UDC 629.3.025.2(045)

Olga Sushchenko

COMPUTER-AIDED DESIGN OF ROBUST SYSTEM FOR STABILIZATION OF INFORMATION-MEASURING DEVICES AT MOVING BASE

National Aviation University
Kosmonavta Komarova avenue 1, 03680, Kyiv, Ukraine
E-mail: sushoa@ukr.net

Abstract. *The paper is devoted to the research of the computer-aided methods for design of the robust systems for stabilization of the information-measuring devices operated on the vehicles. In the paper the basic principles of the computer-aided design system creation are defined, the structure of the mathematical and software support are represented, the basic design procedures and connections between them are characterized. The research results are of interest* for *the field of the information-measuring stabilization systems assigned for the operation on the vehicles of the wide class.*

Keywords: computer-aided design; information-measuring devices; robust optimization; stabilization systems.

1. Introduction

The search of the new approaches to design of the systems for stabilization of the information-measuring devices mounted at the moving base in the complex conditions of the real exploitation is the actual problem for all countries with the high technical level. Creation of the high-precision systems for stabilization of the information-measuring devices assigned for exploitation at the ground and marine vehicles is very important for Ukraine.

The advantages of the robust systems for stabilization of the information-measuring devices at the moving base lie in the possibility to provide the acceptable accuracy of the stabilization and tracking processes in the complex conditions caused by action of the internal parametric and external coordinate disturbances, which are connected with the real exploitation.

Now the tendency to increase the technical requirements to the stabilization systems and to decrease their design period at the same time takes place. The specific feature of design process of the robust systems for stabilization of the information-measuring devices taking into consideration their complexity and necessity to provide the robust control principles is execution of the large quantity of calculations and transformations. These factors require to use the computer-aided design methods.

The modern methods of creation of the robust systems for stabilization of the information-measuring devices require the science-based approaches to realization of the earlier design phases such as preliminary and draft design ones. Exactly at these phases the fundamentals of the future system design in the conditions of uncertainty relative to the real system characteristics are determined. Hence, success of these phases execution influences on the designed system quality.

2. Analysis of the researches and publications

The main problems of creation of the system for stabilization of the information-measuring devices at the moving base are described in [Pelpor 1965; Rivkin 1978]. The modern robust control theory suggests methods which help the designer to create the computer-aided optimal design procedures. The H_∞-synthesis and the robust parametric H_2/H_∞-optimization belong to such methods. The robust control methods have been an active research area during the past decades. The results of these researches are represented in many textbooks and papers, for example [Kwakernaak 1993; Skogestad, Postlethwaite 1997; Zhou, Doyle 1999]. It should be noted that now the great consideration to design of the robust systems for control by the aircraft motion is given. At the same time the appropriate approaches to creation of the robust systems for stabilization of the information-measuring systems operated at the ground and marine vehicles still have not been achieved the necessary level of development.

Taking into consideration the modern trends of increasing the requirements to the technical characteristics of the researched systems and the necessity to reduce the time of their development the creation of the competitive systems is connected with the necessity of their design automation.

The important theoretical and practical developments in the area of the computer-aided design of the complex systems, including control systems, are represented in [Norenkov 2000; Pupkov 2004; Solnitsev 1991].

The above stated textbooks define the general approaches to the computer-aided design of the complex systems in general and control systems specifically but the question of the computer-aided design of the robust systems for stabilization of the information- measuring devices still is not reflected in the modern technical literature.

The purpose of the article lies in determination of the basic principles for development of the automated design system, intended for creation of the systems for stabilization of the information-measuring devices, operated at the ground and marine vehicles.

3. Computer-aided design of the robust systems for stabilization of the information-measuring devices

It should be noted that from the view point of the designer, the control systems in general and the systems of the researched type in particular, as opposed to other systems (for example, the instrument systems) represent the set of devices, operating in the mode of control by some plant. This makes the process of design more complex and adds the set of specific design procedures [Solnitsev 1991], such as the synthesis of the controller, analysis of the characteristics of stability, accuracy and robustness and the development of the mathematical models.

