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Examination of a repetitive process control system

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Abstract: In the present work, the application of repetitive filters in the robust process control systems is examined. The functionality of the proposed system and the improved performance, robust performance and filtering properties has been proven.

1. Introduction

By increasing the performance requirements of the modern technological process control systems, there is considerable interest in the classes of non-stationary control systems in the conditions of a priori uncertainty and unmodulated dynamics, some of which are the following known classes of systems: robust systems; systems with parametric compensation; systems with interference absorption; systems using fractal algorithms; adaptive systems; systems with reduced sensitivity; systems with variable structure; extreme systems; repetitive systems; intelligent control systems (using neural networks, fuzzy multi-theory, genetic algorithms, chaos theory, etc.).
There are differences between them in structural and parametric terms. They are predominantly governed by the class of control objects, the type of control and interfering performance, and the controlled objective. In the case where the parametric disturbances in the objects are dominant and there are periodic external disturbances whose nominal parameters are known in advance but which fluctuate operationally around the nominal ones and one of the main requirements for the performance of the system is the resilience and the robust resilience of the system, application of robust repetitive systems is recommended as an effective.
In this context, **the aim** of the current work is to study the properties and applicability of the repetitive filters in robust systems and systems with robust properties. [1].

2. Robust systems and systems with robust properties.

In literature are known systems with internal model *RMM* [1-3], systems with interference absorption *DAS* [1], and gain scheduling control system *GSC* [1], as well as the methods and the algorithms for their synthesis.
➢ **The free parameter method** solves the task of analytical synthesis of robust systems *RMM* (фиг.1) with an internal model for controlled objects in the conditions of a priori uncertainty, **under the criteria**: (1): robust stability and robust performance of the system for a predetermined in the synthesis parameter set Π, satisfying the requirements (1.a); local criteria for quality *LCQ* (1.b) – process with minimal integral squared error.

$$\begin{cases} a)\to\gg \Pi = \left\{ \begin{array}{c} G: \left|\dfrac{G(j\omega)-G^*(j\omega)}{G^*(j\omega)}\right| \le \bar{\ell}_m(\omega)=G^{\Pi} \\ \bar{\ell}_m(\omega)<|\eta|^{-1},\forall\omega \\ |\eta\,\bar{\ell}_m|+|e\,y^0|<1,\forall\omega \end{array} \right\} \\ b)\to\gg \min\limits_R \|\varepsilon\|_2^2=\min\dfrac{1}{2\pi}\displaystyle\int_{-\infty}^{\infty}|\varepsilon(j\omega)|^2\,d\omega \end{cases} \quad (1)$$

$$Q=Q(Q^*,F_\lambda) \quad (2.a) \qquad Q(p)=Q^*(p)F_\lambda(p) \quad (2.b)$$

$$R_{(M)}(p)=\frac{Q(p)}{1-G^*(p)Q(p)} \quad (3)$$

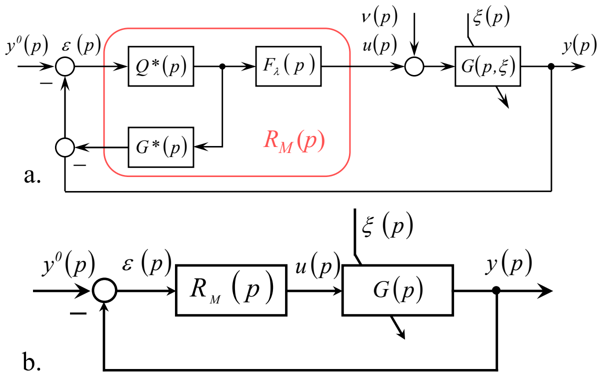

Fig.1. Robust control system with internal model

and initial conditions for synthesis – a priori know G^*, Π, σ, where: $Q^*(p)$ classic regulator (2) with filte $F_\lambda(p)$ (4) [2], corresponding to a nominal model of the controlled object G^* by the set *LCQ;* $R_M(p)$ (3) – robust regulatoer with an internal model of the object G^*. Every l element от $f_l(p)$ (4) should meet the requirements (5), where π_i are the poles G^* in the right half-space.

