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THE DETERMINATION OF DIRECT CONTROL ALGORITHMS ACTIVATION MOMENTS USING A REAL-TIME SCHEDULING ALGORITHM

ANDRZEJ GOŚCIŃSKI, KRZYSZTOF ZIELIŃSKI

The determination problem of direct control algorithms activation moments using a heuristic real-time scheduling algorithm and information concerned with the control quality deterioration is solved. The algorithm for scheduling control computations has been constructed and is presented here. For a reason that this scheduling algorithm operates on dynamic priorities of several direct control algorithms, these ones have been constructed based on information concerned with the performance index deterioration. Using simulation, the proposed scheduling algorithm is compared with periodic scheduling and classic scheduling based on dynamic priority assignment.

1. INTRODUCTION

Let a production system be controlled by a multilayer control system (Fig. 1). A class of systems in our particular interest is a continuous-type production process, i.e. the variables $\mathbf{u}$, $\mathbf{z}$ and $\mathbf{y}$ denote the manipulated input, disturbance input, and output vectors respectively all being continuous in time. However, in particular implementation of computer control, $\mathbf{u}$ may be piecewise constant and $\mathbf{y}(t)$ is generally determined at discrete time instants. Moreover, we restrict our attention to the process designed for a quasi-steady-state optimization.

In this considered control system, the first, direct control layer, applies controlling inputs $\mathbf{u}$ to the process, for the output $\mathbf{y}$ to follow a desired trajectory $\mathbf{y}^z$. This trajectory is determined by the second optimization layer. The organizing layer determines, solving other problems, the control algorithms activation moments.

This paper deals with the problem of determining the activation moments of the direct control algorithms using a real-time scheduling algorithm, and information concerned with the deterioration of control quality defined by a performance index deterioration. The overall motivation of this study is that our approach gives better actions results than using an approach based on constant intervals of the algorithms activation, used up until today.

In this article, we constructed a priority heuristic scheduling algorithm. Priorities of several direct control algorithms (tasks) have been defined using information about the control quality deterioration as a function of activation intervals. The activation

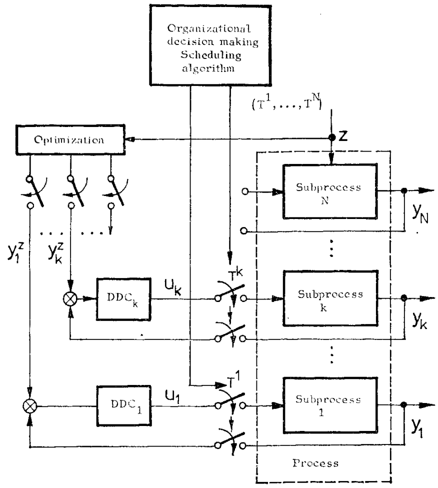

Fig. 1. Multilayer control system; $\boldsymbol{u} = (\boldsymbol{u}_1, \ldots, \boldsymbol{u}_N)$, $\boldsymbol{z} = (\boldsymbol{z}_1, \ldots, \boldsymbol{z}_N)$, $\boldsymbol{y} = (\boldsymbol{y}_1, \ldots, \boldsymbol{y}_N)$.

moments have been determined to minimize the control quality deterioration as well as a solution of a trade-off problem between the performance level achieved and control actions costs.

2. SOLUTION OF THE ACTIVATION MOMENTS DETERMINATION USING THE SCHEDULING ALGORITHM OF A CONTROL COMPUTER

We assumed, as has been presented in Fig. 1, that a direct control layer uses a simple feedback structure, although more complex structures with the same objective are, of course, possible. The general problem we consider is described below.

