EDUCATION AND SCIENCE MINISTRY OF UKRAINE
NATIONAL AVIATION UNIVERSITY
DEPARTMENT OF COMPUTER INTEGRATED COMPLEXES

ADMIT TO DEFENSE
Head of department
Viktor M. Sineglazov
"21" November 2022

MASTER'S THESIS
(EXPLANATORY NOTE)

GRADUATE OF EDUCATION AND QUALIFICATION LEVEL "MASTER"

THEME: Mobile computer-aided design system a system for the remote support of forced avalanche ejection

Executor: **Kovalenko N.V.**

Supervisor: **Professor Ablesimov O.K.**

Advisor on environmental protection: **Ph.D., Associate Professor Iavniuk A.A.**

Advisor on labor protection: **Senior Lecturer Kozlitin O.O.**

Norms inspector: **Ph.D., Professor Filyashkin M.K.**

Kyiv 2022

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
КАФЕДРА КОМП'ЮТЕРНО-ІНТЕГРОВАНИХ КОМПЛЕКСІВ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
В.М. Синєглазов
"__21__" __Листопада__ 2020 р.

Кваліфікаційна робота

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬО-КВАЛІФІКАЦІЙНОГО РІВНЯ "МАГІСТР"

Тема: Система автоматичного проектування мобільного комплексу дистанційного забезпечення примусового сходу снігових лавин

Виконавець: **Коваленко Н.В.**

Керівник: **професор Аблесімов О.К.**

Консультант з екологічної безпеки: **к.т.н., доцент Явнюк А.А.**

Консультант з охорони праці: **старший викладач Козлітін О.О.**

Нормоконтролер: **к.т.н., професор Філяшкін М.К.**

Київ 2022

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра авіаційних комп'ютерно-інтегрованих комплексів

Освітньо-кваліфікаційний рівень бакалавр

Спеціальність 151 «Автоматизація та комп'ютерно-інтегровані технології»

ЗАТВЕРДЖУЮ
Завідувач кафедри
ДТН, професор
Синєглазов В.М.
“ 21 ” Листопада 2022 р.

ЗАВДАННЯ
на виконання дипломної роботи студенту
Коваленку Н.В.

1. Тема роботи: «Система автоматизованого проектування мобільного комплексу дистанційного забезпечення примусового сходу снігових лавин»

2. Термін виконання проекту (роботи): з 18.09. 2022р. до 20.11.2022р.

3. Вихідні данні до проекту (роботи): системи стабілізації і керування літальними апаратами, задана приладова швидкість 50 км/год ± 2 км/год; перерегулювання що не перевищує 2%; час регулювання – відповідно до технічних вимог; технічні параметри системи - відповідно до аналогів промислових зразків.

4. Зміст пояснювальної записки (перелік питань, що підлягають розробці): 1.Аналіз проблеми захисту від сходу сніжних лавин та визначення шляхів її вирішення. 2. Структура й алгоритми етапів проектування технічної системи. 3.Основні процедури проектування. 4.Базові компоненти автоматизованого проектування. 5.Формування алгоритму проектування мобільного комплексу. 6.Математичне забезпечення проектування дрону. 7.Моделювання системи керування. 8.Визначення складу бортової апаратури дрона. 9.Структурне моделювання системи керування. 10. Програмна реалізація імпульсного керування.

5. Перелік обов'язкового графічного матеріалу: 1.Структура системи автоматизованого проектування. 2.Визначення основних процедур проектування. 3.Визначення базових компонент системи. 4.Структурна схема симетричного дрона. 5.Автоматична система керування. 6.Принципи формування команд керування по променю лазера. 7.Алгоритм проектування. 8.Програмна реалізація імпульсного керування. 7.Програмне забезпечення автоматизованого синтезу.

6. Календарний план-графік

№ п/п	Завдання	Термін виконання	Відмітка про виконання
1	Підбір літератури	22-26.08	
2	Технічне завдання	27-28.08	
3	Вступ	29.08	
4	Обгрунтування доцільності автоматизації проектування	30.08-10.09	
5	Формування алгоритму проектування мобільного комплексу	11-25.09	
6	Проектування автоматизованої системи керування	26.09-15.10	
7	Програмно-методичне забезпечення експериментальних досліджень під час проектування	16-30.10	
8	Охорона навколишнього природного середовища	31.10-10.11	
9	Охорона праці	11-15.11	

7. Консультація з окремих розділів:

Назва розділу	Консультант (посада, П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона навколишнього природного середовища			
Охорона праці			

8. Дата видачі завдання: “22” серпня 2022 р.