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$$F_\lambda(p)=diag\{f_1(p),\dots,f_n(p)\} \qquad (4)$$

$$f_i(\pi_i)=1,\ (i=0,1,\dots,k) \qquad (5.a)$$

$$\frac{d^j}{dp^j}f_i(p)\Big|_{s=\pi_i}=0,\ (j=1,\dots,m) \qquad (5.b)$$

➢ **The method** of the equilibrium partial absorption equation [2] solves the task for analytical synthesis of systems (fig.2), absorbing the influence of wave structured disturbances on the adjustable magnetite, for controlled objects under a priori uncertainty, **under the criteria** (6): minimum Euclidean norm (6.a) of the members of the equilibrium balanced absorption equation on the adjustable magnitude; equality stock sustainability (6.b) (or optimal module); *LCQ* (6.c) (process with reordering set $\sigma = const$) etc.

$$\begin{cases} a)->> & \left\{ \left\| E u_d + F\xi \right\| = min,\ \left(u=u_r+u_d\right) \right\} \\ b)->> & \left\{ \begin{aligned} &\left(\left| \mathcal{R}^*\left(j\omega_\pi^{A^\Pi}\right)\frac{k_{opt}^A G^\Pi\left(j\omega_\pi^{A^\Pi}\right)}{Q_2\left(j\omega_\pi^{A^\Pi}\right)}\right| = \atop = \left| R^*\left(j\omega_\pi\right)G^*\left(j\omega_\pi\right)\right| \right)^* \\ &\left(20\log_{10}\left|\frac{1}{1+\mathcal{R}^A\left(k^A, j\omega\right)G^\Pi(j\omega)}\right| \le 0, \atop \forall\omega \ge 0.1\,\omega^\Pi \right)^{**} \end{aligned} \right\} \\ c)->> & \sigma = const \end{cases} \qquad (6)$$

and **initial conditions** for synthesis: a priori known G^*, Π, σ , a representative trend of the system error in operating (simulation) conditions. The control u (6) of the systems (fig. 3) has two additive constituents: u_r - on the basis regulator, R^*, realizing the aim of control of the respective *LCQ* and u_d - to absorb the impact of interference ξ . The matrix E, F и C (7) reflect the dependence of the vector y from the controlled vector u, the disturbance ξ and the condition of the system x . The "nominal" system corresponding to the absorption system is a hypothetical parametric, non-intrusive linear system synthesized at the given *LCQ* (6.c) to the nominal model G^*, determined with the "nominal" regulator R^* (8).

$$y=Cx+E\left(u_r+u_d\right)+F\xi \qquad (7)$$

$$R^*(p)\Leftrightarrow G^*(p) \qquad (8)$$

Corresponding to the disturbance absorbing system (fig.2) "the classical" parametric disturbed system is with regulator R^* и process control, modeled using the $G(p,\xi)$ in real operational conditions (or with adequate computer simulation). y^o , u are signal external interference aggregated on the assignment channel y^o and/or the loading u, and ξ are aggregated internal additive or multiplicative parametric and/or structural disturbances with a wave structure in process control. Analytical design of the absorber A in the structure (fig.2) of the system is according (9), where the fluent $Q_2^{-1}(p)$ is determined by a known methodology [1], and the optimum gain value k^A is determined based on (10) or (11). ω_π^{CLASS} e ω_π - frequency of the closed classical system, $\omega_\pi^{A^\Pi}$ e ω_π - frequency of the closed, disrupted, interference-absorbing system; G^Π - a model of disruption at the highest level process control; $\Phi_{y^o\varepsilon}^{CLAAS^\Pi}$ - transmitting fluent of the closed, top-class classical system.

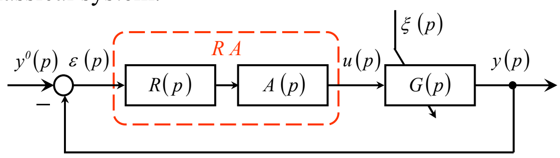

Fig.2. Disturbance absorbing system

$$A(p)=k^A Q_2^{-1}(p) \qquad (9)$$

$$k_{opt}^A = \frac{\left| R^*\left(j\omega_\pi^{CLASS}\right)G^*\left(j\omega_\pi^{CLASS}\right)Q_2\left(j\omega_\pi^{A^\Pi}\right)\right|}{\left|\mathcal{R}^*\left(j\omega_\pi^{A^\Pi}\right)G^\Pi\left(j\omega_\pi^{A^\Pi}\right)\right|} \qquad (10)$$

$$\begin{cases} k_{opt}^A \Leftrightarrow \left| \left[1+\left(\mathcal{R}^*(j\Omega)\,G^\Pi(j\Omega)\frac{k_{opt}^A}{Q_2(j\Omega)} \right) \right]^{-1} \right| \le 1 \\ \left\{ \Omega=0.1\,\omega^\Pi;\ \left(\omega^\Pi \Leftrightarrow \frac{d}{d\omega}\left|\frac{1}{1+\mathcal{R}^*(j\omega)\,G^\Pi(j\omega)}\right| = \atop = \frac{d}{d\omega}\left|\Phi_{y^o\varepsilon}^{CLAAS^\Pi}(j\omega)\right|=0 \right) \right\} \end{cases} \qquad (11)$$