There are N closed-loop systems. The k-th continuous-time controlled process is described in the time horizon $[0, T]$ by the following well known linear equations:

$$
(1) \qquad \frac{\mathrm{d}}{\mathrm{d}t}\,\mathbf{x}_k(t) = \mathbf{A}_k(t)\,\mathbf{x}_k(t) + \mathbf{B}_k(t)\,\mathbf{u}_k(t)
$$

$$
\mathbf{x}_k(0) = \mathbf{x}_{k0}
$$

$$
\mathbf{y}_k(t) = \mathbf{C}_k(t)\,\mathbf{x}_k(t) + \mathbf{z}_k(t)
$$

$$
k = 1, \dots, N\,, \quad t \in [0, T]\,.
$$

The performance index at time t of the k-th closed-loop system may be given in general scalar form as follows:

$$
(2) \qquad Q_k^p(t) = f_k(\mathbf{u}_k, \mathbf{y}_k, \mathbf{y}_k^z, t)
$$

The optimal control algorithm should minimize the average value of performance index in time horizon $[0, T]$

$$
Q_k^p(0, T) = \frac{1}{T}\int_0^T f_k(\mathbf{u}_k, \mathbf{y}_k, \mathbf{y}_k^z, t)\,\mathrm{d}t
$$

In implementations of computer control, $\mathbf{u}_k$ may be the piecewise constant. Its change in value is realised in discrete moments of time t_i^k, $i = 1, \dots, n_k$, $t_1^k \geqq 0$, $t_n^k \leqq T$, where these values define the decision making moments. In time segments (t_i^k, t_{i+1}^k), $i = 1, \dots, n_k$, control values are constant and do not depend on disturbances changes. In general, they differ from the optimal ones computed for the continuous system. This implies a performance index difference of the k-th closed-loop system. Thus, this difference at the time moment $t \in [0, T]$ may be expressed by the formula:

$$
(3) \qquad \delta_k(t) = f_k(\mathbf{u}_k^c, \mathbf{y}_k^c, \mathbf{y}_k^z, t) - f_k(\mathbf{u}_k^0, \mathbf{y}_k^0, \mathbf{y}_k^z, t)
$$

where: $\mathbf{u}_k^0$, $\mathbf{y}_k^0$ – control and output of the continuous controlled process in the time horizon $[0, t]$, respectively; $\mathbf{u}_k^c$, $\mathbf{y}_k^c$ – control and output of the computer controlled process, respectively,

$$
\mathbf{u}_k^c \in \{\mathbf{u}_k : \mathbf{u}_k(t) = \mathbf{u}_k(t_i^k) \text{ for } t_i^k \leqq t < t_{i+1}^k,\ i = 1, \dots, n_k\}\,.
$$

It can be positive for same t and negative for other. The optimal computer controller is a discrete adequacy of the optimal continuous controller.

The average deterioration of the control quality in the k-th closed-loop system in the time segment (t_i^k, t_{i+1}^k) is denoted in the following way:

$$
(4) \qquad \Delta Q_k^p(t_i^k, t_{i+1}^k) = \frac{1}{t_{i+1}^k - t_i^k}\int_{t_i{}^k}^{t_{i+1}{}^k} \delta_k(t)\,\mathrm{d}t\,.
$$

The k-th performance index deterioration in the time horizon $[0, T]$ depends on both the choice of activation moments of the control algorithm, $0 \leqq t_1^k < t_2^k < \dots$ $\dots < t_{n_k}^k \leqq T$, and their number, i.e., the value of n_k.

In further considerations we will use the schedule $\Delta_k[0, T]$, $k = 1, \dots, N$. This is formally denoted as follows:

$$\Delta_k[0, T] \in \{\{t_i^k\} : t_i^k < t_{i+1}^k,\ t_i \in [0, T],\ i = 1, \ldots, n_k\}\,. \tag{5}$$

Now, the k-th performance index deterioration may be denoted as follows:

$$\Delta Q_k^P(\Delta_k[0, T]) = \frac{1}{T}\left\{\int_0^{t_1{}^k} \delta_k(t)\,\mathrm{d}t + \sum_{i=1}^{n_k-1}\int_{t_i{}^k}^{t_{i+1}{}^k} \delta_k(t)\,\mathrm{d}t + \int_{t_{n_k}{}^k}^{T} \delta_k(t)\,\mathrm{d}t\right\} \geqq 0 \tag{6}$$

and is greater or equal to zero.