In the given case the stabilized plant is a platform with information-measuring devices mounted on it. Stabilization and control by the platform motion is implemented with the tracking systems, which consist of sensors, controllers and actuators.

The role of researches, which represent the base of this article, in the process of the stabilized platform design is defined by creation of the mathematical description and development of the methods for the automated synthesis of the system for its stabilization. The main purpose of the fulfilled researches is creation of the computer-aided design system for development of the robust systems for stabilization of the information-measuring devices.

The systems of the researched type are characterized by some features, which significantly complicate their analysis and synthesis. These difficulties are caused by presence of many control channels and operating modes, the high order of the set of the differential equations, that describe a system, the complex structure of the controller and control laws, certain quality requirements to transient processes and some specific requirements, such as providing of the angular stiffness by the external torque for the stabilization system, mounted at the ground vehicles, and the given speed of setting to the meridian for the system of stabilization and determination of the marine vehicle heading.

A specific feature of the optimal design of the complex multi-loop systems is the presence of both the global extremum and large number of the local extremumes. These local extremums appearance is caused by the constraints of the design parameter space due to the requirements of the performance specification. Thus, the problem of analysis of the received results, and, if it is necessary, the problem of repeated fulfillment of the parametric optimization or structural synthesis procedures are arisen. These features lead to the necessity of using of the interactive procedures of the computer-aided design.

Creation of the automated procedures for designing of the robust systems requires using of the package of the models with the different features which are defined by the goal of the research.

In the process of design of any engineering plant the optimization criterion must be chosen [Norenkov 2000]. For the modern systems for stabilization of the information-measuring devices, that operate in conditions of uncertainties, namely the structured parametric and external coordinate disturbances, the H_∞-norm of the complementary sensitivity function of the designed system as the robustness index can be chosen. During the parametric optimization the simultaneous account of the H_2-norm of the sensitivity function and the H_∞-norm of the complementary sensitivity function of the design system is desirable.

To the systems of the researched type the conflicting requirements are given, that is why 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 the designer that is organization of the interactive procedures.

It should be noted, that the design of control systems in general and stabilization systems in particular based on H_2/H_∞ and H_∞-optimization uses combination of the frequency domain methods and the state space methods. These methods are characterized by complex transformations and calculations and demand use of the computer techniques for their implementation. Creation of computer-aided procedures of the robust systems design on the basis of their mathematical description

in the space of states is supported by a large number of specialized embedded functions that are components of the calculating system MATLAB toolboxes.

The advantage of this system is caused by the simplicity of the graphical interfaces and ease of use for the designer. This allows to create the computer-aided design procedures without participation of the specialist on the computer engineering and increases the design efficiency.

The system of the computer-aided design of the robust systems for stabilization of the information-measuring devices operated at the ground and marine vehicles must be provided by the mathematical and software support, structure of which is shown in Fig. 1.

Improving of the systems for stabilization of the information-measuring devices is carried out in two directions, including modernization of the existing systems and design of the perspective systems.

Modernization of the systems of the researched type is convenient to implement using the interactive procedures, based on the robust parametric vector optimization. Design of the new systems requires the use of the interactive procedures based on the robust vector structural synthesis.

The created computer-aided design system provides design process of two classes of systems, such as the systems for stabilization of information-measuring devices for the ground and marine vehicles.

This computer-aided design system is grounded on some methods. The first method is the method of the computer-aided design of the real stabilization and tracking systems for the ground vehicles. This method represents the interactive procedure based on the vector robust parametric H_2 / H_∞-optimization [Sushchenko 2009]. The second method is the method of the computer-aided design of the perspective stabilization and tracking systems for the ground vehicles. This method represents the interactive procedure based on the vector robust structural H_∞-synthesis [Sushchenko, Chaplay 2011]. The third and the fourth methods are the methods of the computer-aided design of the navigation and stabilization contours for marine vehicle stabilization and heading determination system. These methods represent the interactive procedures based on the vector robust parametric H_2 / H_∞-optimization and the vector robust structural H_∞-synthesis.

