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FEATURES OF COMPUTER-AIDED DESIGN OF ROBUST DISCRETE CONTROLLERS FOR INFORMATION-MEASURING DEVICES STABILIZATION SYSTEMS

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Abstract. *The paper deals with problems of computer-aided design of controllers for systems of stabilization of information-measuring devices operated on vehicles of the wide class in difficult conditions of disturbances action. Algorithms of the robust parametrical optimization and robust structural synthesis are suggested. The simulation results are represented.*

Keywords: stabilization systems; information-measuring devices; robust discrete controllers; parametric optimization; structural synthesis.

I. INTRODUCTION

Now the complexity of the control processes, which accompany operation of the information-measuring devices mounted at vehicles of the wide class, continually grows. As a rule, the rigid requirements to such processes by accuracy are given. Such requirements may not be satisfied without stabilization of the moving base, on which the appropriate information-measuring devices are mounted.

Choice of a method for system design depends essentially on its features and operation conditions. In the first place, systems for stabilization of the information-measuring devices are operated in conditions of the external disturbances (sea irregularities, wind, irregularities of the road or terrain relief for the sea, air and land vehicles correspondingly). In the second place, the stabilization plant parameters are essentially changed in time. Taking these factors into consideration the problem of stabilization system design may be solved by means of the robust control. Such approach ensures synthesis of control laws able to provide system accuracy in the given limits in conditions of the external coordinate and internal parametric disturbances action.

It should be noted, that the robust controller design represents a labour-intensive procedure connected with a large quantity of transformations and calculations. The successful design of the robust controller requires the computer-aided computational procedures usage.

In the modern stabilization systems the implementation of the control laws is realized by means of computing technique. This leads to the necessity of discrete controller usage. Design of such controllers is accompanied by specific features, which represent this paper matter of issue.

Creating robust systems it is necessary to consider two basic problems such as design the new systems and modernization of the operated systems. The first problem may be solved based on the robust parametric optimization and the second – using the robust structural synthesis.

II. ANALYSIS OF THE LAST RESEARCHES AND PUBLICATIONS

The large quantity of papers and textbooks, for example, [1], [2] deals with the problems of the robust controllers design. Basic principles of the robust parametrical optimization based on the mixed H_2/H_∞-approach are discussed in [3]. Approaches to the structural synthesis and problems of the appropriate computer-aided procedures creation are represented in [4]. One of the modern approaches to design of the robust controller is based on H_∞-synthesis characterized in [1], [2]. Statement of the H_∞-synthesis problem is given in many textbooks [1], [2]. The method of the mixed sensitivity belongs to the most widespread methods of the H_∞-synthesis. The objective function of the method and features of its algorithmic and program realization are represented in [1], [2], [4].

At the same time the proper attention yet was not given to the problems of design of the robust discrete controllers used for stabilization of the information-measuring devices operated at vehicles of the wide class.

III. THE PROBLEM STATEMENT

In the paper the basic features of computer-aided design of the robust discrete controllers used for stabilization of the information-measuring devices operated at vehicles in the difficult conditions of the parametric and coordinate disturbances are considered.

VI. ANALYSIS OF THE MODERN MEANS OF THE COMPUTER-AIDED DESIGN

Design of the complex systems is impossible without using of the modern computing facilities, which allow to improve essentially the quality of the design solutions and to automate the complex calculating procedures.

Design of the robust systems requires implementation of labour-intensive transformations of the matrix transfer functions, which describe the system. Now these difficulties may be overcome due to usage of the software, which allows to automate complex functional and analytical transformations, for example, Maple, MathCAD, SCILAB, Matlab. Among the above listed software the latter is the most important as it includes the special toolboxes directed to creation of procedures for design of the optimal control systems in general and the robust systems in particular. Solution of the problem of the control systems design is sufficiently simplified in the case of usage of Matlab toolboxes.

Control System Tollbox provides synthesis, simulation and analysis of control systems of the wide class. Advantages of this toolbox are caused by usage both traditional methods of control systems creation based on the transfer functions and modern control theory methods based on the state space models. The toolbox allows to create procedures of optimal design of both continuous and discrete systems.

The strong tool of the robust systems creation is Robust Control Toolbox, which ensures implementation of the complex calculations necessary for the controller structural synthesis using the optimization criterion based on the H_∞-norms of the studied system sensitivities functions.