The total deterioration of the control quality for N closed-loop systems is expressed by the sum:

$$\Delta Q^P(\Delta[0, T]) = \sum_{k=1}^{N} \Delta Q_k^P(\Delta_k[0, T]) \tag{7}$$

where

$$\Delta[0, T] = (\Delta_1[0, T], \ldots, \Delta_N[0, T])\,. \tag{8}$$

The object is to find a schedule for the control algorithms of closed-loop systems (the moments of their activation) that minimize the total deterioration of the control quality. Such a schedule is, of course, fully specified by the activation moments sequence of the control algorithms. All these algorithms are to be computed by a single machine (processor). The problem stated above is solved by the organizing layer.

Let us look at this minimization problem from a control computer viewpoint. The scheduling algorithm determines a sequence of control algorithms (tasks) and defines their activations times so that the computation of the algorithms, according to a given schedule and at the indicated moments, optimizes the performance index. The above scheduling problem is equivalent to the scheduling algorithm problem of an operating system for the control computer when the performance index is the same for both problems.

Taking into account that all control algorithms are processed by a single machine, the schedule is obtained with essential constraints given by the formula:

$$\sum_{k=1}^{N} n_k p_k \leqq T\,, \tag{9}$$

were p_k is the processing time of the k-th control algorithm.

The problem which arises now is to construct a suitable scheduling algorithm. Since we dispose of information concerned with each scheduled task (control algorithm) at each time t given by the performance index deterioration, we propose to construct the scheduling algorithm with dynamic priorities for the tasks. The dynamic priorities are to be constructed on the basis of the deterioration functions. Another problem is the scheduling procedure. A study of various strategies has shown that a new construction of the scheduling algorithm should be done.

3. CONSTRUCTION OF THE CONTROL ALGORITHMS DYNAMIC PRIORITIES

The average control quality deterioration of the k-th closed-loop system is a function of the time segment length $[t_i^k, t_{i+1}^k)$. Let $T_i^k = t_{i+1}^k - t_i^k$.

The problem is to define the control quality deterioration as a function of the length T^k. (Since T^k is an argument of the function $\Delta Q_k(T^k)$ the subscript i may be omitted). In practice, that function may be constructed as follows. Assuming that the control algorithm structure and its parameters are optimal with regard to the performance index for the given T^k and the given class of the disturbances $\mathbf{z}_k$, one can repeat the choice of the control algorithm parameters. For this we must use various T^k, changing it from 0 (i.e. continuous time control system) to the value equal, for example, 30% of the greatest process time constant. For each T^k we can get the optimal value of the assumed performance index. As a result of this process we will get various values of the performance index as a function of the activation period T^k.

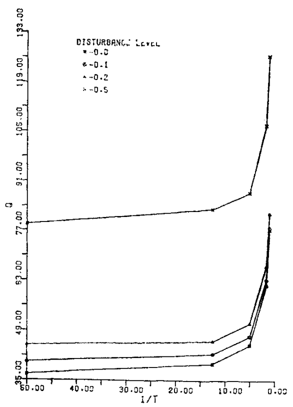

Fig. 2. The exemplary deterioration of the performance index.

Finally, the deterioration of the performance index Q_k^P for the increasing activation period may be presented using the function $\Delta Q_k^P(T^k)$. It is well known, that this function has a monotonic property, i.e. $\mathrm{d}(\Delta Q_k^P)/\mathrm{d}T^k > 0$.