Керівник: професор ____Аблесімов О.К.

(підпис)

Завдання прийняв до виконання _______________________________ Коваленко Н.В.

(підпис)

NATIONAL AVIATION UNIVERSITY

Faculty of aeronavigation, electronics and telecommunications

Department of Aviation Computer Integrated Complexes

Educational qualification level master

Specialty 151 «Automation and computer-integrated technologies»

APPROVED
Head of Department
Ph.D., professor
Sineglasov V. M.
“ 21 ” November 2022

TASK
For the student’s thesis
Kovalenko N.V.

1. Theme of the project: «Mobile computer-aided design system a system for the remote support of forced avalanche ejection»

2. The term of the project (work): from 18.09. 2022 until 20.11.2022

3. Output data to the project (work): Stabilization and aircraft control systems, set instrument speed 50 km/h ± 2 km/h; overshoot not exceeding 2%; regulation time – according to technical requirements; technical parameters of the system – according to prototype analogues.

4. Contents of the explanatory note (list of questions to be developed): 1. Analyze the problem of avalanche protection and identify ways to resolve it. 2. Structure and methods of technical system. 3.Basic design procedures. 4.The basic components of computer aided design. 5.Formation of mobile system design method. 6.Mathematical support for drone design. 7.Modelling the control system. 8.Determination of the composition of the drone’s on-board hardware. 9.Structural modeling of the control system. 10. Software implementation of pulse control.

5. List of compulsory graphic material: 1. Structure of the computer-aided design system. 2. Definition of basic design procedures. 3. Definition of the basic components of the system. 4. Structural diagram of a symmetric drone. 5. Automatic control system. 6. Principles of laser beam control command generation. 7. Design algorithm. 8. Software implementation of pulse control. 7. Software for automated synthesis.

6. Planned schedule:

№	Task	Execution term	Execution mark
1	Selection of literature	22-26.08	
2	Terms of reference	27-28.08	
3	Introduction	29.08	
4	Rationale for design automation	30.08-10.09	
5	Algorithm formation of mobile complex design	11-25.09	
6	Design of automated control system	26.09-15.10	
7	Software and methodological support of experimental researches at designing	16-30.10	
8	Environmental protection	31.10-10.11	
9	Labor protection	11-15.11	

7. Section-by-section consultation:

Title of section	Consultant (position, name and surname)	Date, signature	
		Task issued	Task accepted
Environmental protection			
Labor protection			

8. Date of task receiving: "22" august 2022

Supervisor: professor ____________________ Ablesimov O.K.
(signature)

Issued task accepted ____________________ Kovalenko N.V.
(signature)

ТЕХНІЧНЕ ЗАВДАННЯ

1. Найменування та галузь застосування

Робота має на меті розробку структури САПР, математичного та програмного забезпечення автоматизованого проектування запропонованого високоточного мобільного комплексу дистанційного забезпечення примусового сходу снігових лавин.

2. Мета та призначення розробки

В роботі визначаються завдання та основні процедури автоматизованого проектування, розглядається структура САПР мобільного комплексу, розробляються інженерні методи проектування дронів та систем керування ними у мобільних комплексах. Виконано експериментальну перевірку дієздатності та достовірності запропонованих рішень. Розроблено програмне забезпечення автоматизованого синтезу автоматизованої системи керування дроном.

3. Технічні вимоги

3.1. Основні технічні вимоги

– швидкості, км/год до ...……………....…………………......................200

3.2. Вимоги до засобів захисту

– робоча температура, °С...……………………………..................–55..... +85

– робоча вологість, %...98 (25°С)

3.3. Додаткові вимоги

– максимальний кут крену , град ....30°

– максимальний кут тангажу , град ....10°

4. Стадії та етапи розробки

4.1. Технічний проект

На даному етапі проектування повинно бути проаналізовано і вибрано варіант функціонального виконання мобільного комплексу. Розробка алгоритмів побудови автоматизованої системи керування дроном.

4.2. Робочий проект

На даному етапі розроблюється САПР автоматизованої системи наведення. Планується проведення досліджень спроектованої системи автоматизованого наведення. Розробляється програмно-методичне забезпечення.

