COMPUTER-AIDED DESIGN SYSTEMS

UDC 629.7.027 (045)
DOI: 10.18372/1990-5548.54.12320

O. A. Sushchenko

COMPUTER-AIDED PROCEDURES ASSIGNED FOR DESIGN OF ROBUST INERTIALLY STABILIZED PLATFORMS

Educational & Research Institute of Air Navigation, National Aviation University, Kyiv, Ukraine
E-mail: sushoa@ukr.net

Abstract—*The paper deals with basic computer-aided procedures assigned for design of robust inertially stabilized platforms. The general scheme of design process is represented. Feature of design of inertially stabilized platforms are described. The most important subsystems of automated design procedure are given. Basic features of mathematical and program supports are presented. Hardware structure is proposed. The structural scheme of robust controller design based on the robust structural synthesis is shown. Computer-aided facilities of design of computer-aided procedures are analyzed. Usage of proposed computer-aided procedures decreases time and cost of design works.*

Index Terms—Computer-aided design; inertially stabilized platforms; mathematical models; robust control; structural synthesis; parametrical optimization.

I. INTRODUCTION

Design of robust systems assigned for stabilization of information and measuring devices deals with many complex transformations and calculations. This requires using computer-aided design procedures.

It should be noted that robust control systems in general and robust systems for stabilization of information and measuring devices in particular have some features, which distinguish them from another complex engineering systems, for example, instrumentation systems. In fact a system for stabilization of information and measuring devices is a set of devices, which operate in the mode of control of a plant. Therefore design of such systems must include some specific procedures such as development of mathematical models and synthesis of controllers. Analysis of synthesized system characteristics including stability, accuracy, and robustness must be carried out too.

In this case, the plant presents a platform with mounted informational and measuring devices. Stabilization and control of platform motion is implemented by means of a servo system, which consists of inertial sensors, controllers, and motors.

II. REVIEW

The large quantity of papers and books, for example, [1], [2] deals with problems of robust controllers design. Main principles of robust parametrical optimization based on the mixed H_2/H_∞-optimization are discussed in [3]. Approaches to the structural synthesis and problems of the appropriate computer-aided procedures development are given in [4]. One of modern approaches to design of the robust controller based on the H_∞-synthesis is characterized in [1], [2]. Basics of computer-aided design of control systems are given in [5].

At the same time the proper attention yet was not given to problems of design of the robust systems for stabilization of information and measuring devices. If stabilization is carried out in the inertial space, such systems can be called inertially stabilized platforms.

III. PROBLEM STATEMENT

The structural scheme of design process of inertially stabilized platform is represented in Fig. 1.

The first phases of design of the inertially stabilized platform include choice of the functional, kinematical, structural schemes and technical facilities. This process can be implemented based on specification of requirements and taking into consideration experience of previous developed platforms.

One of the most important phases of the computer-aided design of the robust inertially stabilized platform is synthesis of a robust controller. It requires close connections with procedures of mathematical models development, simulation, analysis, and making decision. The main goal of research is representation of approach to creation of computer-aided procedures, which provide design of inertially stabilized platforms.

The following design phase is development of math-based environment, which must include nominal and parametrically disturbed models of inertially stabilized platforms and models of external disturbances. The model of the inertially stabilized platform is developed on the basis of its separate devices by means of aggregation. Further synthesis of the robust controller is carried out. Next design procedures include calculations, prototyping, construction and technological development, manufacturing of pre-production models, and tests. These design works are implemented both for the inertially stabilized platform and its separate components.