The exemplary deterioration is depicted in Fig. 2 for the performance index given by formula:

$$\Delta Q_k^P = \mathsf{E}\{| \sum_{i=1}^{n_k} \mathbf{e}_k^0(iT^k))^2 \, T^k - \sum_{i=1}^{n_k} (\mathbf{e}_k(iT^k))^2 \, T^k |\} \tag{10}$$

where $\mathbf{e}_k^0 = \mathbf{y}_k^z - \mathbf{y}_k^0$, $\mathbf{e}_k = \mathbf{y}_k^z - \mathbf{y}_k$. The process is described by the equation:

$$G_0(s) = \frac{e^{-\Theta s}}{(as + 1)(bs + 1)} \tag{11}$$

and controlled by the digital PID controller denoted by the relation:

$$\mathbf{u}_k(iT^k) = K\left[\mathbf{e}_k(iT^k) + \frac{T_D}{T^k}\left[\mathbf{e}_k(iT^k) - \mathbf{e}_k((i-1)T^k)\right] + \frac{T^k}{T_I}\sum_{j=1}^{i-1}\mathbf{e}_k(jT^k)\right] \tag{12}$$

where K, T_D, T_I – optimal controller parameters.

It has been assumed that: (i) $\theta = 1$, $a = 6{\cdot}70$, $b = 3{\cdot}26$, (ii) white noise, which is used as the disturbance signal $\mathbf{z}_k(iT^k)$, has four exemplary amplitude values, i.e., 0%, 10%, 20%, and 50% of the signal $\mathbf{y}_k^z(iT^k)$.

The desired trajectory $\mathbf{y}^z(iT_k)$ is the signal defined by the optimization layer of the control system, as shown in Fig. 1.

The example given above confirms the hypothesis stated earlier and concerned with the performance index deterioration and the possibility of using this function to characterize the control algorithm as a scheduled task.

The controllers of the type studied above and the other ones which have been analyzed, i.e. PI, PIDD^2, Smith's controller (all of them of the discrete nature) have a property that the optimal parameters of them are little sensitive on a change of the length T^k in some range around the nominal value of it. This implies that T^k can vary without adaptation of the controller parameters.

Another important parameter for our approach is the completion time of the last computation of the k-th control algorithm denoted here by t_k. Taking into consideration that p_k is processing time of the k-th control algorithm, it may be described from the scheduling process viewpoint by the triple $(\Delta Q_k^P(T^k), t_k, p_k)$. The dynamic feature of the task is given by the first element of this triple and is a dynamic priority of the control algorithm.

The next problem connected with the dynamic priority function is generated by some real-time operating system requirements. They may be formulated as follows: (i) programs implementing the functions of the real-time operating systems ought to be very effective and short from the computing time viewpoint and (ii) amount of core storage is limited. This implies the suitableness of an approximation of the $\Delta Q_k^P(T^k)$ function by a more simple one. Our studies, concerned with the above problem, show that the best results assure the approximation given as follows:

$$Q_k(T^k) = \begin{cases} 0 & \text{for} \quad T^k \leqq d_k \\ \alpha_k(T^k - d_k) & \text{for} \quad T^k > d_k \,, \end{cases} \tag{13}$$

where the coefficient α_k defines performance index sensitivity of the k-th closed-loop system into the increase of the activation interval.

Taking the above into consideration the scheduling problem may be solved in such a way as to minimize the performance index defined as follows:

$$Q = \sum_{k=1}^{N} \sum_{i=1}^{n_k} Q_k(t_{i+1}^k - t_i^k)\,. \tag{14}$$

4. DESCRIPTION OF THE SCHEDULING ALGORITHM

The scheduling algorithm, utilizing dynamic priorities, has been constructed on the basis of the work referred to in [6] and discussed in detail in work [4].