5. Порядок контролю та приймання

Контроль здійснюється керівником проекту відповідно до завдання та календарного плану.

Приймання здійснюється на підставі захисту дипломної роботи ДЕК ФАЕТ.

Термін здачі дипломної роботи: “10” листопада 2022 р.

TECHNICAL TASK

1. Name and field of application

The work aims to develop the structure of CAD, mathematical and computer-aided design software for the proposed high-precision mobile complex for remote control of forced avalanches.

2. The purpose of the design

The paper defines the tasks and basic procedures of computer-aided design, considers the CAD structure of the mobile complex, develops engineering methods for designing drones and control systems in mobile complexes. Experimental verification of the efficiency and reliability of the proposed solutions is carried out. The software for automated synthesis of the automated drone control system is developed.

3. Technical requirements

3.1. Basic technical requirements

– velocities, km/h to ..……………...........………………….....................200

3.2. Requirements for protective equipment

– working temperature, °C...…………………………….................–55..... +85

– operating humidity, %..98 (25°C)

3.3. Additional requirements

– maximum roll angle , deg ....30°

– maximum pitch angle , deg ....10°

4. Stages and phases of development

4.1. Technical project

At this stage of the design should be analyzed and selected variant of functional performance of the mobile complex. Development of algorithms for building an automated drone control system.

4.2. Work project

At this stage, CAD of the automated guidance system is being developed. It is planned to conduct studies of the designed automated guidance system. Software and methodological support is being developed.

5. The order of control and acceptance

Control is carried out by the project manager in accordance with the task and schedule..

Admission is carried out on the basis of the defense of the diploma work of the FAET.

Deadline for thesis submission “10” November 2022

ANNOTATION

Explanatory note to the diploma work «Mobile computer-aided design system a system for the remote support of forced avalanche ejection»: _____ p., ___ fig., _____ tab.

CAD, DRONE, AUTOMATED CONTROL; LASER BEAM, MODELING, SOFTWARE.

Object of research - mobile complex for remote support of forced avalanches; subject of research - CAD of the automated drone control system.

The purpose of the thesis is to develop the structure of CAD, mathematical and computer-aided design software for the proposed high-precision mobile complex for remote control of forced avalanches.

Research method - modeling and synthesis on the basis of basic application packages, software development of analysis and synthesis methods that are most common in engineering practice.

CONTENT

GLOSSARY

AC – aircraft.

CAD – computer aided design system

MHPC - mobile high-precision complex

AMCS – automatic control system.

ACS – aircraft control system.

ATS - active trajectory section.

ARCD - automatic range control device.

AD - aiming device.

CP - control panel.

CFD - command formation device.

CTL - command transmission lines.

FLC - flight control lines.

EMR - executive mechanisms (drives) of rudders.

ED - executive drive.

O - operator.

R - rudders.

A - amplifier.

PSD - phase-sensitive device.

GCL - gyroscopic command layout.

SCC - sine-cosine converters.

GAS - gyroscopic angle sensor.

INTRODUCTION

Effective use of cannons for avalanche control is limited by their small ranges of 1000-1500m of firing with a low probability of P=0.15 of hitting the designated area. In this case, the noise created by the gun shot can cause the ascent of other avalanches not provided by the plan. However, for safety reasons, it is necessary to ensure reliable (P=0.9) forced avalanches from large distances with minimal damage to the rest of the territory.

This task can be solved by the use of mobile high-precision complexes for remote support of forced avalanches.

Since the composition and technical design of the basic components of such complexes can be very different, it is advisable to use automated systems in their design. This will allow:

- reduce the complexity of design and planning;
- shorten the design time;
- reduce the cost of design and manufacturing, reduce operating costs;
- improve the quality and technical and economic level of design results;
- reduce the cost of full-scale modeling and testing.

Design automation is understood as optimization of decisions, i.e. achievement of the specified indicators of the designed object with limited expenditure of available resources. The structure of the computer-aided design system is a set of subsystems that should include technical, mathematical and information tools, united by a common objective function.

A design procedure in the processes of computer-aided design is called typical if it is intended for repeated use in the design of a given object. Mathematical support of CAD serves to provide the designer with a wide range of services on design technology. The CAD software is made taking into account the skeleton computers, which are equipped with the designed system.

In this work the structure of CAD, mathematical and computer-aided design software of the proposed high-precision mobile complex for remote control of forced avalanches is developed.