➢ **The method** of the compensation equation of the parametric balance [1] solves the task of analytical synthesis of gain scheduling control system with combined $G(C)$ (fig.3) parametric compensation for controlled objects under a priori uncertainty, **under the criteria** (12): constant value (corresponding to optimal system setup under σ) of the transmission coefficient $k_{\ell 1}$ of the regulatory body (12.a); constant value (corresponding to optimal system setup under σ) of the transmission coefficient $k_{SYSTEM\ 1}$ of the system (12.b); *LCQ* (12.c) (process with reordering set $\sigma = const$ etc.)

$$\begin{cases} a)->> & \left\{ k_{\ell i}\left(\nabla s_i, t\right)=k_{\ell 1}=const \atop \Leftrightarrow\left(k_p, T_i, T_d\right)_{optimal} \right\} \\ b)->> & \left\{ \begin{aligned} &k_{\ell i}\left(\nabla s_i, t\right)=k_{\ell 1}=const \\ &\qquad\Leftrightarrow\left(k_p, T_i, T_d\right)_{optimal} \\ &k_{SYSTEM\ i}\left(\nabla s_i, \xi_i, t\right)=k_{SYSTEM\ 1}=const \\ &\qquad\Leftrightarrow\left(k_p, T_i, T_d\right)_{optimal} \end{aligned} \right. \\ c)->> & \sigma=const \end{cases} \qquad (12)$$

and **initial conditions** for synthesis: a priori known σ , type of regulator, where: $R^*(p)\Leftrightarrow G^*(p)$, $\left(l=l_0^*,\ s=s_0^*\right)$; y^o , s are signal external interference aggregated on the assignment channel y^o and/or loading s, and ξ are aggregated internal additive or multiplicative parametric and/or structural interferences in process control; l_t, y_t, q_t - position of the valve control system PO; adjustable magnitude and cost of output at PO; $\nabla \ell_t^{G(A)}$, $\nabla \ell_t^{G(C)}$, $\nabla a_t^{G(C)}$ - compensation variables; $\nabla \ell_{t,rornp}$, $\nabla \ell_{t,rolin}$ (13) - compensation variables for PO with equal and linear flaw characteristics; ∇s_t (13) - ∇ - loading changes.

$$\left\{ \begin{array}{l} \nabla \ell_t^{G(C)} = -\dfrac{k_{s_0^*}}{k_{l_0^*}} \nabla s_t , \left(\begin{array}{l} \nabla \ell_{t,rornp} = \dfrac{0.5\left(e^{2n(l-l)}-1\right)}{nse^{2n(l-l)}} \nabla s_t \; ; \\ \nabla \ell_{t,rolin} = \dfrac{0,5\left(l^{-2}-1\right)l^3}{s} \nabla s_t \end{array} \right) \\ \nabla a_t^{G(C)} = c_0^* \left(\dfrac{d(y_t)}{d(l_t)} \right)^{-1} , \left(\begin{array}{l} \nabla a_t^{G(C)} \approx c_0^* \left(\dfrac{\Delta(y_t)}{\Delta(l_t)} \right)^{-1\,-1} , \\ c_0^* = k_{SYSTEM}^{G(C)} k_p^{-1} = const \end{array} \right) \end{array} \right. \tag{13}$$

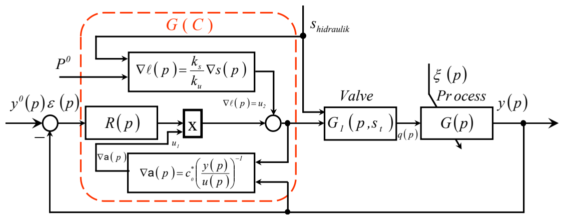

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Fig.3. Gain scheduling control system#

3. Repetitive control and *ML* filters.

The repetitive control is effectively applied in systems for controlled technological objects characterized by periodic signal interference [4,5]. In the structure of the repetitive regulator, the internal model in the *ML* (***Memory Loop***) [6-11] $M_L(p)$ (fig.4 and fig.6) is used, which consists of a periodic signal generator allowing compensation of periodic disturbances with a predetermined and fixed value of the period T_p. The base *ML* has the ability to "memorize" the frequency of "cut-off" and effectively to counteract it, through its specific structure as a dynamic system. There are dependency bridges for it (14)-(16):

$$\varepsilon^*(p) = \varepsilon(p) + \varepsilon^\diamond(p) \tag{14}$$

$$M_L(p) = \frac{\varepsilon^\diamond(p)}{\varepsilon(p)} = \frac{e^{-pT_p}}{1-e^{-pT_p}} \tag{15}$$

$$\varepsilon^\diamond(p) = M_L(p)\varepsilon(p) = \left(\frac{e^{-pT_p}}{1-e^{-pT_p}} \right) \varepsilon(p) \tag{16}$$