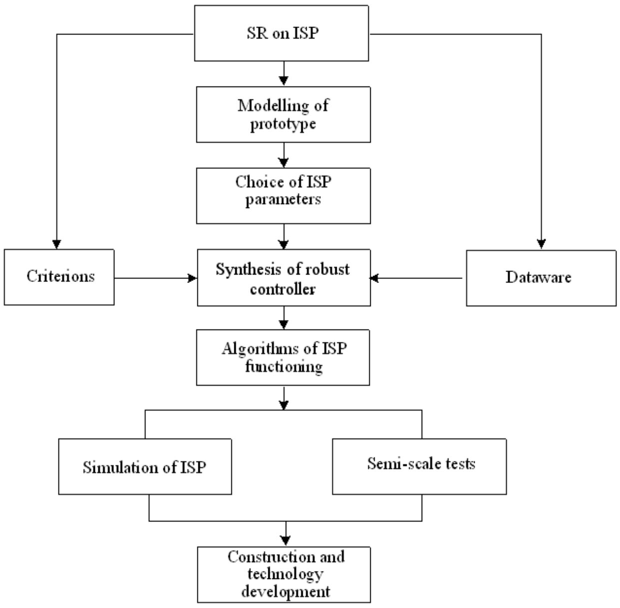

Fig. 1. Structural scheme of design process of the inertially stabilized platform: SR is a specification of requirements; ISP is the inertially stabilized platform

It should be noted that systems of the researched type have some features that complicate their analysis and synthesis. The systems are multichannel and multimode. They have the high order and complex structure of the controller. Rigid requirements to quality of transient processes are given in this case.

The specific feature of optimal design of complex multichannel systems is the possibility to have local extremums. This is caused by constraints imposed on space of design parameters. These constraints can be defined based on specification of requirements. Therefore it is necessary to analyze results obtained during fulfilment of the robust parametrical optimization or the robust structural synthesis. These features lead to necessity to use interactive procedures of automated design.

IV. COMPUTER-AIDED FACILITIES

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

As stated above, design of robust systems requires implementation of labour-intensive transformations and calculations. Now these difficulties can be overcome due to usage of software, which allows to automate the complex functional and analytical transformations, for example, Maple, MathCAD, Scilab, and 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 inertially stabilized platforms in particular. Design of inertially stabilized platforms can be simplified due to Matlab usage.

Control System Toolbox provides synthesis, simulation and analysis of control systems of the wide class. Advantages of this toolbox are caused by usage of both the traditional methods of control systems design based on the frequency methods and the modern control theory methods based on the state space methods. The toolbox allows to develop procedures of optimal design of both continuous and discrete systems [6].

The strong tool of the robust systems design is Robust Control Toolbox, which provides implementation of complex calculations necessary for controller structural synthesis using the optimization criterion based on the H_∞-norms of sensitivity functions defined for a transfer function of a closed loop system [4].

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 just such models can prove efficiency of the optimal synthesis. Matlab has wide possibilities for creation of models based on Simulink.

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

V. COMPUTER-AIDED PROCEDURES

The inertially stabilized platforms are characterized by some features, which significantly complicate their analysis and synthesis. These difficulties are caused by complex structure of the controller, certain quality requirements to transient processes and some specific requirements. Design of robust inertially stabilized platforms requires development of forming filters to provide simulation of the disturbed angular motion.

In the process of design of any technical object the optimization criterion must be chosen [5]. For inertially stabilized platforms that operate in conditions of uncertainties such as the structured parametric and coordinate disturbances. The H_∞-norm of the complementary sensitivity function of the designed system as the robustness criterion can be chosen. During parametric optimization it is necessary to take into account simultaneously both performance and robustness criteria (the H_2 and H_∞-norms of the sensitivity function and the complementary sensitivity function respectively).

The conflicting requirements are given to robust inertially stabilized platforms. Therefore the process of their computer-aided design must be based on the principles of the vector optimization. In this case, achievement of the effective solution requires participation of a designer that is usage of interactive procedures.

Design of control systems in general and inertially stabilized platforms in particular based on the H_2/H_∞-optimization and the H_∞-synthesis requires combination of the frequency domain methods and the state space methods. These methods are characterized by complex transformations and calculations and require usage of computer techniques for their implementation. Creation of computer-aided procedures of the robust systems design on the basis of their mathematical description in the state space is supported by a large number of specialized embedded functions that are components of Matlab toolboxes.

Improving of inertially stabilized platforms is carried out in two directions, including modernization of operated systems and design of perspective systems. The system of the computer-aided design of the robust inertially stabilized platforms operated on moving vehicles must be provided by the mathematical and software support, structure of which is shown in Fig. 2. Structure of robust inertially stabilized platforms computer-aided design system is given in Fig. 3. Structure of the computer-aided design procedure is given in Fig. 4.

