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Structures and efficiency areas of object control systems with various types of recycling

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Abstract. The work is devoted to the study of automatic control systems (ACS) of objects with various types of recycling. The characteristic feature of such objects is the presence of a delay element in the coordinates. It is known that only with the help of recycling the use of raw materials and energy resources can be maximized. However, little attention has been paid to the control of such objects in the well-known publications, which gives the study a particular importance. The paper describes a classification of objects with recycling proposed by the authors with the identification of four classes of objects: recycling "by concentration", "by mass", "by parameters", combined recycling. ACS are synthesized for the first three classes of objects. The task of comparative analysis of the systems effectiveness with a model control law and the proposed synthesized systems is set, as well as the task of determination of areas of systems effective operation depending on the variable value of the ratio of the delay time in the recycling chain and in the direct circuit, the conclusions are drawn.

1. Introduction

Increase in the efficiency of technological processes of raw materials processing, environmental processes, and sometimes their feasibility is achieved through the introduction of positive feedbacks in controlled objects (objects with recycling). Examples of such objects include water-slime systems for mineral processing, pelletization of materials during the production of agglomerate in metallurgical production, socio-economic systems in the allocation of material and financial resources, in a variety of chemical processes [1, 2], in the formation of fractal structures of materials [3 - 6]. The introduction of positive feedbacks into controlled objects gives them qualitatively new properties, significantly changes the dynamics of behavior and complicates the control process.

2. Methods of research

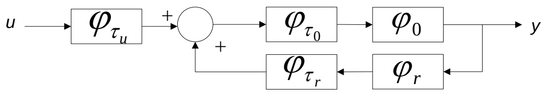
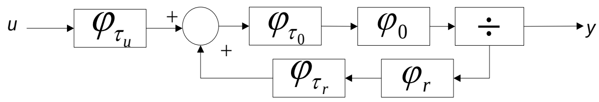
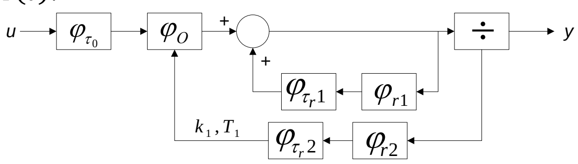
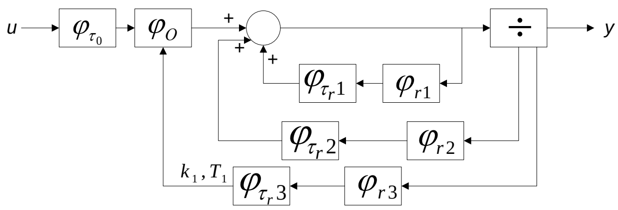
Mathematical models of objects with a recycling in the state space in the general form are described by the expressions [7]:

$$\dot{X}(t) = A(t) \cdot X(t-\tau_x) + B(t) \cdot U(t-\tau_u) + C(t) \cdot W(t-\tau_w);$$
$$Y(t) = D(t) \cdot X\left(t-\tau_y\right) + F(t) \cdot E(t-\tau_e),$$

where X, U, W, Y, E – vectors of states, control, external influences, outputs and measurement errors; $\tau_x, \tau_u, \tau_w, \tau_y, \tau_e$ – corresponding delay times; $A(t), B(t), C(t), D(t), F(t)$ – matrices of the corresponding dimensions; t – continuous time.

Classification of objects with recycling, depending on the type of recycling and its effect on the controlled object is presented in table 1 [8].

Table 1. Classification of objects with recycling (with indication of the structure of the object model).

1 class	2 class
Object with recycling "by concentration". All material costs are fixed and the concentration of elements (temperature, etc.) of the material varies. The matrix $A(t)$ does not depend on the state $X(t)$ and $D(t) = 1$. 	Object with recycling "by mass". For the output action a part of the material (finished product) arriving at the outlet of the object is taken and the other part of the material enters the recycling chain. The matrix $A(t)$ depends on the state $X(t)$ and $D(t) \neq 1$. 
3 class	**4 class**
Object with recycling "by parameters". The recycling affects the parameters of their individual components. In this case the matrices $B(t)$ and $C(t)$ depend on the state $X(t)$. 	Object with a combined recycling. 

For the objects with recycling "by concentration", "by mass", "by parameters", the automatic control systems (ACS), presented in figure 1 [9 - 12], were synthesized.