SECTION 1

JUSTIFICATION OF THE FEASIBILITY OF DESIGN AUTOMATION

1.1 Analysis of the problem of avalanche protection and identification of ways to solve it

It is no exaggeration to say that avalanches are the most serious threat to the mountains. And not only in winter or during the off-season, but even in summer, as the highlands are known to be the realm of eternal snow.

Fig. 1.1 Snow avalanche

Avalanche is one of the natural phenomena that can cause death and significant destruction. Among other hazards, avalanches are distinguished by the fact that their collapse can be caused by human activity.

According to the facts of deaths in the 90s - 2000s, avalanches most often found their victims in houses and on roads. Modern studies of statistics of deaths in avalanches show an increase in the share of tourists. And in countries where snow is becoming a profitable business that displaces all other types of economic activity, tourists, moving on the slopes often outside the service areas of avalanche services, dominate the list of victims.

The statistics of victims by type of activity in recent years is shown in Fig.1.2.

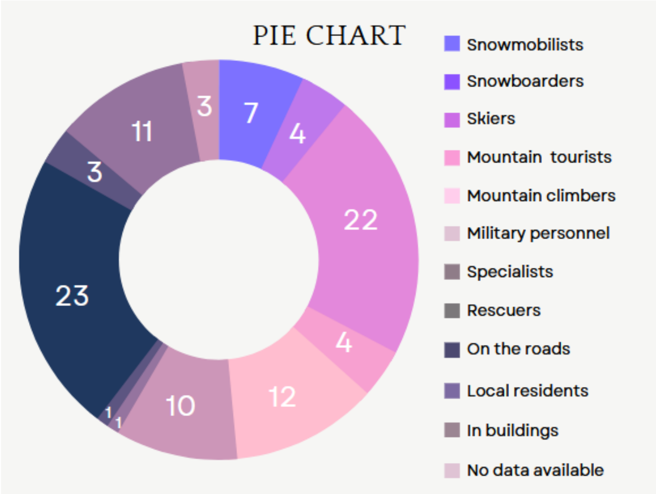


Fig.1.2 Statistics of victims by type of activity

Faced with the destructive effect of avalanches, mankind gradually developed countermeasures. Today, various methods of forced avalanches are widely used in the world.

Active preventive measures consist in the systematic artificial collapse of snow from avalanche-prone slopes with the help of mortars (Fig.1.7.), "avalanches" (Fig.1.8.), artillery guns (Fig.1.9.), as well as a modern system of forced avalanche descent Gazex (Fig.1.10.).

Fig.1.3 Mortar - the most effective means of avalanche control

Fig. 1.4 Avalancher pneumatic system

Fig.1.5 Artillery guns for avalanche control

Fig. 1.6 Gazex: anti-avalanche system

Each of the known and justified in practice methods has its advantages and disadvantages, but none of them is able to solve the problem completely - a set of measures is needed. Only a combination of active, passive and engineering methods of avalanche protection guarantees almost 100% result.

If the area of avalanche origin is difficult to access, but is in the line of sight, it is best to deliver a blasting charge using artillery systems. An indicator that allows to assess the degree of perfection of firearms in the fight against avalanches is P - probability of hitting with the first shot.

The value of the efficiency index P is determined by the conditions of fire and depends mainly on the accuracy of calculation and input of the initial settings for firing - aiming angles and side warning.

Firing conditions are usually divided into ballistic (wear of the channel barrel, charge temperature, shape and mass of the projectile, its initial velocity, etc.), meteorological (air temperature, atmospheric pressure, wind speed), topographical (roll of the axis of the trunnions of the firearm, location of the target). This takes into account a stationary or moving avalanche.

It is known that when shooting from the spot, the probability of hitting decreases with increasing distance to the avalanche (Fig. 1.7).

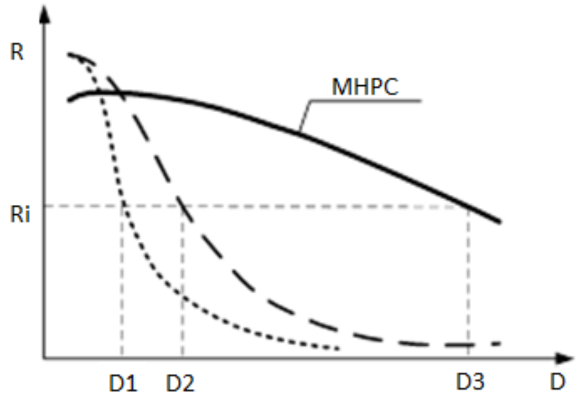


Fig.1.7 Dependence of hit probability on firing range for different types of firearms

The less perfect is the fire means of forced avalanches, the more noticeable is the decrease in firing accuracy.