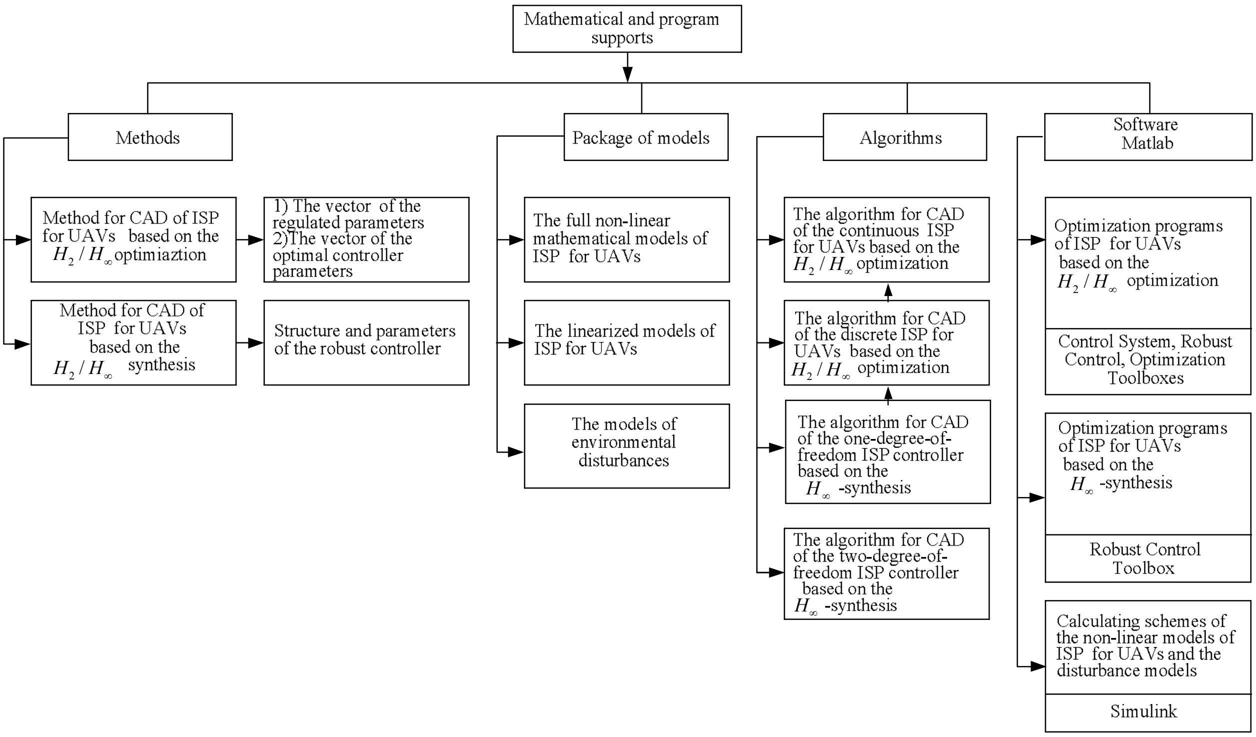

Fig. 2. Structural scheme of mathematical and software supports

Choice of structure and technical facilities of the system is carried out by means of search of possible variants of system construction based on definite technical facilities. Characteristics of these facilities are components of dataware of computer-aided system. Such approach allows to form the generalized structure of the system. For example, functions of angular rate measurement can be implemented by means of sensors of some types (gyroscopic tachometer, MEMS-gyroscope and fiber-optic gyroscope), as it is shown in Table I.

TABLE I CHARACTERISTIC OF RATE GYROSCOPE

Function	Sensor	Characteristics
Measurement of angular rate	GT-46	1. Measuring range. 2. Sensitivity. 3. Resistance to shocks. 4. Dimensions. 5. Cost.
	MEMS	
	FOG	