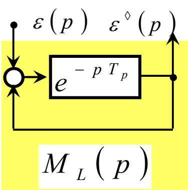

Fig.4. Base ML filter

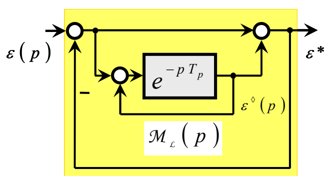

Fig.5. Improved ML filter

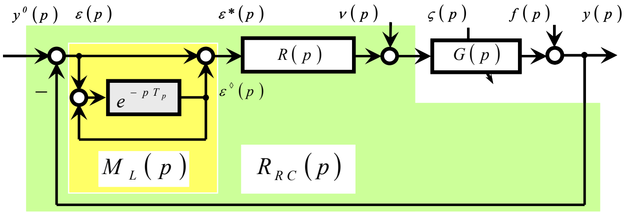

Fig.6. Repetitive control system

In the literature is well-known and improved [9] ML (fig.5). It differs from the basic one [6-11] because it uses a model of delay, but in a different structure. Unlike basic one (17), the improved $\mathcal{ML}$- filter (19) is a sustainable dynamic system.

$$M_L(p) = \frac{\varepsilon^*(p)}{\varepsilon(p)} = \frac{1}{1-e^{-pT_p}} \tag{17}$$

$$\frac{\varepsilon^\diamond(p)}{\varepsilon(p)} = \frac{e^{-pT_p}}{2-e^{-pT_p}} \tag{18}$$

$$\mathcal{M}_\mathcal{L}(p) = \frac{\varepsilon^*(p)}{\varepsilon(p)} = \frac{1}{2-e^{-pT_p}} \tag{19}$$

The values of the regulator setting parameters in the controlled technological objects systems are subject to the aim and the criteria presented to the system in its synthesis. They are not a function of the respective *ML*-filter, which is added to the regulator. In this sense, the design of the *ML*-filter in the control systems is autonomous and is not related to the synthesis of the regulator. For designing $\mathcal{ML}$-filters with memory is used "*rejecting module bandpass filter criterion*". The essence of this method is a *sequential frequency correction.* The design filter criterion is defined by (20).

$$\left| \mathcal{M}_{\mathcal{L},i}(j\omega) \right| \equiv \left\{ \begin{array}{ll} 0, & \begin{array}{l} \forall \omega \in \Delta\omega_i , \\ (\omega_{b,i} < \omega_p < \omega_{h,i}) \end{array} \\ 1, & \begin{array}{l} \forall \omega \in [0, \omega_{b,i}], \\ \forall \omega \in \left[\begin{array}{l} \omega_{h,i}, \infty), \\ (\omega_{b,i} < \omega_p < \omega_{h,i}) \end{array} \right. \end{array} \end{array} \right. \tag{20}$$

4. Robust repetitive control systems with internal model. Synthesis.

1. They are set below (chart 1): nominal model $G^*(p)$ of a minimal-phase object $G(p)$; an embarrassed object (model) at the top $G^{\Pi}(p)$; synthesis criteria (1.a); period T_p of constant intermittent disturbance $d = sin(\omega_p t) = const$.

2. It is necessary to synthesize: robust R_M regulator (free parameter method); repetitive $\mathcal{ML}$-filter (19), (20); compensation variables $\nabla \ell_t^{PCS}$, ∇a_t^{PCS} (13) (method of the parametric balance equation); absorber $A^{das}(p)$ of the wave structure disturbances (equilibrium partial absorption of the disturbances method).

Based on the synthesis methods and the advanced $\mathcal{ML}$-filter described above, the configuration of robust repetitive systems is based on development in the structure (fig.1) using the principle of consistent correction of

R_M with $\mathcal{ML}$-filter, compensation variables $\underline{\nabla\ell}_t^{PCS}$, ∇a_t^{PCS} and/or absorber $A^{das}(p)$. In fact, four completely new systems are illustrated respectively:
- in fig.7 – robust repetitive internal model control $RMREP$, where the controlled algorithm $R_M^{\mathcal{ML}}(p)$ is presented analytically with (21), and the results of the synthesis are plotted in table 1;
- in fig.8 – robust stabilization repetitive $RMGSCREP$, where the controlled algorithm $R_M^{GSC\mathcal{ML}}(p)$ is presented analytically with (22), and the results of the synthesis are plotted in table 1;
- in fig.9 – robust repetitive disturbance absorbing $RMDASREP$, where the controlled algorithm $R_M^{GSC\mathcal{ML}}(p)$ is presented analytically with (23), and the results of the synthesis are plotted in table 1;
- in fig.10 – robust stabilization repetitive disturbance absorbing $RMGSCDASREP$, where the controlled algorithm $R_M^{DASGSC\mathcal{ML}}(p)$ is presented analytically with (24), and the results of the synthesis are plotted in table 1.

