-68; Pł II January 1959, p. 35-56.

[4] Sajkiewicz J.: Testowanie wskaźników eksploatacyjnych elementów systemów maszynowych, Wrocław 1963 (praca niepublikowana).

[5] Gładysz S.: Proces awarii układu technologicznego kopalń odkrywkowych, Węgiel brunatny 1 (1964), s. 62-74.

[6] Sajkiewicz J.: Interpretacja struktury złoża w stochastycznym modelu układu technologicznego. Węgiel Brunatny 4 (1964), s. 363-365.

[7] Sajkiewicz J.: Podstawy teorii systemów technologicznych o ciągłych strukturach, Wyd. "Ossolineum" 1982.

[8] Jakovac M., Hadziavdic D., Sajkiewicz J., Dzindic M., Zivkowic S.: Metode izbora i analiza masinskog sistema pri selektivnom dobiranju za uslove lezista lignita "Juzna sinklinala" i "Sikulje", Savjetovanje o selektivnom dobiranju i homogenizacji u povrsinskoj eksploataciji uglja boksita i zeljeznih ruda, Tuzla 1985, s. 1-24.

[9] Gładysz S.: Wpływ rozdzielni (rozgałęzień) taśmociągów na pracę układu technologicznego kopalń odkrywkowych, Węgiel Brunatny 1 (1965), s. 43-51.

[10] Sajkiewicz J.: Ogólna zasada redukcji systemów maszynowych z transportem ciągłym, Zagadnienia Eksploatacji Maszyn 4 (1974), s. 501-508.

[11] Sajkiewicz J.: Wpływ systemu eksploatacji na wydajność układu technologicznego, Węgiel Brunatny 2 (1966), s. 90-93.

[12] Sajkiewicz J.: Wpływ ilości i długości przenośników na poziomie roboczym na niezawodność pracy układu technologicznego, Węgiel Brunatny 3 (1966), s. 217-220.

[13] Sajkiewicz J., Sajkiewicz S., Hadživdić D.: Pouzdanost rada mašinskih sistema, Delo I-V, Wrocław-Tuzla 1985.

[14] Sajkiewicz J.: Interpretacja struktury złoża w stochastycznym modelu układu technologicznego 4 (1964) s. 363-365.

[15] Battek J.: Czas pracy i awarii przenośników z punktami rewersji, Węgiel Brunatny 2 (1965).

[16] Sajkiewicz J.: Zagadnienia niezawodności systemów rozwiązywane przy pomocy grafów. Komunikat Instytutu Górnictwa Politechniki Wrocławskiej 5 (1972).

[17] Pardyka K.: Zastosowanie macierzy transponowanej do układania równań na graniczne prawdopodobieństwa stanów eksploatacji. Komunikat Instytutu Górnictwa Politechniki Wrocławskiej 4 (1972).

[18] Battek J., Dyrka K., Janczewski K., Rychlikowski E.: Model matematyczny układu KTZ w kopalni odkrywkowej, Górnictwo Odkrywkowe 2 (1969) s. 137-145.

[19] Sajkiewicz J.: Zastosowanie symboliki cyfrowej do ustalania technicznie możliwych stanów pracy systemu maszynowego i równań na graniczne prawdopodobieństwa ich zaistnienia. Komunikat Instytutu Górnictwa Politechniki Wrocławskiej 57 (1974).

[20] Sajkiewicz J.: Zastosowanie symboliki cyfrowej do ustalania technicznie możliwych stanów pracy systemu maszynowego. Zagadnienia Eksploatacji Maszyn 2 (1975) s. 219-236.

[21] Gładysz S.: Wielkości rezerw układu technologicznego kopalni "Turów". Raport Katedry Matematyki Politechniki Wrocławskiej, 1965.

[22] Gładysz S.: Niektóre aspekty teorii górniczych układów technologicznych, Przegląd Górniczy 2 (1967), s. 58-64.

[23] Król M., Galanc T.: Określenie wpływu zbiorników przeładowczych na pracę układu technologicznego. Raport Katedry Matematyki Politechniki Wrocławskiej, 1968.

[24] Sajkiewicz J.: Zbiorniki rezerwujące w systemach technologicznych. Raport Zakładów Badawczych i Projektowych Miedzi -"Cuprum" Wrocław 1967.