An idea of the algorithm utilizes moreover a precedence relation defined as follows:

$$\forall P_j, P_i \in \{P\} : (P_j \prec P_i) \Leftrightarrow (t_j + d_j \leqq \max [t_i + d_i, t_i + p_i] \wedge \wedge\, \alpha_j \geqq \alpha_i \wedge p_j \leqq p_i) \tag{15}$$

where P_j, P_i define the direct control algorithms, and $\{P\}$ the set of direct control algorithms, t_j, t_i the completion time of the last computation of the algorithms P_j and P_i, respectively.

The precendence relation, defined in such a way, is invariant with time. That means that if $P_j \prec P_i$ at the moment t, then $P_j \prec P_i$ for $t + \Delta t$, where $\Delta t > 0$ means, of course, any increment of the time. This relation orders all algorithms implementing direct control actions and defines these that are first in an optimal schedule. Since the precedence relation is the partial order relation, two or more algorithms may be defined. For this reason one of them must be chosen. This problem has been solved on the basis of an heuristic approach that utilizes the following information: the values of the dynamic priorities at this time moment, processing times and logical names (indexes k, $k = 1, \ldots, N$). The flow chart of the proposed heuristic scheduling algorithm is given in Fig. 3. In the flow chart, t denotes the current moment of time, and $\gamma(k)$ is defined as follows:

$$\gamma(k) = \begin{cases} \min j & \text{if } j \in \{l : P_l \in \{P\}_{\mathrm{OPT}} \text{ and } l > k\} \\ \emptyset & \text{in other cases} \end{cases}$$

where

$$\{P\}_{\mathrm{OPT}} = \{P_k : P_k \in \{P\} \text{ and } \nexists P_i : P_i \prec P_k,\ \forall_i : P_i \in \{P\},\ i \neq k\}\,.$$

5. AN ESTIMATION OF THE PROPOSED METHOD FOR THE ACTIVATION MOMENTS DETERMINATION

To show the proposed scheduling algorithm effectiveness and utility, as a solution of the organizational layer decision making problem, simulation studies have been done.

The investigations have been carried out using the set of 60 control algorithms,

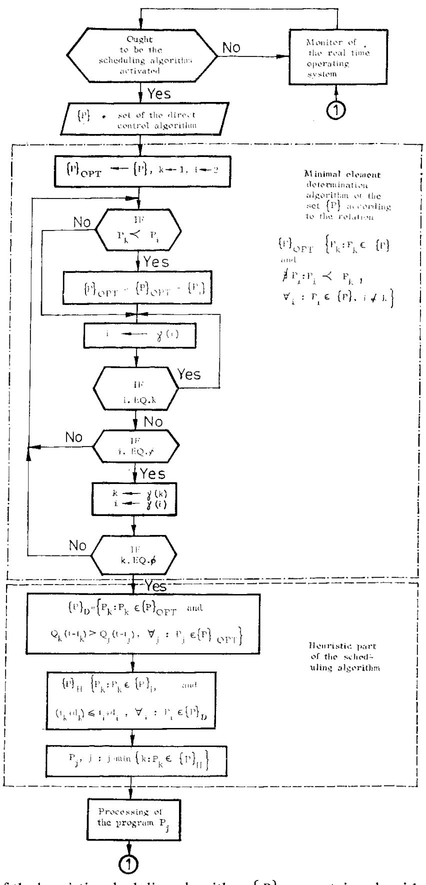

Fig. 3. Flowchart of the heuristic scheduling algorithm; $\{P\}_D$ — contains algorithms whose dynamic priorities at this time have maximum values; $\{P\}_H$ — contains algorithms whose next time of processing starts to have minimum values.

of which 49 ($k = 1, \ldots, N = 49$) required periodic service and the remaining ones ($k = N + 1 = 50, \ldots, R = 60$) were activated at random. The incidental algorithms were activated according to the results of the stochastic procedure activated after each interval H. This one generated the following data: the activated programs numbers (the number from the set $\{k = 50, \ldots, 60\}$), the activation time moments (in the time horizon $(t, t + H)$, where t is an actual time). Q_{DDC}, Q_R denote the values of the performance index oriented towards the direct digital control algorithms and algorithms activated at random, respectively. The parameters of the algorithms are shown in Table 1. The table contains complete data as an example from all the

Table 1.