For analysis of the synthesized system it is expedient to use models, which take into consideration all the typical non-linearities inherent to real systems. Results of simulation carried out with application of such models prove efficiency of the optimal synthesis. Matlab has wide possibilities for creation of such models based on Simulink Toolbox usage.

Matlab foresees the possibility of simultaneous usage of Control System, Robust Control, Simulink Toolboxes that widens possibility of each other and allows to create effective procedures of the optimal design of the robust stabilization systems.

V. ROBUST STRUCTURAL SYNTHESIS OF DISCRETE CONTROLLERS

Design of the discrete controllers is actual due to the wide application of the discrete computing devices as components of the modern systems. In such systems the control unit based on the microprocessor or computer operates in the mode of the real time together with a continuous stabilization plant.

A continuous stabilization plant with the discrete controller represents a hybrid system. There are two approaches to such systems investigation [5]. Using the first approach the transition to the discrete form of the mathematical description of both the discrete controller and the plant stabilization is carried out. The second approach foresees investigation of the continuous system and correspondingly synthesis of the continuous stabilization laws (the continuous controller). Further the transition to the discrete stabilization laws (the discrete controller) and investigation of the synthesized continuous-discrete system dynamics is carried out. The latter approach is called the method of the continuous models [5]. It is convenient to use this method for synthesis of the discrete systems taking into consideration experience of system-prototypes design.

One of the most widespread methods of robust controller design represents the robust structural optimization based on the H_∞-synthesis. It includes solution of two Riccati equations, checking of some conditions and minimization of the H_∞-norms of the mixed sensitivity function of a system, which includes a plant and controller and may be represented by the vector of output signals characterizing the quality of control processes, the vector of input signals consisting in the general case of command signals, disturbances and measurement noise, the vector of controls and the vector of measured signals used for organization of feedbacks [1], [2]. The modern approach to solution of the robust structural H_∞-optimization problem is based on providing of the system desired frequency characteristics (loop-shaping). It is implemented with the help of the augmented plant forming by means of the weighting transfer functions introducing.

There are two the most widespread approaches to the robust structural optimization of the discrete controllers [4].

For the first approach the discretization of the plant model including the weighting transfer functions is carried out. Further, the w-transformation, implementation of the structural synthesis and z-representation of the controller by means of the inverse w-transformation is realized [4]. All the listed actions may be automated by means of the function *dhinfopt* belonging to the Robust Control Toolbox.

For the second approach the automated design of the robust controller is carried out by the knowm methods of the continuous system H_∞-synthesis. The discrete controller is obtained based on the continuous one by means of the z-transformation. Automation of this transformation is carried out by means of the function *c2d*. At that some requirements to the design process are given [4]. In the first place, the discretization method must be chosen as the Tustin bilinear transformation because the H_∞-norm stays the same during its application. In the second place, the discretization frequency must exceed the bandwidth in some times.

Flow charts of algorithms of the discrete robust controller automated design are shown in Figs 1, 2.