With the appropriate level of automation of the firearm, it is possible to ensure a high probability of hitting the target in the most difficult firing conditions - to bring the real probability of hitting to the limit.

Effective use of cannons for avalanche control is limited by their small ranges of 1000-1500m of firing with a low probability of P=0.15 of hitting the designated area. In this case, the noise created by the gun shot can cause the ascent of other avalanches not provided by the plan. However, for safety reasons, it is necessary to ensure reliable (P=0.9) forced avalanches from large distances with minimal damage to the rest of the territory.

This task can be solved (see Fig. 1.7) by the use of mobile high-precision complexes (MHC) for remote support of forced avalanches.

Since the composition and technical design of the basic components of such complexes can be very different, it is advisable to use automated systems in their design. This will allow:

- reduce the complexity of design and planning;
- shorten the design time;
- reduce the cost of design and manufacturing, reduce operating costs;
- improve the quality and technical and economic level of design results;
- reduce the cost of full-scale modeling and testing.

Based on the above, the purpose of the work is:

Development of the CAD structure, mathematical and computer-aided design software of the proposed high-precision mobile complex for remote control of forced avalanches.

At the same time, tasks were set:

- define the tasks and basic procedures of computer-aided design;
- to propose the CAD structure of the mobile complex;
- to develop engineering methods for designing drones and their control systems in mobile complexes;
- to conduct experimental verification of the efficiency and reliability of the proposed solutions;
- develop software for automated synthesis of an automated drone control system.

1.2 Development of structure and algorithms of technical system design stages

With the advent of personal electronic computers (PCs) of the new generation, a developed network of external devices, as well as software, there were favorable conditions for the creation of CAD.

In accordance with the established tradition, the CAD structure is a set of subsystems that solve problems for each stage of creating a technical system.

In this case, each subsystem of computer-aided design should include technical, mathematical and information tools, united by a common objective function. Functional diagram of CAD is shown in Fig. 1.8.