Number of Control Algorithm	Computation Time p_k	Conditions					
		W1		W2		W3	
		d_k	α_k	d_k	α_k	d_k	α_k
1–5	1	50	50	75	50	250	50
6–10	1	50	40	75	40	250	40
11–15	2	50	40	75	40	250	40
16	2	75	40	115	40	375	40
17–20	1	75	40	115	40	375	40
21–25	2	50	30	75	30	250	30
26–35	1	150	20	225	20	750	20
36–45	2	150	30	225	30	750	30
46–49	2	300	20	450	20	1500	20
50	100	100	1	100	1	100	1
51–53	2	50	50	75	50	250	50
54–56	1	75	40	115	40	375	40
57–58	1	50	40	75	40	250	40
59	1	50	20	75	20	250	20
60	2	50	20	75	20	250	20

Table 2.

Condition	T	H	$\min\{d_k\}$ $k \in \{1, \ldots, N\}$	$\sum_{k=1}^{N} p_k$
W1	3 000	500	50	74
W2	4 500	750	75	74
W3	10 000	2 500	250	74

investigated sets of data selected at random. Three groups of parameters have been taken into consideration to assure processor loads given in Table 2.

For comparison, some simulation studies have been carried out for two well known and applied scheduling algorithms [1, 7], i.e.:

(i) periodical algorithm – those which determine schedule of the control algorithms characterized by the time intervals d_k, $k = 1, \ldots, N$;

(ii) algorithm with dynamic priorities – which always activates an algorithm whose value of the dynamic priority function has a maximum value; the dynamic priority function proposed in this work has been used.

The both algorithms effectiveness have been estimated also using the performance index given by formula (14).

The comparison of these three scheduling algorithms is presented while using the relative numbers given in Table 3.

Table 3.

Scheduling Algorithm	Conditions								
	W1			W2			W3		
	Q	Q_R	Q_{DDC}	Q	Q_R	Q_{DDC}	Q	Q_R	Q_{DDC}
Periodical	679	250	429	459	332	127	756	747	4
With Dynamic Priorities	757	225	532	600	330	270	822	736	86
Heuristic	268	224	43	332	329	3	751	738	13

Analysis of Table 3 points out that the scheduling algorithm exerts a strong influence on the operating costs. In this case, the algorithm utilizing heuristic methods is the most effective. The heuristic scheduling algorithm gave much better results than the periodical algorithm for heavy loading of the computer, in conditions W1 and W2. These algorithms gave comparable results in conditions W3. The algorithm utilizing the dynamic priorities decidedly shows much worse results than the two remaining algorithms.

From graph Fig. 4 obtained with the help of a plotter, it is evident and confirms the above assumptions that heuristic algorithm possesses a very important feature, namely, an ability to discharge the accumulations. Periodical scheduling algorithms used nowadays lack this property. The same concerns the algorithms with dynamic priorities. The ability to discharge the accumulations is very important when multi-layer control systems are used. The accumulations of the direct control algorithms in this system are generated by the optimization algorithm activations because at these times all algorithms of the lower layer must be computed. This property must also be taken into consideration when many algorithms activated at random must be computed. The analysis of Fig. 5 indicates the operating costs accumulations when the control horizon increases, with both the periodical scheduling algorithm and the algorithm with dynamic priorities.

The simulation results of the execution process of the control algorithms computed according to the heuristic scheduling algorithm decision making, shows that the control algorithms after the accumulations discharge are activated periodically, with intervals equal d_k, $k = 1, \ldots, N$.