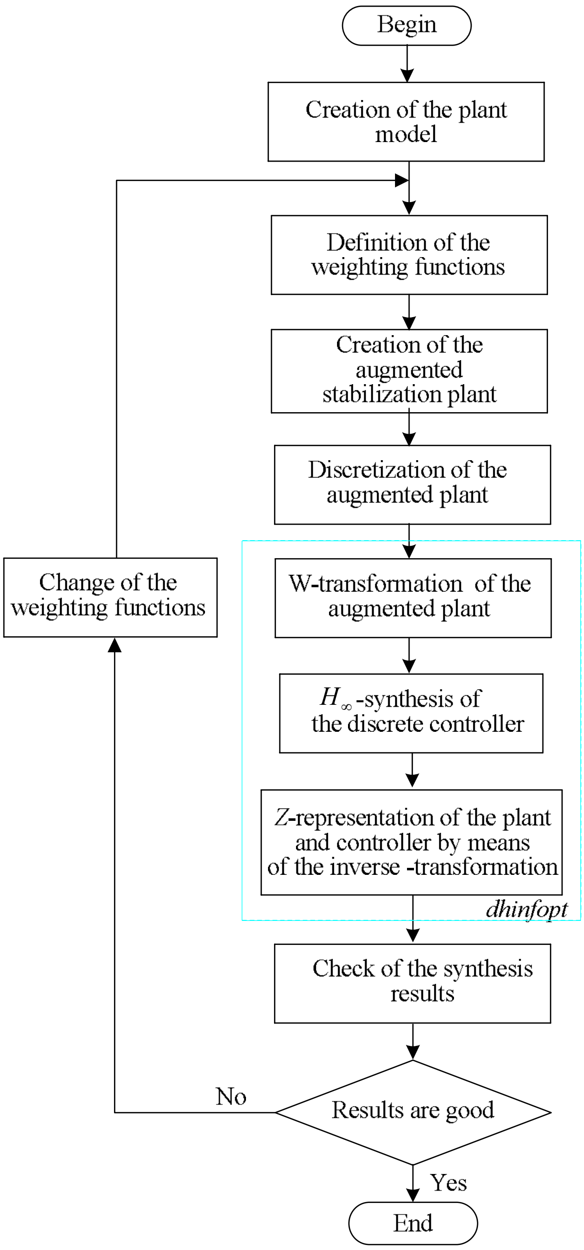


Fig. 1. The algorithm of the discrete controller design (the first approach)

Usually design of the complex control system at primary stages of its creation requires usage of two types of models such as linearized and non-linear ones. The linearized models are used for implementation of procedures of the designed system synthesis. The non-linear models allow to carry out simulation similar to processes in real systems and to analyze the efficiency of the synthesized system based on simulation results. The models of the first type may be created based on the Control System and Robust Control Toolboxes, and for the models of the second type creation it is convenient to use Simulink Toolbox [6].

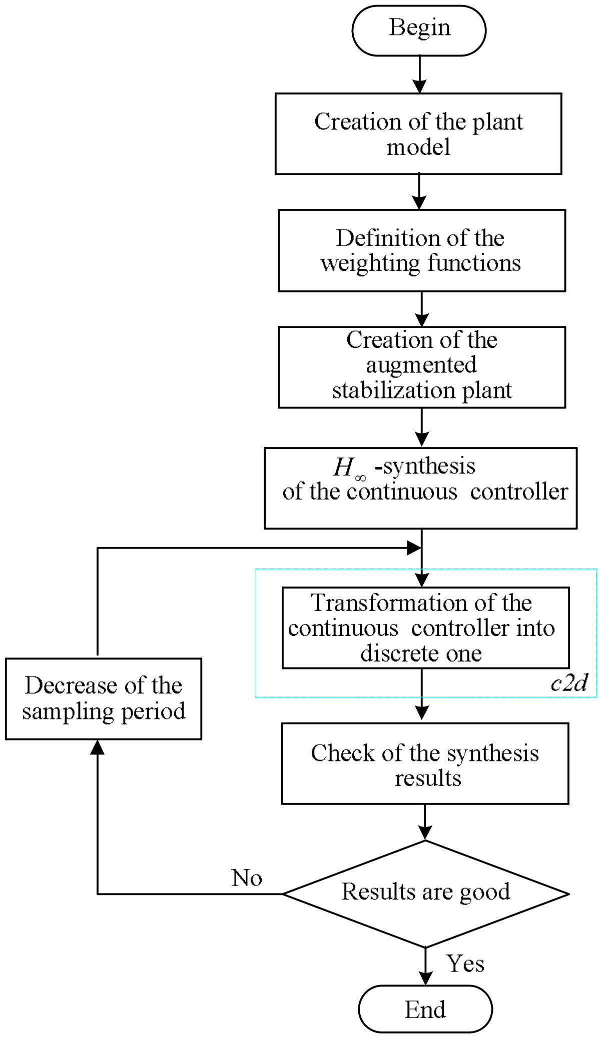


Fig. 2. The algorithm of the discrete controller design (the second approach)

Taking into account these features the method of the computer-aided design of the stabilization system with the discrete controller includes such stages.

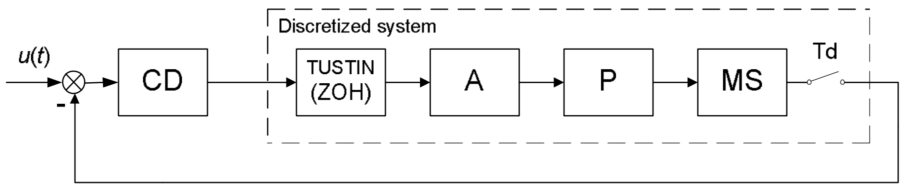
1. Studying of the basic principles of construction of the stabilization system.

2. Creation of the mathematical description of the stabilization system as a set of the models of its basic devices and units. The description must include both full models taking into consideration all non-lineraities inherent to real systems and the linearized models.