For the obtained ACS and ACS with a model control laws a comparative efficiency analysis was carried out, and areas of effective system operation were determined depending on the ratio of the delay times in the recycling chain and in the direct chain.

3. Results and discussion

Formulation of the problem.

Given.

1. Structures of ACS objects with recycling "by concentration", "by mass", "by parameters" with a typical law of regulation f_R and basic structures of ACS.

2. Operators of ACS blocks

$\varphi_0(S) = \frac{k_0}{T_0 S+1}$, $\varphi_O^M(S) = \frac{k_O^M}{T_O^M S+1}$, $k_0 = k_O^M, T_0 = T_O^M$ – object with self-leveling in the direct chain; $\varphi_r(S) = \frac{k_r}{T_r S+1}, \varphi_r^M(S) = \frac{k_r^M}{T_r^M S+1}, k_r = k_r^M, T_r = T_r^M$, where k_0, k_r – transmission factors, T_0, T_r – time constants; $f(S)$ – the proportional-integral control law, $f^e(S)$ is the extrapolation operator in the form of a "shift".

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3. Variations of the ratio τ_r/τ_0 in the range [1; 45] for objects with recycling "by concentration" and "by mass" (at α = 0.6), in the range [1; 2.5] – for objects with recycling "by parameters".

4. Limitations on the magnitude of the input action $u_2 \in [0; 100]$, affecting the value of the division block, for the ACS object with recycling "by parameters".

5. The efficiency criterion: $q(t) = \frac{1}{T}\int_{t-1}^{T}|y^*(\theta) - y(\theta)|d\theta$, where T – time of the transient process.

Required. To identify the area of ACS effective performance of objects with recycling of all classes.

The transition from the operators φ_0, φ_r, φ_{τ_u}, φ_{τ_0}, φ_{τ_r} to the recursive-difference form is made by the method of finite differences. The programming is carried out in the Microsoft Office Excel system. The results of numerical studies with variation of ratios τ_r/τ_0 for objects ACS with recycling "by concentration", "by mass", "by parameters" are presented in tables 2-4.

Table 2. Efficiency criterion for synthesized ACS with recycling "by concentration" and ACS with a model control law.

τ_r/τ_0	Performance criterion, rel.u.	
	ACS with a model control law	Synthesized ACS
1	unstable	4.99
5	unstable	5.02
10	unstable	6.13
15	unstable	7.50
20	unstable	8.66
30	unstable	10.61
35	unstable	11.48
37	stability boundary	11.82
38	19.26	11.98
40	19.14	12.28
45	18.78	12.98

Table 3. Efficiency criterion for synthesized ACS with a recycling "by mass" and ACS with a model control law.

τ_r/τ_0	Performance criterion, rel.u.	
	ATS with a model control law	Synthesized ACS
1	3.84	2.32
5	3.97	2.48
10	4.62	2.59
15	5.27	2.99
20	5.42	3.19
25	5.82	3.65
30	6.20	4.40
35	6.52	4.87
40	6.79	5.28
45	7.04	5.70