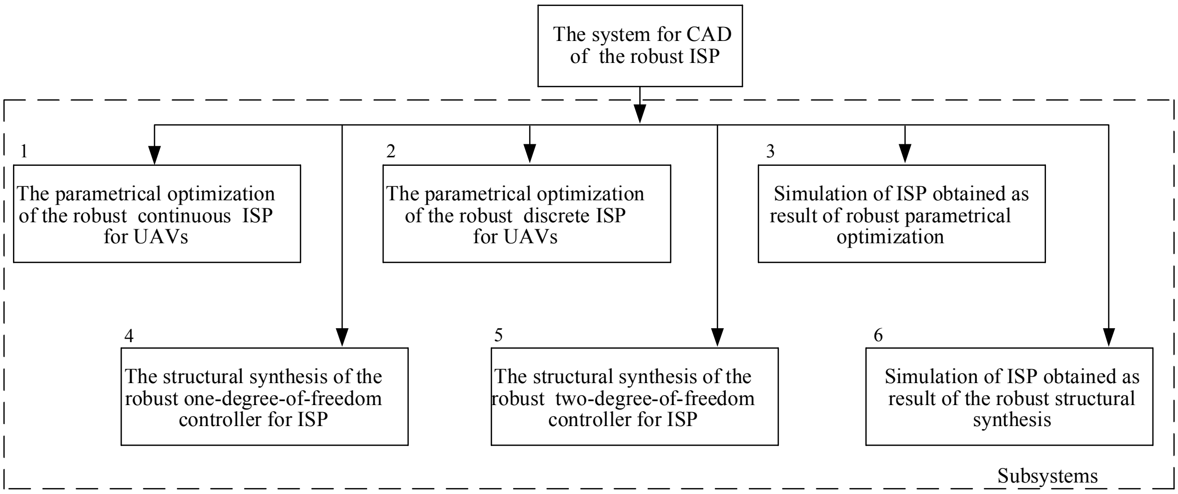

Fig. 3. The computer-aided subsystems of design of inertially stabilized platforms: CAD is computer-aided design

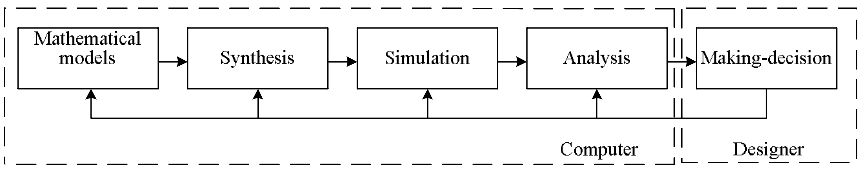

Fig. 4. Structure of the computer-aided design procedure

VI. PROCEDURES OF COMPUTER-AIDED DESIGN

The structure of hardware of the inertially stabilized platform is given in Fig. 5.

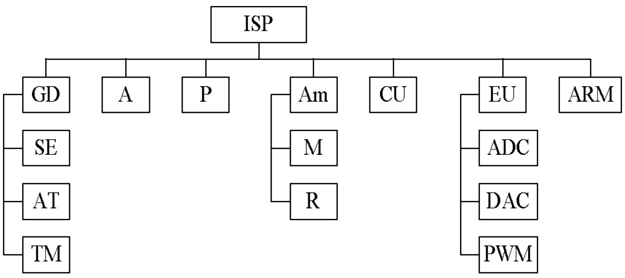

Fig. 5. Structure of inertially stabilized platform hardware: ISP is an inertially stabilized platform; GD is a gyroscopic device; SE is a sensitive element; AT is an angle data transmitter; TM is a torque motor; A is an accelerometer; P is a platform; Am is an amplifier; M is a motor; R is a reducer; CU is control unit; EU is electronic units; ADC is analog-digital converter; DAC is digital-analog converter; PWM is a pulse-width-modulator; ARM is a sensor of angular relative motion

Implementation of computer-aided design procedures of robust inertially stabilized platforms includes the following stages.

1) Problem statement and determination of the objective function.

2) Development of the mathematical models taking into consideration non-linearities inherent to real systems.

3) Development of the linearized mathematical model in the state space.

4) Analysis of requirements given to the system and forming the optimization criterion and the penalty function.

5) Creation of models of coordinate disturbances taking into consideration influence of environmental perturbations.

6) Choice of the optimization method.

7) Creation of an algorithm for design of robust inertially stabilized platform using modern automated means of optimal control synthesis.

8) Simulation and analysis of results.

The design procedure of the model development is based on combination of the analytical methods and Matlab software.