The structure of the computer-aided design system for creation of the robust systems for stabilization of the information-measuring devices and the appropriate design procedures are represented in Figs 2, 3. The block-scheme represented in Fig. 3 describes connections between the main design procedures for creation of the systems for stabilization of the information-measuring devices.

The developed system includes instruments for creation of the continuous and discrete systems for stabilization of the observation equipment operated at the ground vehicle and the system for the marine vehicle stabilization and heading determination.

To implement the computer-aided methods of the design of the robust systems for stabilization of the information-measuring devices is necessary to carry out some stages such as:

1. Statement of the problem and determination of the optimal design goal.
2. Creation of the full mathematical description of the system with maximally possible taking into consideration of all non-linearities inherent to the real systems.
3. Development of the linearized mathematical model of the system in the space of states.
4. Analysis of the requirements given to the system and forming of the optimization criterion and the penalty function.
5. Development of the mathematical models of the external disturbances taking into consideration the features of the motion of the vehicle on which the researched system is mounted.
6. The choice of the optimization method.
7. Development of the algorithm for design of the robust system for stabilization of the information-measuring devices with using of the modern automated means of the optimal control synthesis.
8. Simulation and analysis of the obtained results.

The system of the computer-aided design of the system for stabilization of the information-measuring devices must automate the following design procedures [Pupkov 2004].

1. Development of the mathematical models of the system for stabilization of the information-measuring devices.
2. Synthesis of the robust stabilization systems.
3. Simulation of the robust systems for stabilization of the information-measuring devices.
4. Analysis of the designed systems for stabilization of the information-measuring devices.