3. The robust structural synthesis of the stabilization system with the discrete controller using the Control System and Robust Control Toolboxes.

4. Analysis of the synthesized system characteristics taking into consideration non-linearities inherent to real systems based on the full non-linear model created on the basis of Simulink Toolbox.

Discretization of stages of the structural synthesis and analysis of the synthesized system has some differences as it is shown in Fig. 3. In the first case, the plant discretization is carried out. In the second case, the plant stays continuous but this requires modeling of the analog-digital and digital-analog transformation [5].



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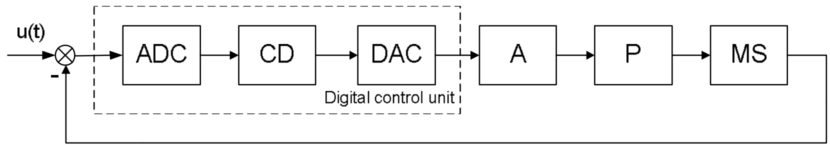


b

Fig. 3. Features of discretization of stages of synthesis (a) and analysis (b) of the stabilization system with the discrete controller: CD is the computing device; A is the actuator; P is the plant; MS is the measuring system; T_d is the sampling period; ADC is the analog-digital conveter; DAC is the digital-analog converter

During synthesis of the discrete system it is necessary to carry out the plant discretization. This process is connected with the choice of the sampling period and discretization method. The most widespread approach to the problem solution is the Kotelnikov theorem [7]

$$\Delta_d \le 1/(2f_g),$$

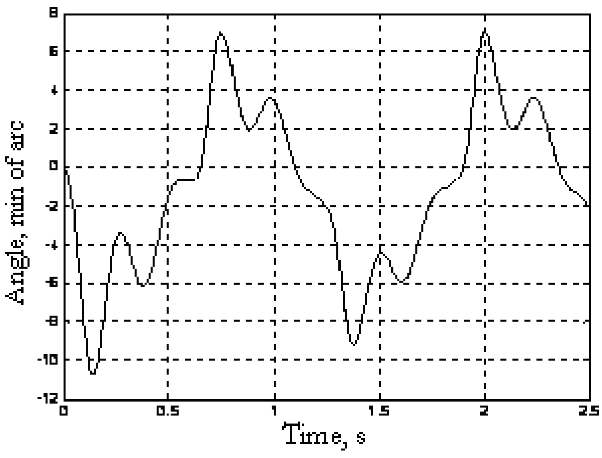
where Δ_d is the sampling period, f_g is the frequency of harmonic with the highest frequency.

As result of representation of the stabilization plant in the discrete form by means of function *c2d* it is possible to create a system, which may be described by the following relationships [8]

$$\mathbf{x}(k+1) = \mathbf{A}_d\mathbf{x}(k) + \mathbf{B}_d\mathbf{u}(k);$$

$$\mathbf{y}(k) = \mathbf{C}\mathbf{x}(k) + \mathbf{D}\mathbf{u}(k),$$

where $\mathbf{x}$ is the state vector; $\mathbf{A}_d, \mathbf{B}_d, \mathbf{C}, \mathbf{D}$ are matrices of the state, control, measurement and disturbances; $\mathbf{u}$ is the vector of controls; $\mathbf{y}$ is the vector of measurements; vectors and matrices are fixed at instants of time kT_d. Results of the robust discrete controller structural synthesis for the stabilization system operated on the land vehicle [7] are represented in Fig. 4. Using of two approaches shows practical coincidence of results. Therefore for design of the studied system the second approach was chosen as it is more evident and convenient for a designer.



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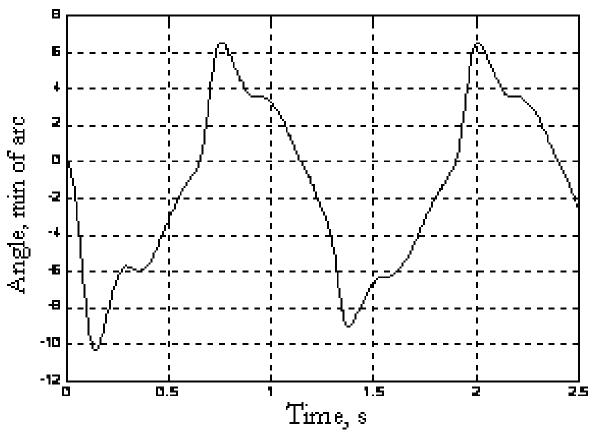

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Fig. 4. The dynamic error of the stabilization system for the sampling time 0,0025 s (a) and 0,0005 s (b)

VI. Robust parametric optimization of discrete controllers

The parametrical optimization of systems for stabilization of the information-measuring devices may be carry out using the mixed H_2 / H_∞-optimization, which allows to achieve compromise between accuracy and robustness of the designed system. Such approach provides successful operation of systems in complex conditions of the intensive parametric and coordinate disturbances.