The mathematical models are the necessary components of the above stated design procedures. By the level of the complexity they can be represented by the hierarchical structure consisting of two levels as it is represented in Fig. 6.

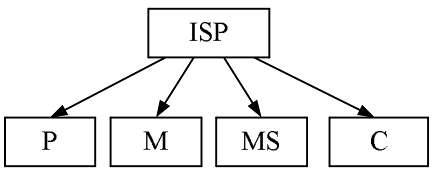

Fig. 6. The hierarchical structure of the mathematical models: ISP is an inertially stabilized platform; P is a platform; M is a motor; MS is a measuring system; C is a controller

Matlab software provides formalized representation of the inertial platform structure including connections between devices. The formalized representation of the stabilization system can include mathematical models in the form of transfer functions and state space matrices.

The feature of the computer-aided design subsystem is the necessity to include the models of coordinate disturbances that influence on the system in conditions of real operation. These models can be represented in the form of the transfer function of the forming filters.

Design procedure of the mathematical model development necessary for computer-aided design of the inertially stabilized platforms must include the following basic stages.

1) Development of the full mathematical models of the design system components in the analytical form based on the classical laws, which define their principles of operation. These models must include all the non-linearities inherent to real systems.

2) Development of the full model of the inertially stabilized platform based on device models by means of the aggregation principle.

3) Development of models of various disturbances including environmental ones.

4) Simplification of the stabilization plant and devices models, including linearization, which provides the possibility to represent the models in the state space or in the form of transfer functions.

5) Development of the model of the inertially stabilized platform in the form, which is suitable for automated representation and takes into consideration structural connections between system components.

The computer-aided design of the robust stabilization system requires interconnected design procedures of the mathematical models development, synthesis, simulation and analysis, that is described by the block-scheme represented in Fig. 7.

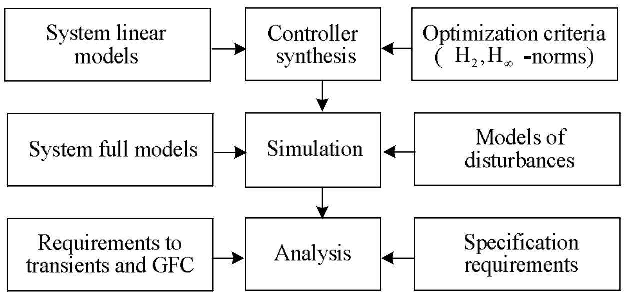

Fig. 7. Design of the robust controller: GFC is gain-frequency characteristic

The simulation design procedure is used for simulation of inertially stabilized platforms.

Generalized scheme of process of inertially stabilized platform design by means of computer-aided procedures is given in Fig. 8. The process represents the interactive procedure based on the H_∞-synthesis [2], [7].