Table 1. Results of the synthesis

initial conditions of synthesis	$G^*(p)$		$G^{ll}(p)$	control valves CV
	$\frac{1{,}25e^{-2p}}{10p+1}$		$\frac{2{,}1e^{-4p}}{10\,p+1}$	equal percent control valves ECV
permanent intermittent disturbance	$T_p = 100\,s \;\; d = \sin(\omega_p t) = \sin(0{,}0628\,t) = const$			$(\omega_p = \omega_{pf} = 0{,}0628\,rad/s\,; T_{pf} = 100\,s)$
system synthesis results				
$R_M(p)$	$1{,}25\left(1+0{,}909\,p+\frac{1}{11\,p}\right)\frac{1}{(0{,}71\,p+1)}$			
$\mathcal{M}_{\mathcal{L}}(p)$	$(2-e^{-pT_p})^{-1}, \left(T_p \equiv 2\pi(\omega_p)^{-1} = 2\pi(0{,}0628)^{-1}\right)$			
compensation variable $\underline{\nabla\ell}_t^{PCS}$	$\frac{0.5\left(e^{2n(1-l)}-1\right)}{nse^{2n(1-l)}}\nabla s_t$	compensation variable ∇a_t^{PCS}		$c_0^*\left(d(y_t)/d(l_t)\right)^{-1}$
$A^{das}(p)$	$\frac{0{,}08666}{p^2+5p+1}$			

$$R_M^{\mathcal{ML}}(p) = \mathcal{ML}\,R_M,\left(R_M \underset{\{\min\|\varepsilon\|_2^2\}}{\Leftrightarrow} G^*\right) \quad (21)$$

$$R_M^{GSC\mathcal{ML}}(p) = \mathcal{ML}\,R_M^{GSC},\left(R_M \underset{\{\min\|\varepsilon\|_2^2\}}{\Leftrightarrow} G^*\right) \quad (22)$$

$$R_M^{DAS\mathcal{ML}}(p) = \mathcal{ML}\,R_M^{DAS} = \mathcal{ML}\,R_M\,A,\left(R_M \underset{\{\min\|\varepsilon\|_2^2\}}{\Leftrightarrow} G^*\right) \quad (23)$$

$$R_M^{DASGSC\mathcal{ML}}(p) = \mathcal{ML}\,R_M^{GSC}\,A,\left(R_M \underset{\{\min\|\varepsilon\|_2^2\}}{\Leftrightarrow} G^*\right) \quad (24)$$

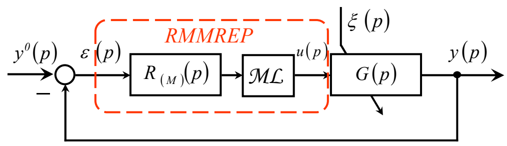

Fig.7. Robust repetitive internal model control system

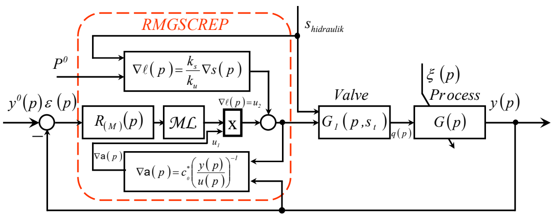

Fig.8. Robust stabilization repetitive control system

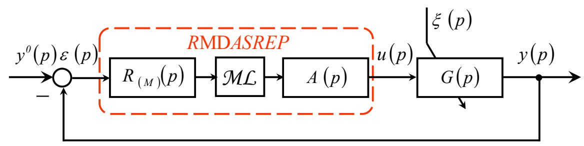

Fig.9. Robust repetitive disturbance absorbing system

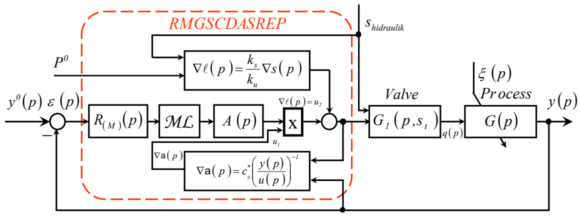

Fig.10. Robust stabilization repetitive disturbance absorbing system

5. Analysis and quality assessment. Comparative analysis.

The four synthesized systems are modeled and simulated under the same conditions. The simulation model results- time and frequency characteristics for closed Φ_i and for open W_i control systems are shown in fig.11 и fig.12. The system features are visualized *in nominal parametric mode* ($G \hat{=} G^*$, $d \equiv 0$, fig.11) and *in perturbance mode on the upper limit* ($G \hat{=} G^{ll}$, $d \equiv 0$, fig.12) without the presence of a permanent intermittent external signal disturbance d. The following symbols