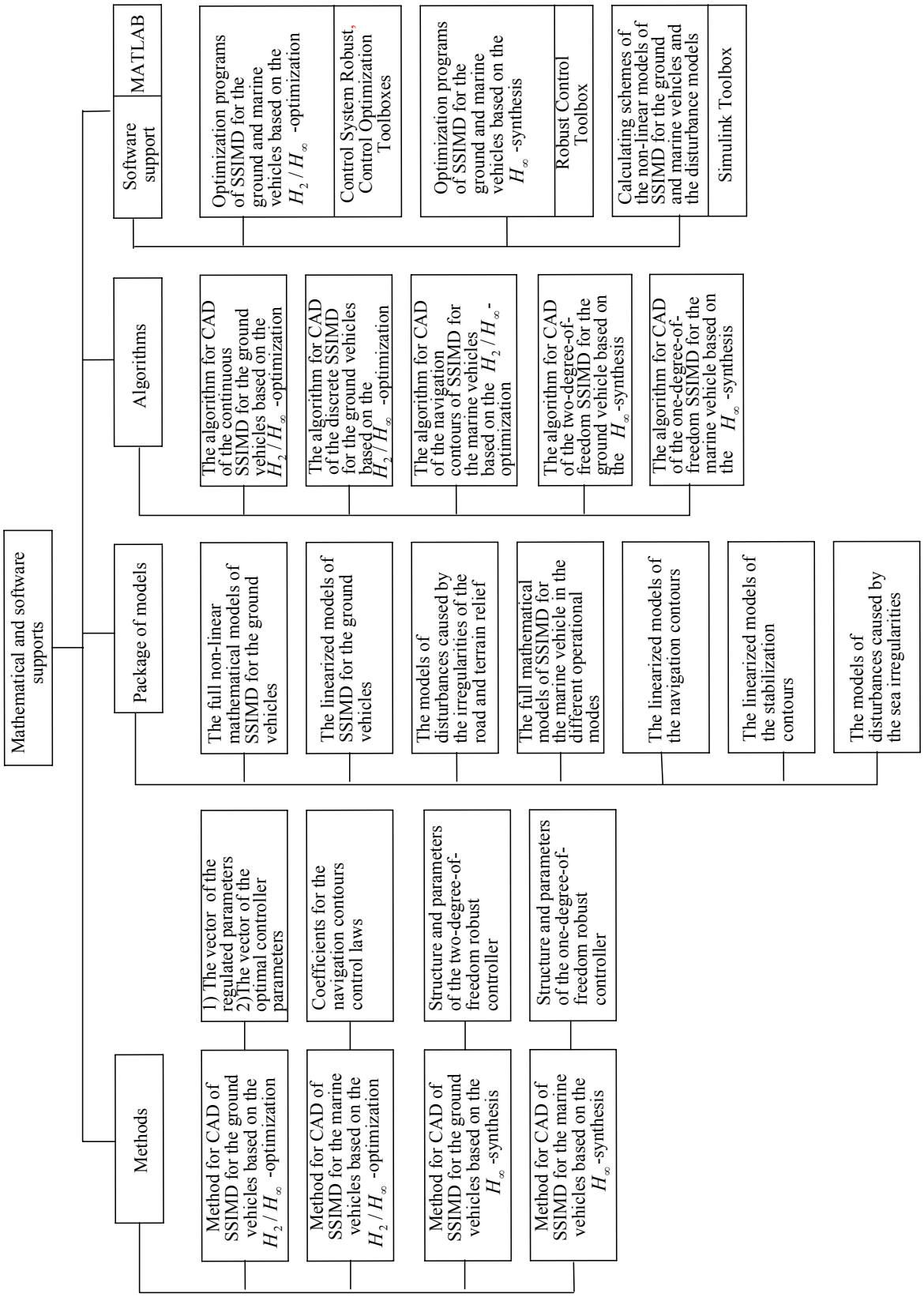

Fig. 1. The mathematical and software support of the CAD system for the SSIMD design: CAD – computer-aided design; SSIMD – system of stabilization for information-measuring devices

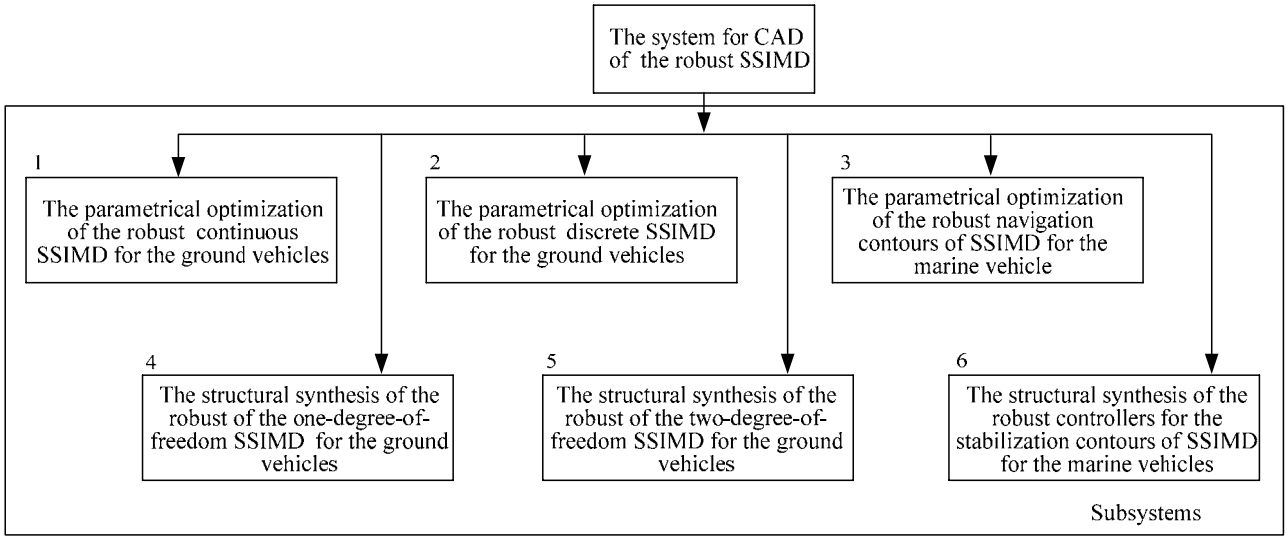

Fig. 2. The CAD subsystems for the design of systems for stabilization of the information-measuring devices