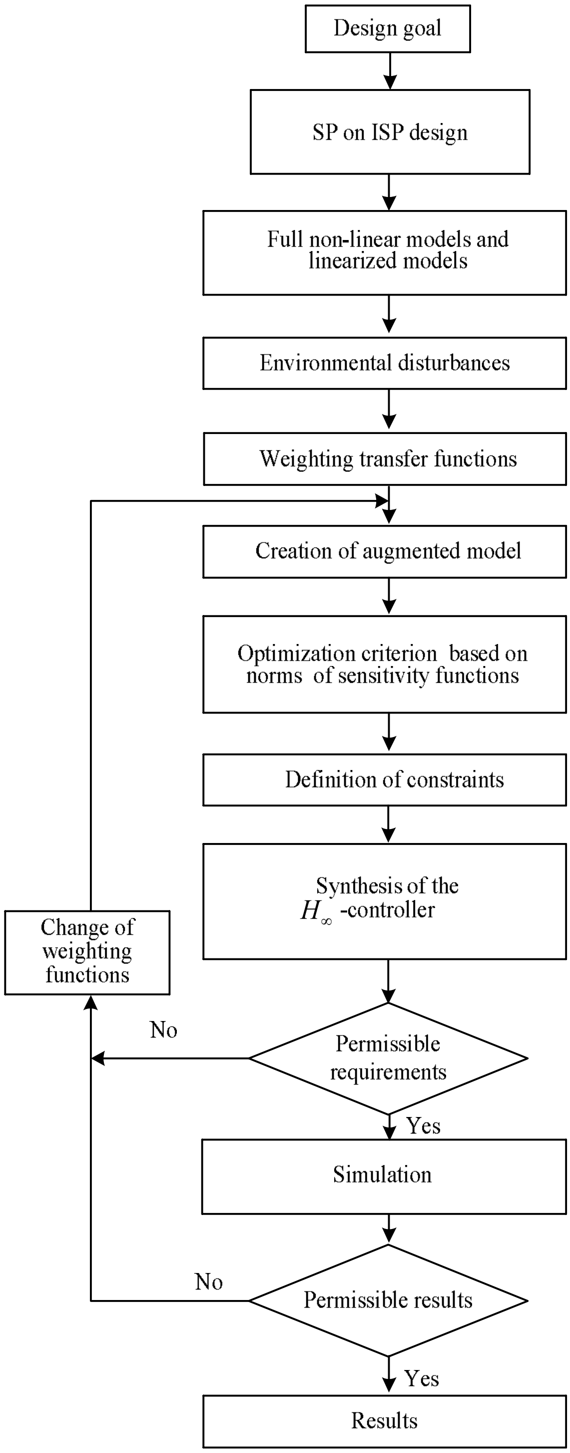

Fig. 8. The structural scheme of interactive computer-aided procedure

Taking into consideration complexity of the researched systems, the simulation accuracy estimation it is convenient to carry out by method of the gain-frequency characteristics comparison [5]. In this case the model gain-frequency characteristics are compared with the appropriate characteristics obtained at the real equipment by means of the experiments. This process includes following stages.

1) Analysis of the design purposes of the inertially stabilized platform.

2) Research of structural parametrical and external coordinate disturbances, which influence on the inertially stabilized platform.

3) Estimation of the stability, dynamical and static characteristics.

4) Making-decision about the final correspondence of results of designed system simulation to technical requirements.

Design of systems of the researched type is the complex problem. Its solving is carried out in conditions of uncertainty. This causes necessity to use heuristic approaches to realization of proposed methods of computer-aided design. In this case, experience and intuition of a developer is combined with possibility of quick checking proposed solutions by means of computer technique. This improves quality of decisions made by a developer.

So, taking into consideration complexity of the optimal solution search for the tasks of the research type and the rigid requirements to engineering time and cost, the most effective mode of the design procedures implementation is the interactive mode. It combines the computer-aided design procedures, which are carried out by means of the computer and designer actions for realization of the procedures, which can not be formalized and automated. These procedures include making-decision, results estimation and introduction of conditions and data for the further design.

As stated above, computer-aided design procedures described in the paper depend on the type of the solved problem such as modernization or design of a new system. In the first case, these procedures are based on the interactive procedures of the parametric robust optimization. In the second case, they use interactive procedures of the vector robust structural synthesis. The structural scheme for design process of the inertially stabilized platform on the basis of H_2 / H_∞-optimization is not given due its similarity to the scheme given in Fig. 8. Moreover, both design processes (modernization and creation of new systems respectively) have the same phases [8].

Usage of system of computer-aided design improves efficiency of design process due to decrease of the design time. This improves also quality of design works owing to decrease of designer errors and quantity of prototypes and the possibility to change tests by simulation.

VII. CONCLUSIONS

The basic principles of the computer-aided design system for creation of inertially stabilized platform for moving vehicles are given.

The most important subsystems of design process are described. The basics of algorithmic, software and method supports are represented.

The generalized structural scheme of interactive design process based on the H_∞-synthesis is given.

The proposed approach allows decreasing the design time and improving quality of design systems due to automation of complex and labour-intensiveness calculations and transformations.

REFERENCES

[1] D. W. Gu, P. Hr. Petkov, and M. M. Konstantinov, *Robust Control Design with MATLAB*. London: Springer-Verlag, 2005, 389 p.

[2] S. Skogestad and I. Postlethwaite, *Multivariable Feedback Control*. New York: Jonh Wiley, 1997, 559 p.