Usage of calculating procedures of the discrete controller parametric synthesis requires representation of a plant in the discrete form with the sampling period of the designed controller. For this the different discretization methods may be used, for example, the zero order hold and the Tustin bilinear approximation. Usage of the latter method provides more accurate transformation of the continuous system in the discrete form.

The procedure of the parametric optimization of the continuous stabilization system with the discrete controller consists of the following stages.

1. Creation of the continuous mathematical model.
2. Choice of the discrete controller structure based on experience of the previous prototype systems design and new scientific achievements.
3. Choice of the discretization method and transformation of the model of the continuous plant into the discrete form.
4. Creation of the full model of the studied system taking into consideration non-linearities inherent to real systems such as saturations, hysteresis, dead zones, limits by the signal values and models of the essentially nonlinear units such as the pulth-width-modulator.
5. Creation of the linearized model of the plant necessary for the optimization performance including model of the separate units in the form of both transfer functions and state space models.
6. Determination of the minimal realization of the system model.
7. Determination of the balanced realization of the system model.
8. Performance of the optimization program, which may be based on the Nelder-Mead method or the genetic algorithm including such steps as:
   – calculation of the H_2- and H_∞-norms of the discrete synthesized system;
   – determination of the system poles and their arrangement for calculation of the penalty function;
   – calculation of the complex quality index taking into consideration accuracy, robustness and restrictions defined by the penalty function.
9. Analysis of the synthesized system including such steps:
   – calculation of the H_2-, H_∞-norms of the system;
   – plotting of the logarithmic amplitude-frequency characteristics;
   – plotting of the transients and determination of their quality indices.
10. Conclusion about termination of the parametric optimization procedure or its continuation with the new initial data and new coefficients in the complex quality index.

Results of the parametrical optimization of the continuous stabilization system with the discrete controller in the mode of tracking are represented in Fig. 5 [7]. Such system implement stabilization of information-measuring devices operated at the land vehicles. Results of the comparative analysis of different ways of the continuous stabilization system discretization are represented in the table.

Results of comparative analysis of the discretization different ways

Type of a model	H_2	H_∞	ΔA ,dB	$\Delta\varphi$, degree
Continuous model	0.3182	0.1261	59.4	91.1
Model discretized by the method of the bilinear approximation, T_d= 0,0005c	0.3003	0.1247	59.4	91.1
Model discretized by the zero order hold, T_d = 0,001c	0.4670	0.1679	50.2	91.1
Model discretized by the method of the bilinear approximation, T_d = 0,001c	0.3389	0.1263	59.4	91.1
Model discretized by the zero order hold, T_d = 0,0025c	0.3112	0.1251	59.4	91.1