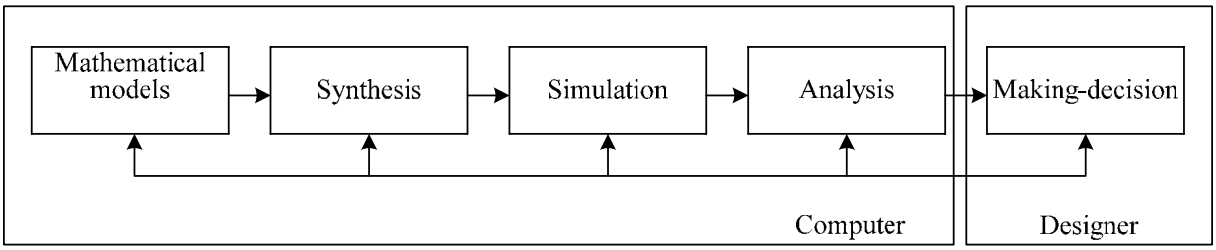

Fig. 3. The procedures of the design of the systems for stabilization of the information-measuring devices

The basic procedure of the computer-aided design of the systems for stabilization of the information-measuring devices is the procedure of synthesis. It requires the tight interconnections with the procedures of analysis, simulation and development of the mathematical models.

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

The mathematical models are the necessary components of the above stated design procedures. By the level of the complexity they may be represented by the hierarchical structure consisting of two levels as it is represented in Fig. 4 [Solnitsev 1991].

In this structure the first level corresponds to the mathematical model of the stabilization system. The second level corresponds to the mathematical models of its devices.

The mathematical models of the stabilization system in the whole may be described by the structural scheme, components of which may be represented by the mathematical models of the different type, for example, models in the space of states and the transfer functions. Such approach makes easier determination of the close system transfer functions necessary for execution of procedures of the vector robust parameterization and the robust structural synthesis. Analysis of the MATLAB software shows that it provides the formalized representation of the stabilization system structure scheme including the structure connections between the devices. The calculating system MATLAB provides the formalized representation of the stabilization system devices mathematical models in the form of the transfer functions and the matrices in the space of states.

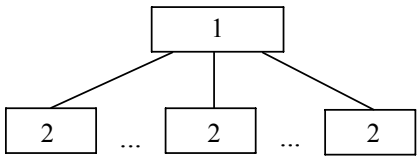

Fig. 4. The hierarchical structure of the mathematical models of the system for stabilization of the information-measuring devices:
1 – the level of the stabilization system;
2 – the level of the stabilization system devices

The feature of the computer-aided design subsystem lies in the necessity to include the models of the external disturbances that act on the system in the condition of the real exploitation. These models may be represented in the form of the transfer function of the forming filters. It should be noted that the systems of the researched type may be subjected to action of the many various disturbances that makes necessary creation of the models which correspond to the different typical disturbances.

Besides, the researched systems belong to the multimode systems that must be taken into consideration during the system design and leads to increasing of the quantity of the developed models.

So, the design procedure of the mathematical model development necessary for computer-aided design of the systems for stabilization of the information-measuring systems must include the following basic stages.

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

2. Development of the full model of the stabilization system based on their device models using the aggregation principle.

3. Development of models of the various disturbances and their inclusion in the information support.

4. Simplification of the stabilization plant and separate devices models, including linearization, which provides the possibility to represent the models in the space of states or in the form of transfer functions, and subsequent implementation of the optimal design.

5. Development of the stabilization system in the form suitable for its automated representation, taking into consideration the structural connections between separate components of the system.

The mathematical support of the computer-aided design system for creation of the system for stabilization of the information-measuring devices must include the following mathematical models.

1. The mathematical model of the continuous system for tracking and stabilization of the information-measuring devices operated at the ground vehicles. This model includes the mathematical models of the plant (stabilized platform), actuating mechanism, control unit, and pulse-width modulator.