are used: h_{Φ_i} - transient functions, $\Phi(j\omega)$, $W(j\omega)$- frequency characteristics of closed and open systems.
Quality analysis [1,12] *in nominal parametric mode of the systems* (fig.11) confirms that all four systems meet *LCQ*, reflecting the adjustment times (fig.11.a) and their

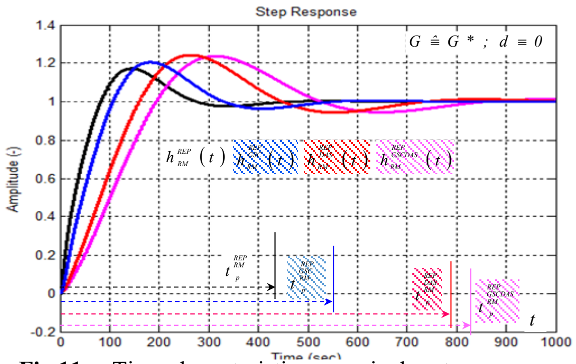

Fig.11.a. Time characteristics - nominal systems

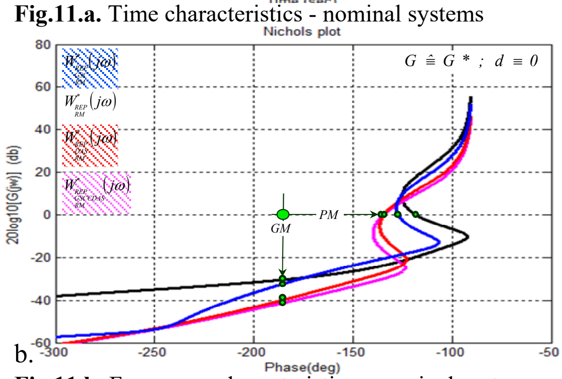

Fig.11.b. Frequency characteristics - nominal systems

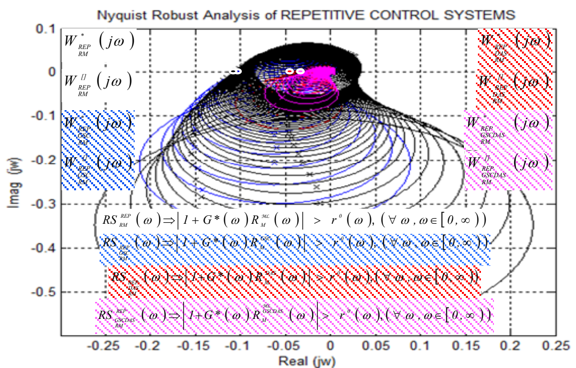

Fig.13.a. Robust analysis of the characteristics of the open loop systems

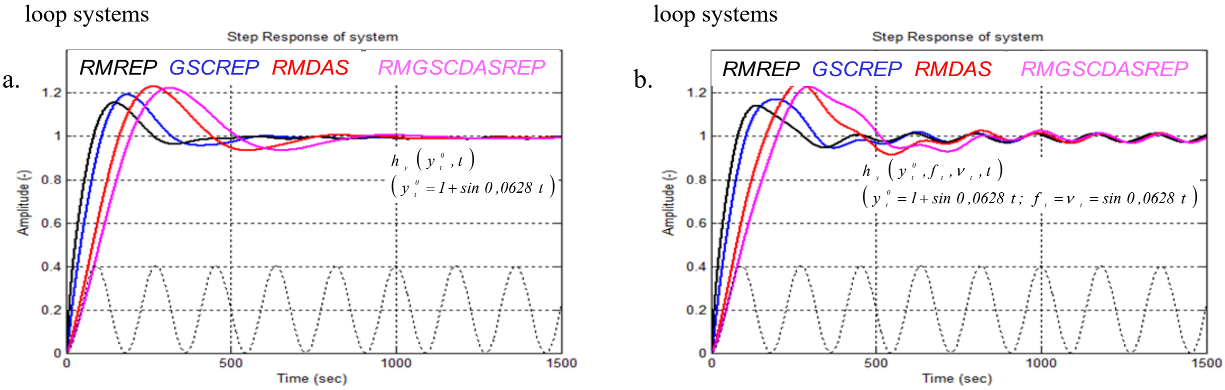

Fig.14. Time analysis of the filtering properties systems

6. Robust analysis.

By definition, the system analyzed is: robust stability and robust performance [1] for the set Π (1.a), if it meets the requirements (29) и (31) for the entire fre-

stocks by module and phase (fig.11.b).
Quality analysis in perturbance mode on the upper limit systems (fig.12) *confirms that*: systems remain stable, reflecting the times regulation (fig.12.a) and their gain margin and phase margin (fig.12.b).