[3] A. A. Tunik, H. Rye, and H. C. Lee, “Parametric optimization procedure for robust flight control system design,” *KSAS Int. Journal*, vol. 2, no. 2, pp. 95–107, 2001.

[4] *Robust Control Toolbox*, User’s guide, Mathworks, 2001.

[5] R. I. Solnitsev, *Automation of Automatic Control Systems*. Moscow: Visha shkola. 1991, 335 p.

[6] *Control System Toolbox*, User’s guide, Mathworks, version 4.2, 1992.

[7] O. A. Sushchenko, “Design of two-axis robust system for stabilization of information-measuring devices operated at UAVs,” in *Proc. IEEE 3rd Int. Conf. Actual Problems of Unmanned Aerial Vehicles Developments, APUAVD-2015*, Kyiv, Ukraine, October 13–15, 2015, pp. 198–201.

[8] O. A. Sushchenko and O. V. Shyrokyi, “H2/H∞ optimization of system for stabilization and control by line-of-sight orientation of devices operated at UAV,” in *Proc. IEEE 3rd Int. Conf. Actual Problems of Unmanned Aerial Vehicles Developments, APUAVD-2015*, Kyiv, Ukraine, October 13–15, 2015, pp. 235–238.

Received September 16, 2017

Sushchenko Olha. Doctor of Engineering Science. Professor.
Aircraft Control Systems Department, Education & Research Institute of Air Navigation, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Polytechnic Institute, Kyiv, Ukraine, (1980).
Research interests: systems for stabilization of information-measuring devices operated at vehicles of the wide class.
Publications: 120.
E-mail: sushoa@ukr.net

О. А. Сущенко. Автоматизовані процедури проектування робастних інерціальних стабілізованих платформ

У статті представлено основні процедури автоматизованого проектування, які призначені для робастних інерціальних платформ. Представлено узагальнену структуру процесу проектування. Описано особливості проектування інерціальних стабілізованих платформ. Представлено найбільш важливі підсистеми процедур автоматизованого проектування. Описано основні особливості математичного і програмного забезпечення. Приведено структурну схему проектування робастного контролера на основі робастного структурного синтезу. Проаналізовано засоби створення автоматизованих процедур проектування. Використання запропонованих комп'ютеризованих процедур зменшує терміни та вартість проектних робіт.

Ключові слова: автоматизоване проектування; інерціальні стабілізовані платформи; математичні моделі; робастне управління; структурний синтез; параметрична оптимізація.

Сущенко Ольга Андріївна. Доктор технічних наук. Професор.
Кафедра систем управління літальних апаратів, Навчально-науковий інститут аеронавігації, Національний авіаційний університет, Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1980).
Напрям наукової діяльності: системи стабілізації інформаційно-вимірювальних пристроїв, експлуатованих на рухомих об'єктах широкого класу.
Кількість публікацій: 120.
E-mail: sushoa@ukr.net

О. А. Сущенко Автоматизированные процедуры проектирования робастных инерциальных стабилизированных платформ

В статье представлены основные процедуры автоматизированного проектирования, предназначенные для робастных инерциальных платформ. Представлена обобщенная структура процесса проектирования. Описаны особенности проектирования инерциальных стабилизированных платформ. Представлены наиболее важные подсистемы процедур автоматизированного проектирования. Описаны основные особенности математического и программного обеспечения. Приведена структурная схема проектирования робастного контроллера на основе робастного структурного синтеза. Проанализированы средства создания автоматизированных процедур проектирования. Использование предложенных компьютеризованных процедур уменьшает сроки и стоимость проектных работ.

Ключевые слова: автоматизированное проектирование; инерциальные стабилизированные платформы; математические модели; робастное управление; структурный синтез; параметрическая оптимизация.

Сущенко Ольга Андреевна. Доктор технических наук. Профессор.
Кафедра систем управления летательных аппаратов, Учебно-научный институт аэронавигации, Национальный авиационный университет, Киев, Украина.
Образование: Киевский политехнический институт, Киев, Украина, (1980).
Направление научной деятельности: системы стабилизации информационно-измерительных устройств, эксплуатируемых на подвижных объектах широкого класса.
Количество публикаций: 120.
E-mail: sushoa@ukr.net