2. The linearized mathematical model of the continuous tracking and stabilization system for the ground vehicle in the space of states.

3. The mathematical model of the discrete system for tracking and stabilization of the information-measuring devices operated at the ground vehicles taking into consideration all non-linearities.

4. The linearized mathematical model of the discrete system for tracking and stabilization of the information-measuring devices operated at the ground vehicles in the space of states.

5. The full mathematical models of the system for stabilization and heading determination in the modes of the previous and precision levelling and the gyro compass taking into account all non-linearities inherent to the real systems.

6. The mathematical model of the system for stabilization and heading determination in the mode of the previous levelling in the space of states.

7. The full mathematical models of navigation contours in the modes of the precise levelling and the gyro compass.

8. The linearized mathematical models of the navigation contours in the modes of the precise levelling and the gyro compass.

9. The full mathematical model of the stabilization contour of the stabilization and heading determination system.

10. The linearized mathematical model of the stabilization contour of the system for the marine vehicle stabilization and heading determination.

All above stated models are realized in the calculating system MATLAB. The full mathematical models taking into consideration all non-linearities inherent to the real systems are developed by means of the Simulink Toolbox.

The synthesis design procedure is intended for solving of the most complex task of the system for stabilization of the information-measuring devices design, namely determination of the controller structure and parameters.

In the represented paper this procedure depending on the solved problem (modernization or new system design) is based on the interactive procedures of the vector robust parametric optimization or the vector robust structural synthesis.

The computer-aided design of the robust stabilization system requires interconnected design procedures of the mathematical models development, synthesis, simulation and analysis. This is described by the block-scheme represented in Fig. 5.

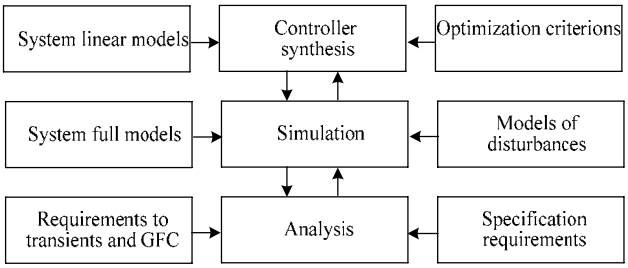

Fig. 5. Design of the robust regulator:
GFC – gain-frequency characteristic

The simulation design procedure is used for simulation of the system for stabilization of the information-measuring devices.

The simulation design procedure is used for simulation of the systems for stabilization of the information-measuring devices based on the mathematical models by means of the computers. The simulation is the effective change of breadboarding at all design phases, especially at the earlier phases of the system creation. The modeling procedure of the robust systems for stabilization of the information-measuring devices must include simulation that allows to carry out checking of the system synthesis results in conditions of the random external influences action. The results of such checks must be subjected to the statistical processing.

Taking into consideration the complexity of the researched systems, the simulation accuracy estimation is convenient to carry out by method of the gain-frequency characteristics comparison [Solnitsev 1991]. In this case the model gain-frequency characteristics are compared with the appropriate characteristics obtained at the real equipment by means of the experiments.

The analysis design procedure must provide.

1. The analysis of the realization of the functional purpose of the system for stabilization of the information-measuring devices.

2. Research of the structural parametric and external coordinate disturbances influencing on the stabilization system characteristics.

3. Estimation of the stability, dynamic and static characteristics.

4. Making-decision about the finite correspondence of the system design results to the given requirements.

The design of the researched systems represent the complex problem, solution of which is carried out in the conditions of uncertainty. This factor defines the necessity to use the heuristic approaches during implementation of the developed methods for the computer-aided design.

At that the experience and intuition of the designer are combined with the computer possibilities. The main task of the designer is execution of such design procedure as decision-making. The basic function of the computer is the quick check of the designer propositions due to use of the calculating possibilities.