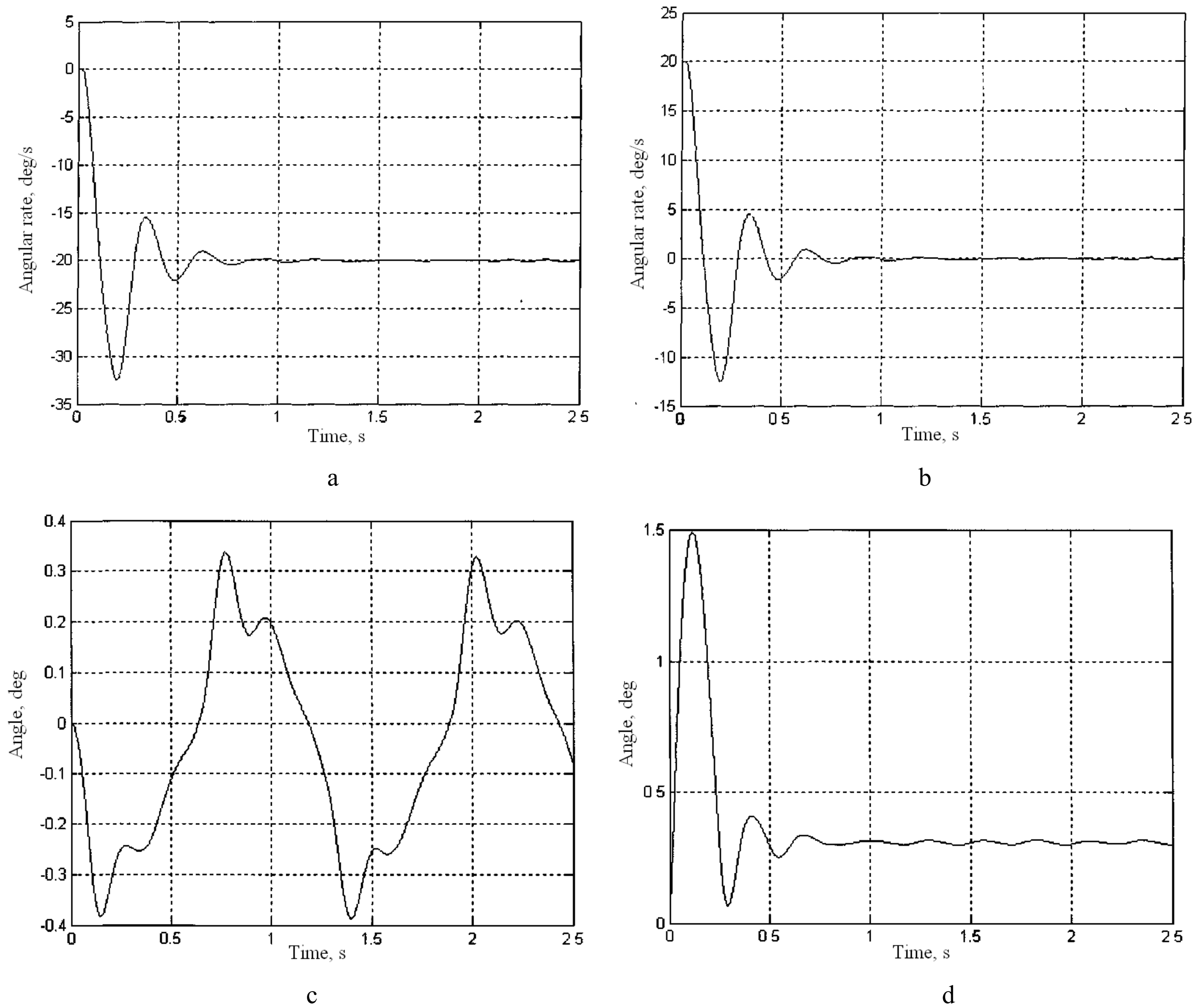

Fig. 5. Simulation results: a is the transient by angular rate 20 deg/s in the tracking mode; b is the transient by angular rate 20 deg/s in the stabilization mode; c is the transient by the absolute angle for the given harmonic angular rate; d is the transient by the absolute angle for the given constant angular rate

VII. Conclusions

Basic approaches to the design of the robust discrete controllers for systems information-measuring devices stabilization are considered. The simulation results are represented. Algorithms of the computer-aided procedures of the robust parametrical optimization and robust structural synthesis are suggested.

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О. А. Сущенко. Особливості автоматизованого проектування робастних дискретних контролерів для систем стабілізації інформаційно-вимірювальних пристроїв

Статтю присвячено проблемам автоматизованого проектвання контролерів для систем стабілізації інформаційно-вимірювальних пристроїв експлуатованих на рухомих об'єктах широкого класу в складних умовах дії збурень. Запропоновано алгоритми робастної параметричної оптимізації та стрктурного синтезу. Представлено результати моделювання.

Ключові слова: системи стабілізації; інформаційно-вимірювальні пристрої; робастні дискретні контролери; параметрична оптимізація; структурний синтез.

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О. А. Сущенко. Особенности автоматизированного проектирования робастных дискретных контроллеров для систем стабилизации информационно-измерительных устроств

Статья посвящена проблемам автоматизированного проектирования контроллеров для систем стабилизации информационно-измерительных устройств, эксплуатируемых на подвижных объектах широкого класса в сложных условиях воздействия возмущений. Предложены алгоритмы робастной параметрической оптимизации и структурного синтеза. Представлены результаты моделирования.

Ключевые слова: системы стабилизации; информационно-измерительные устройства; робастные дискретные контроллеры; параметрическая оптимизация; структурный синтез.

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