[25] König D., Sajkiewicz J., Stoyan D.: Leistungsberechnung für Fördersysteme. VEB Deutscher Verlag für Grundstoffindustrie, Leipzig 1985.

[26] Surma T.: Badanie metodą symulacji pracy układów transportowych ze zbiornikiem pośrednim. Raport Centrum Obliczeniowego Politechniki Wrocławskiej, Wrocław 1972.

[27] Bernardyn R., Pawluk D.: Badanie układów szeregowo-równoległych metodą symulacji. Raport Centrum Obliczeniowego Politechniki Wrocławskiej, Wrocław 1974.

[28] Dałkowski T.: Modelowanie cyfrowe systemów transportu ciągłego. Raport Instytutu Górnictwa Politechniki Wrocławskiej, Wrocław 1977.

[29] Sajkiewicz-Kręt M.: Sterowanie jakością dostaw węgla do elektrowni "Bełchatów", Raport Instytutu Organizacji i Zarządzania Politechniki Wrocławskiej, Wrocław 1981.

[30] Kręt Z.: Metoda kierowania eksploatacją w KWB "Bełchatów". Raport Instytutu Organizacji i Zarządzania Politechniki Wrocławskiej, Wrocław 1983.

[31] Sajkiewicz J.: Metoda sterowania homogenizacją węgla w KWB "Bełchatów", Raport Centrum Uczelniano-Przemysłowego WSI w Radomiu, 1982.

[32] Sajkiewicz J.: Zasada łączenia pojedynczych dynamicznych systemów masowej obsługi w dynamiczne systemy wielokrotne. Zagadnienia Eksploatacji Maszyn 1 (1978) s. 107-119.

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ROZWÓJ TEORII EKSPLOATACJI GÓRNICZYCH SYSTEMÓW MASZYNOWYCH O CIĄGŁYCH STRUKTURACH TECHNOLOGICZNYCH - PODSTAWOWE WYNIKI PRAC

S t r e s z c z e n i e

W pracy podano przykłady aktualnie pracujących złożonych wieloproduktowych systemów o ciągłych strukturach technologicznych: podano zasady ich syntezy w rozumieniu redukcji podsystemów o strukturach szeregowych, a także o strukturach szeregowo-równoległych; podano zasady uwzględnienia w procesie obliczeń systemów struktury i budowy geologicznej urabianych skał (kopalina, nadkład); omówiono sposoby ustalania przestrzeni technicznie możliwych stanów eksploatacji systemów ze szczególnym uwzględnieniem metody algorytmicznej przystosowanej do stosowania na m.c; omówiono problem sterowania systemami w czasie rzeczywistym. Z uwagi na objętość pracy ograniczono się do syntezy wyników odsyłając zainteresowanych do prac źródłowych.

Również z uwagi na objętość pracy nie omówiono niektórych istotnych zagadnień, jak np. warunki rozruchu w metodzie algorytmicznej, zasady dekompozycji systemów (rys. 12), zasady uśredniania cech kopalin na składowiskach.

РАЗВИТИЕ ТЕОРИИ ЭКСПЛУАТАЦИИ ГОРНЫХ МАШИННЫХ СИСТЕМ СО СПЛОШНЫМИ ТЕХНОЛОГИЧЕСКИМИ СТРУКТУРАМИ - ОСНОВНЫЕ РЕЗУЛЬТАТЫ РАБОТЫ

Р е з ю м е

В работе представлены примеры актуально работающих сложных многопродуктных систем о сплошных технологических структурах, представлены принципы их синтезов в понимании редукции подсистем с последовательными структурами и также со структурами последовательно - параллельными. Представлены тоже принципы учитывания в процессе рассчетов систем структуры и геологического строения разрабатываемых горных пород (ископаемое, вскрыша). Показаны способы фиксирования пространства технически возможных состояний эксплуатации систем с особенным учётом аглоритмического метода приспособленного для применения ЭВМ. Представлена проблема управления системами в реальном времени. Из-за того, что работа обширная, не представлены некоторые существенные проблемы, нпр. условия пуска в методе аглоритмическом, принципы декомпозиции систем (рис. 12), принципы усреднения свойств ископаемых на складовой площадке.