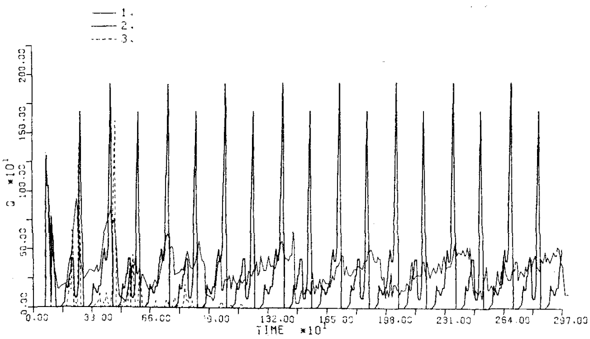

Fig. 4. Graph-plotter showing the discharge accumulation abilities of scheduling algorithms under the test; 1 — algorithm with dynamic priorities; 2 — periodical algorithm; 3 — heuristic algorithm.

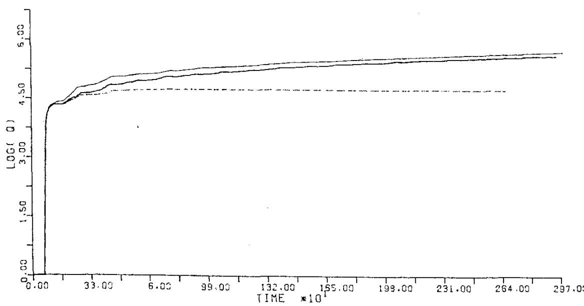

Fig. 5. Behaviour of indices, evaluating the control quality deterioration with the increase of the control horizon.

Moreover, the investigations carried out contain the analysis of the average times spent on the choice of one control algorithm by various scheduling algorithms. The results have been given in Table 4. (The algorithms have been simulated by the computer system CYBER 72 of CDC). They say that the times of the heuristic algorithm and the algorithm with the dynamic priorities are comparable and they

Table 4.

	Scheduling Algorithm		
	Periodical	With Dynamic Priorities	Heuristic
Average Choosing Times of One Program in Seconds	0·00130	0·00515	0·00550
Amounts of the Core Storage in Words	150	50	70

are about 4 times worse than the average time spent by the periodical algorithm. After all, it seems that the choice time of one program is so short that the heuristic scheduling algorithm has a chance to be used in practice being much better than the periodical one (the discussion concerned with the operation costs and the accumulations discharging). The estimated amounts of the core storage required by the several discussed algorithms are given in Table 4 (programs have been coded in FORTRAN).

6. IMPLEMENTATION COSTS INFLUENCE ON BOTH THE TOTAL OPERATING COSTS AND THE FREQUENCY OF THE CONTROL ALGORITHMS ACTIVATION

To solve this problem, we will generalize the problem stated in Section 2. Let us consider the control actions implementation costs. Based on the results presented in [4, 5], let us assume, that the control actions implementation costs of the k-th closed-loop system are defined in the time horizon $[0, T]$ as $\Delta Q_k^c(T^k)$. That function has a monotonic property, and $\mathrm{d}(\Delta Q_k^c(T^k))/\mathrm{d}T^k \leqq 0$.

The total implementation costs of the production process represented by N closed-loop systems are presented by the formula

$$\Delta Q^c(\Delta[0, T]) = \sum_{k=1}^{N} \Delta Q_k^c(\Delta_k[0, T]), \tag{16}$$

where $\Delta[0, T]$ is given in (8). The total operating cost is the sum of the shape

$$\Delta Q(\Delta[0, T]) = \Delta Q^r(\Delta[0, T]) + \Delta Q^c(\Delta[0, T]). \tag{17}$$

The object now is to find a schedule for the control algorithms (the activation moments) of closed loop systems that minimizes the total operating costs.