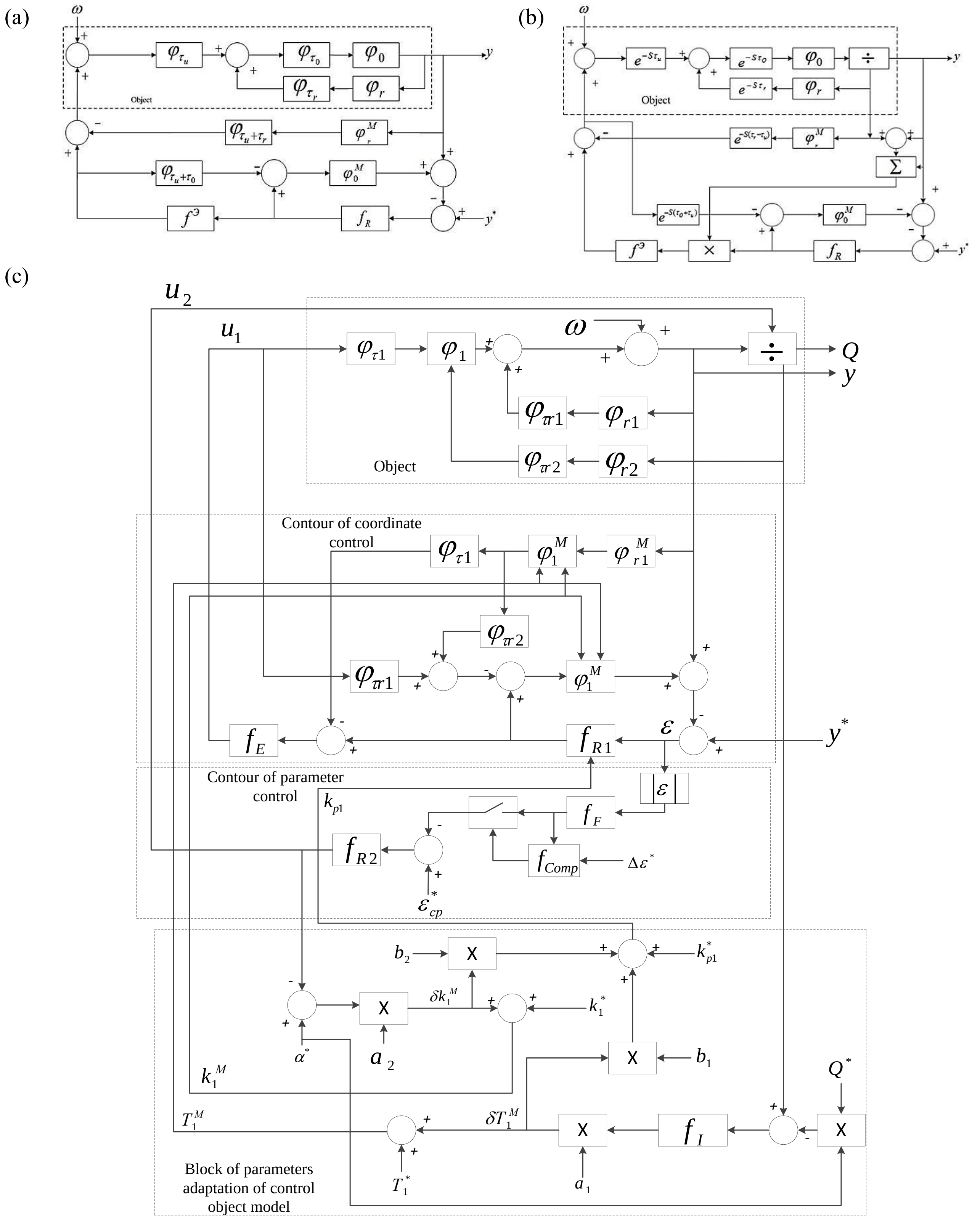

Figure 1. The structures of synthesized ACS of the object with recycling: (a) by concentration, (b) by mass, (c) by parameters.

Table 4. Performance criterion for a synthesized ACS with a recycling "by parameters"

ACS under the influence of external step actions according to disturbing input $\omega(t)$		ACS under the influence of external step actions according to controlling input $y^*(t)$	
τ_r/τ_0	Performance criterion, rel.u.	τ_r/τ_0	Performance criterion, rel.u.
1	3.708	1	5.248
1.25	3.824	1.25	5.310
1.5	3.954	1.5	5.369
1.75	3.943	1.75	5.429
2.0	4.521	2.0	5.512
2.1	Boundary of stability	2.1	Boundary of stability
2.25	unstable	2.25	unstable
2.5	unstable	2.5	unstable

4. Conclusions

Based on the results of problem solution the following conclusions are drawn:

1. The synthesized ACS of the object with the recycling "by concentration" remains stable for any ratios $\tau_r/\tau_0 \in [1; 45]$, while the ACS with a model control law becomes stable only when τ_r/τ_0 reaches value of 38.

2. The synthesized ACS and ACS with a model law of object regulation with recycling "by mass" are stable for any ratios $\tau_r/\tau_0 \in [1; 45]$.

3. ACS of object with recycling "by parameters" is stable for any values of the delay ratio in the straight chain and the recycling chain τ_r/τ_0 in the range [1; 2.1]; at $\tau_r/\tau_0 > 2.1$ the system becomes unstable.

4. For stable systems in the entire range of ratios τ_r/τ_0, the synthesized ACS of the object with a recycling exceeds the average modulus criterion ACS with a model control law not less than by 1.5 times.

5. Throughout the investigated range of ratios τ_r/τ_0, the time of the transient process of the synthesized ACS is less than the time of the ACS transient process with the model control law no less than 3 times.

The results of solution of this problem can be applied both to adjust the regulators in the creation of automation systems and to develop technological solutions at the design stage of units and process regulations, so that the design of aggregates of direct chain and in the recycling chain could meet the calculated conditions.

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