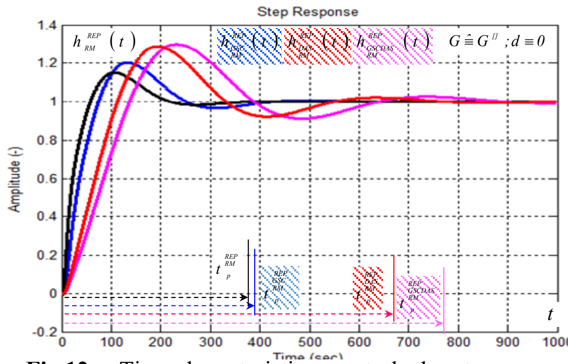

Fig.12.a. Time characteristics - perturbed systems

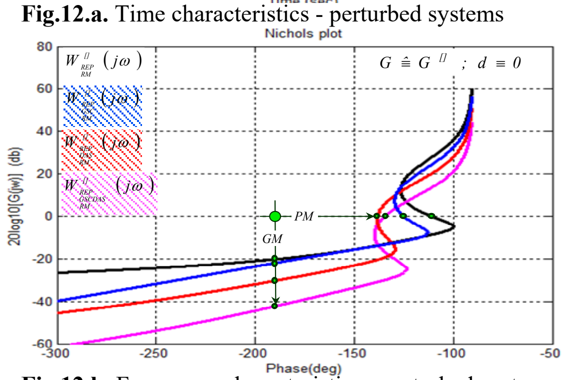

Fig.12.b. Frequency characteristics - perturbed systems

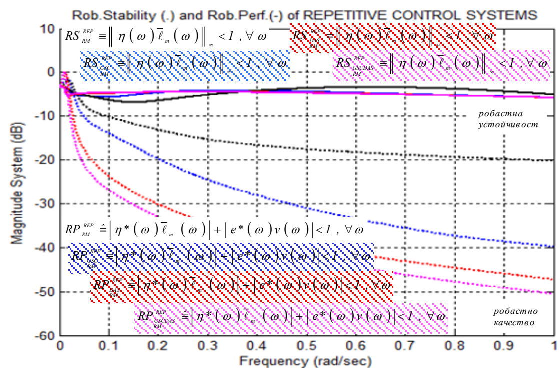

Fig.13.b. Robust analysis of the characteristics of the closed loop systems

quency range. If the nominal W_i^* and the perturbed W_i^{Π} are open systems (25), so the circle π (26) with radius r^0 (27) and with centers in points ω_i, depicting the uncertainty in the process control, so the requirements for the robust stability and robust performance can also be expressed in the characteristics of an open system with (28) and respectively with (30).

$$W_i^* = R_i G^* \; ; \quad W_i^{\Pi} = R_i G^{\Pi} \tag{25}$$

$$\pi(j\omega) \in \mathcal{W}(j\omega), (\forall \omega, \omega \in [0,\infty)) \tag{26}$$

$$r^0(\omega_i) = | \, l_m(\omega_i) R(\omega_i) G^*(\omega_i) \, | \tag{27}$$

$$RS(\omega) \Rightarrow | \, 1 + G^*(\omega) R(\omega) \, | > r^0(\omega), \quad (\forall \omega, \omega \in [0,\infty)) \tag{28}$$

$$RS(\omega) \Rightarrow \| \eta^*(\omega) \bar{\ell}_m(\omega) \|_\infty < 1, \quad (\forall \omega, \omega \in [0,\infty)) \tag{29}$$

$$RP(\omega) \Rightarrow | 1 + G(\omega) R(\omega) | \geq | 1 + G^*(\omega) R(\omega) | - r^0(\omega), \quad (\forall \omega, \omega \in [0,\infty)) \tag{30}$$

$$RP(\omega) \Rightarrow | \eta^*(\omega) \bar{\ell}_m(\omega) | + | e^*(\omega) \upsilon(\omega) | < 1, \quad (\forall \omega, \omega \in [0,\infty)) \tag{31}$$

The results (fig.13) from the robust analysis of the characteristics of the open loop $W_i(j\omega)$ (fig.13.a) and close loop $\Phi_i(j\omega)$ (fig.13.b-c) systems, *analytically prove* that under uncertainty ξ, ξ^{Π} (table 1): the repetitive systems (fig.7-fig.10) meet the requirements (28)-(31) both for robust stability and robust performance**.**

7. Time analysis

A *time analysis of the filtering properties* of the four (fig.7÷fig.10) synthesized systems with "test" periodic effects was also carried out [11], by modeling the systems and evaluating the simulation results by time criteria. The four systems were modeled with nominal parametric mode. Their transitional functions $h_i(t)$ of periodic impact d (table 1) are simulated.