Since the above generalizations have been made, the description of each control algorithm from the scheduling algorithm viewpoint must be extended. An extension is oriented towards the dynamic properties of the task and caused by the control actions implementation costs. The k-th control algorithm is described now by the following quadruple: $(\Delta Q_k^P(T^k), \Delta Q_k^C(T^k), t_k, p_k)$. $\Delta Q_k^P(T^k)$ is the increasing function whereas $\Delta Q_k^C(T^k)$ is the decreasing function of the interval T^k. So, there is an optimal activation interval d_k that minimizes the sum of the expressions given by (16) and (17). Moreover, the introduction of the coefficient α_k defining the operating costs sensitivity of the k-th closed-loop system into the activation period increase is suitable. That implies, that the dynamic priority of each control algorithm is defined by a function given by the formula (13).

In the light of the above argument it seems very interesting to present both the implementation costs influence on the scheduling process performance index and on the frequency of the control algorithms activation. It has been assumed that the control actions implementation costs are constant and not dependent on the activation period. Investigations were carried out for three values of C_k, $k = 1, \ldots, R$: 0, 300, 600.

Table 5.

Conditions	Implementation Costs of Control Actions								
	$C_k = 0$			$C_k = 300$			$C_k = 600$		
	Q	Q_R	Q_{DDC}	Q	Q_R	Q_{DDC}	Q	Q_R	Q_{DDC}
W1	268	225	43	599	8	591	530	7	523
W2	332	329	3	646	9	637	552	6	546
W3	751	738	13	984	2	982	719	8	711

Table 6.

Number of Control Algorithm	C_k					
	0		300		600	
	f_k	f_{0_k}	Number of Control Algorithm	f_k	Number of Control Algorithm	f_k
1—10	60	60	1— 5	54	1— 5	49
11—12	59	60	6— 7	53	6—10	46
13—15	58	60	8—12	52	11—15	45
16	39	40	13—15	51	16	32
17—20	40	40	16—20	36	17—20	33
21—23	58	60	21—23	48	21—25	40
24—25	56	60	24	48	27—45	16
26—35	20	20	25	46	46—50	9
36—44	19	20	26—45	18		
45	18	20	46	19		
46—50	9	10	47—50	9		

The implementation costs influence on the total operating costs measure is presented in Table 5 using relative numbers. The influence of the implementation costs on the activation frequency of individal algorithms is presented in Table 6 as an example for condition W1 (f_{0_k} is the calculation frequency at which the control algorithm P_k is carried out at costs equal to zero, $f_{0_k} = T/d_k$; f_k represents the frequencies obtained in the course of simulation investigations carried out at $C_k = 0$).

7. CONCLUSIONS

The investigations and presented discussions carried out permit the formulation of several conclusions. First of all, the determination of the control algorithms activation moments (as a problem of organizational layer decision making) may be solved in an effective way using a real time scheduling algorithm for control computer. Secondly, the proposed scheduling algorithm is much better than the periodical conventional scheduling algorithm in the sense of the total control quality deterioration. This is caused by the following factors: (i) periodical scheduling algorithm is based on the fixed times of the control algorithm activation and on the static priorities. It is necessary to know some special characteristics of these algorithms, i.e. the control quality deterioration and the implementation costs as the functions of the increasing activation period, (ii) possibility lack to discharge the algorithms accumulations, and (iii) losses in the control quality due to the delay of the control algorithms activation.

The proposed approach and its final result, (i.e. scheduling algorithm), is deprived of these unprofitable features. Moreover, it has been shown that the dynamic priorities may be constructed in an effective way while using information connected with the control quality deterioration of several closed-loop systems and the implementation costs of the control actions as activation period function.

The accumulation discharge ability of the heuristic scheduling algorithm and the periodical activation of the control algorithms after a discharging time indicate that it is possible to use the heuristic scheduling algorithm only at the time segments when a recognition of an interrupt signal implies the damage situations service (the tasks accumulation). After the accumulation discharge, the conventional periodical scheduling algorithm may be used for its greater computation time effectiveness.

The stimulation studies have shown the influence of the control actions implementation costs on the frequency of individual control algorithms activation. The changing of the control algorithms activation frequency induce considerable increase in the total operating costs measure.

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