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

Use of the computer-aided methods for design of the system for stabilization of the information-measuring devices increases efficiency of the design process due to decrease of the design time, quantity of the prototypical and pilot models and increase of the design works quality. The improvement of the design works is caused by decrease of the designer errors. To reduce the necessary quantity of the prototypical and pilot models is possible changing breadboarding and tests by the simulation.

4. Conclusions

The basic principles of the computer-aided design system for design of systems for stabilization of the information-measuring devices, operated at the ground and marine vehicles, are determined.

References

Kwakernaak, H. 1993. *Robust Control and H_∞-Optimization*. Automatica. Vol. 29. N 2: 255–273.

Norenkov, I.P. 2000. *Computer-aided design*. Moscow, MSTU named after N. E. Bauman. 188 p. (in Russian).

Pelpor, D.S. 1965. *Theory of the gyro stabilizers*. Moscow, Mashinostroenie. 347 p. (in Russian).

Pupkov, K.A. 2004. *Methods of classical and modern automatic control theory*. T.2. Statistical dynamics and identification of automatic control systems. Edition K.A. Pupkov, N.D. Egupov. Moscow, MSTU named after N. E. Bauman. 640 p. (in Russian).

Rivkin, S.S. 1978. *Stabilization of measuring devices at swinging base*. Moscow, Nauka. 320 p. (in Russian).

Skogestad, S.; Postlethwaite, I. 1997. *Multivariable Feedback Control*. New York, Jonh Wiley. 559 p.

Solnitsev, R.I. 1991. *Automation of automatic control systems design*. Moscow, Vishca shkola. 335 p. (in Russian).

Sushchenko, O.A. 2009. *Robust parametrical optimization of discrete system for stabilization of the ground vehicle*. Proceedings of the National Aviation University. N 2: 60–65 (in Ukrainian).

Sushchenko, O.A.; Chaplay, I.V. 2011. *Synthesis of robust controller for stabilizing system of informational-measuring devices*. Proceedings of the National Aviation University. N 3: 36–42.

Zhou, K.; Doyle, J. 1999. *Essential of robust control*. New Jersey, Prentice Hall. 425 p.

Received 1 July 2013.

О.А. Сущенко. Автоматизоване проектування робастних систем стабілізації інформаційно-вимірювальних пристроїв на рухомій основі

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680

E-mail: sushoa@ukr.net

Досліджено методи автоматизованого проектування робастних систем стабілізації інформаційно-вимірювальних пристроїв, експлуатованих на рухомих об'єктах. Визначено основні принципи побудування системи автоматизованого проектування. Наведено структуру математичного та програмного забезпечення. Охарактеризовано основні проектні процедури та взаємозв'язки між ними. Показано, що результати дослідження становлять інтерес для галузі систем стабілізації інформаційно-вимірювальних пристроїв, призначених для експлуатації на рухомих об'єктах широкого класу.

Ключові слова: автоматизоване проектування; інформаційно-вимірювальні пристрої; робастна оптимізація; системи стабілізації.

О.А. Сущенко. Автоматизированное проектирование робастних систем стабилизации информационно-измерительных устройств на подвижном основании

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680

E-mail: sushoa@ukr.net

Исследованы методы автоматизированного проектирования робастных систем стабилизации информационно-измерительных устройств, эксплуатируемых на подвижных объектах. Определены основные принципы построения системы автоматизированного проектирования. Приведена структура математического и программного обеспечения. Охарактеризованы основные проектные процедуры и связи между ними. Показано, что результаты исследования представляют интерес для отрасли систем стабилизации информационно-измерительных устройств, предназначенных для эксплуатации на подвижных объектах широкого класса.

Ключевые слова: автоматизированное проектирование; информационно-измерительные устройства; робастная оптимизация; системы стабилизации.

Sushchenko Olga (1956). Candidate of Engineering. Professor.
Aircraft Control Systems Department, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Polytechnic Institute, Kyiv, Ukraine (1980).
Research area: the systems for stabilization of the information-measuring devices at the moving base, the robust systems for control by the vehicles of the wide class.
Publications: 100.
E-mail: sushoa@ukr.net