The time characteristics of the systems as a result of their parallel simulation for a "test" frequency $\omega_p = 0{,}0628 \; rad/s$, are illustrated in fig.14 – under disturbance $d(t)$ on the assignment channel y^0 (fig.14.a), as well as in parallel along the three channels y^0, ν и f (fig.14.b).

The results of the study of the four systems with a *time analysis of the robust filtering properties* with respect to the quality evaluation for performance of the process confirm that the repetitive systems (fig.7, fig.8, fig.9, fig.10) have a reduced sensitivity to external harmonic impact $d(t)$ with frequency $\omega_p = 0{,}0628 \; rad/s$.

Conclusion

The present study examines and analyzes the results of the research on the peculiarities and properties of the repetitive robust systems. Results of research are presented, which are confirmation and proof of their quality. The stability, performance, accuracy, robust performance and stability, filtering properties of external periodic effects of this class of systems are all proven. In comparative terms, the properties of robust repetitive (fig.7), robust stabilization repetitive (fig.8), robust repetitive disturbance absorbing (fig.9) and robust stabilization repetitive disturbance absorbing (fig.10) control systems of the process G, described in table 1, using the methods for**: ● *Performance analysis in nominal and parametric mode*** *of the systems* (fig.11, fig.12)**; ● *time analysis of the filtering properties*** *of systems with "test" periodic effects* (fig.14)**; ● *robust analysis*** of the behavior of uncertainty systems Π, G, G^*, G^{Π}, ξ, ξ^{Π} of the object (fig.13)**.**

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References

1. E. Nikolov, D. Jolly, N. Nikolova, B. Benova, *Commande Robuste*, Sofia, Ed de l'Université Technique de Sofia, ISBN 954-438-500-2, **216**, (2005)
2. M. Morari, E. Zafiriou, *Robust Process Control*, Prentice-Hall Int., Inc Englewood Cliffs, NJ, **479**, (1989)
3. V.Karlova-Sergieva, *Control systems with conditional feedback*, International Conference Automatics'2016, FA, June 03-05, Sozopol, Publishing House of Technical University of Sofia, ISSN 0374-342X, ISSN 1311-0829, Vol 66 (2), pp. **181-187**, (2016)
4. S. Guergov, *A review and analysis of the historical development of machine tools into complex intelligent mechatronic systems*, Journal of Machine Engineering, ISSN 1895-7595 (Print), ISSN 2391-80-71 (Online), Vol. 18, No. 1, **107-119**, (2018)
5. S. Guergov, *A modular multifunctional system for complex physiotherapy*, Series on Biomechanics, Peer-reviewed Journal Edited by Bulgarian Academy of Science, Vol.31, No.2, ISSN 1313-2458, **41-44**, (2017)
6. R. Gricy, R. Cardoner, R. Costa-Castelló, E. Fossas, *Digital repetitive control of a three-phase four-wire shunt active filter*, IEEE Transactions on Industrial Electronics 54 (3), **1495-1503**, (2007)
7. M. Steinbuch, *Repetitive control for systems with uncertain period-time,* Automatica 38, **2103-2109**, (2002)
8. R. W. Longman, *On the Theory and Design of Linear Repetitive Control Systems*, European Journal of Control, vol. 5, DOI: 10.3166/EJC.16, **447-496**, (2010)
9. N. Nikolova, E. Nikolov, *ML- Structures In The Repetitive Robust Control Systems*, Cybernetics and Information Technologies Journal, Vol. 8, No 2, BAS, **15-28**, (2007)
10. N. G. Nikolova, *Filters in Repetitive Control Systems*, Proceedings of the Technical University Sofia, Publishing House of Technical University of Sofia, ISSN 0374-342X, ISSN 1311-0829, Vol 63, (2), pp. **45-52**, (2013)
11. N. G. Nikolova, E. Nikolov, *Predictive and Repetitive Control (Applied Methods for Process Control - part III)*, Sofia, Publishing House of Technical University of Sofia, ISBN 978-619-167-136-6, **258**, (2014)
12. V.Karlova-Sergieva, *Design of control systems with guaranteed performance*, Publishing House "Radix" OOD, ISBN 978-619-7140-01-9, **164**, (2013)