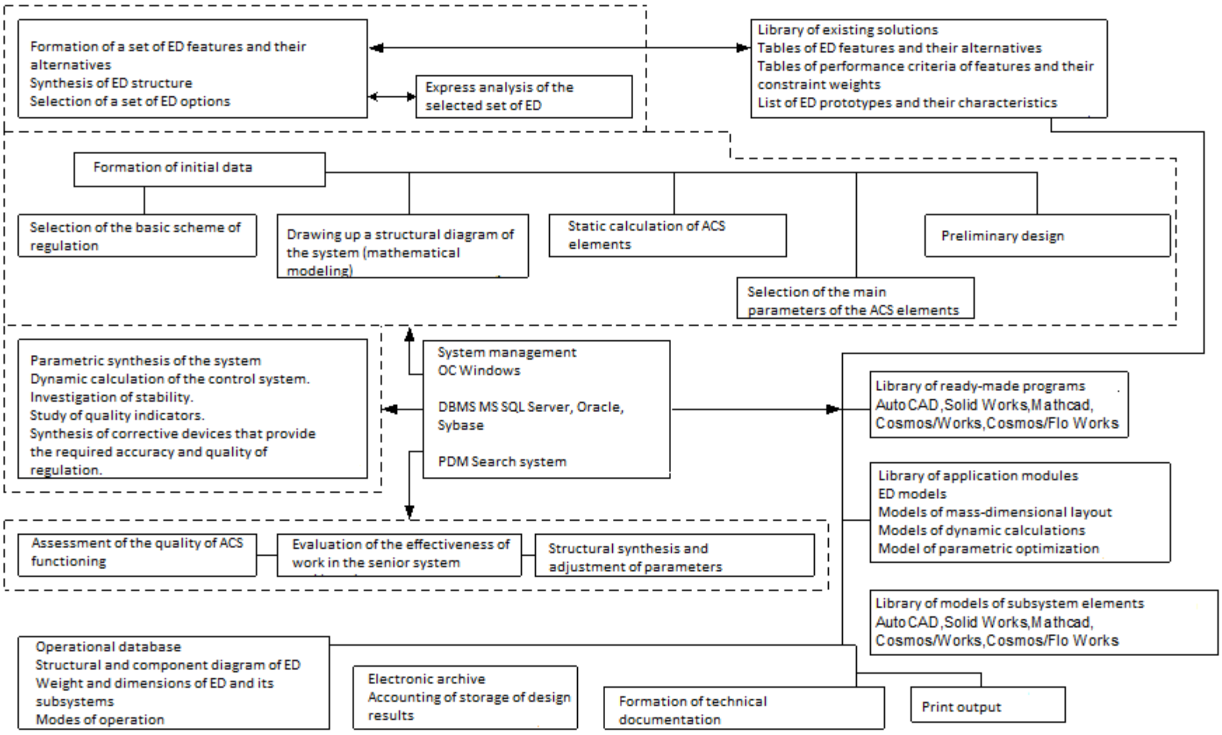


Fig. 1.8 Functional diagram of MHPC CAD

The first level of CAD is occupied by an automated variant search system based on the method of structural synthesis.

The essence of the methodology of structural synthesis is to use an approach in which the system is dismembered into separate components (features) and the construction of a general solution. The set of selected variants of system structures is investigated by analyzing simplified mathematical models.

The second level reflects the automated process of generating the initial data, which are determined on the basis of the terms of reference (TOR) and the results of preliminary studies of the system structure options. Then the automated process of structural-parametric and functional modeling of subsystems and their interconnection into one whole is carried out.

The third level contains an automated procedure for calculating, studying stability, quality indicators, synthesis of corrective devices that ensure the required accuracy and quality of regulation.

The fourth level is occupied by automated procedures for determining the assessment of the quality of systems functioning, evaluation of the effectiveness of work as part of the senior system, structural synthesis and adjustment of parameters. The end of design work is the formation of initial data for design.

The process of automated solution of partial tasks of each CAD level is accompanied by repeated use of electronic materials of the general database of mathematical models, library of electronic layouts of subsystem elements and operational database. Simultaneously with the execution of mathematical modeling of the system and its subsystems, parametric optimization can be performed using a multi-criteria optimization algorithm.

The CAD software structure should include system and application software.

As a rule, the system software includes a standard Windows operating system (OS) in full configuration, which serves as a software platform for application software and a database management system, which is used to work with data files, automate information retrieval, support network resources, etc.

The application software contains a group of standard programs. Typical programs running under Windows are an environment for mass-geometric, structural-parametric and functional modeling.

The newest computer technologies allow to organize automated workstations (AWS) of engineers - designers involved in the synthesis of the ACS on the basis of Windows and integrated into it universal systems, such as MathLAB, using standard computers and network equipment.

The next step is the synthesis of the control loop. The synthesis method is selected, which is carried out according to the algorithm of the library of a typical program.

If the study reveals shortcomings of the synthesized system, for example, providing acceptable static characteristics, the dynamic characteristics of the ACS deteriorate, the developer decides either to change the selected quality criteria in the direction of weakening the requirements, for example, for static characteristics, or to formulate the quality functionality in the form of providing both dynamic and static characteristics with a simultaneous change in the concept of building the CAD. This iterative procedure is repeated until the results of the research confirm the compliance of the synthesized system with all quality requirements. The structure and parameters of the synthesized circuit are documented and entered into a common database for further use.

If there is a discrepancy between the quality of the characteristics and the selected criteria, it is decided either to change the criteria or to synthesize an adaptive control system. If a decision is made to reduce the requirements for the system, an additional synthesis can be carried out to meet the specified level of assessments with repeated studies.

When deciding on the synthesis of an adapted system, the principle of adaptation and stabilization of the dynamic characteristics of the control object is chosen.

For the synthesized system, an additional synthesis of correction loops can be carried out. The final studies of the synthesized system are carried out on the full model of the nonlinear system. Upon completion of the studies, technical documentation is drawn up for the synthesized control loop, and it is entered into the catalog of the general database for use.

1.3 Definition of basic design procedures

A design procedure in computer-aided design processes is called typical if it is intended for repeated use in the design of a given object. Procedures of synthesis and analysis are referred to typical design procedures.

The scheme of the procedure of computer-aided design of the automatic control system and some of the modern methods of analysis and synthesis are shown in Fig. 1.9. The task of CAD is to provide the engineer with a wide range of alternative design methods.

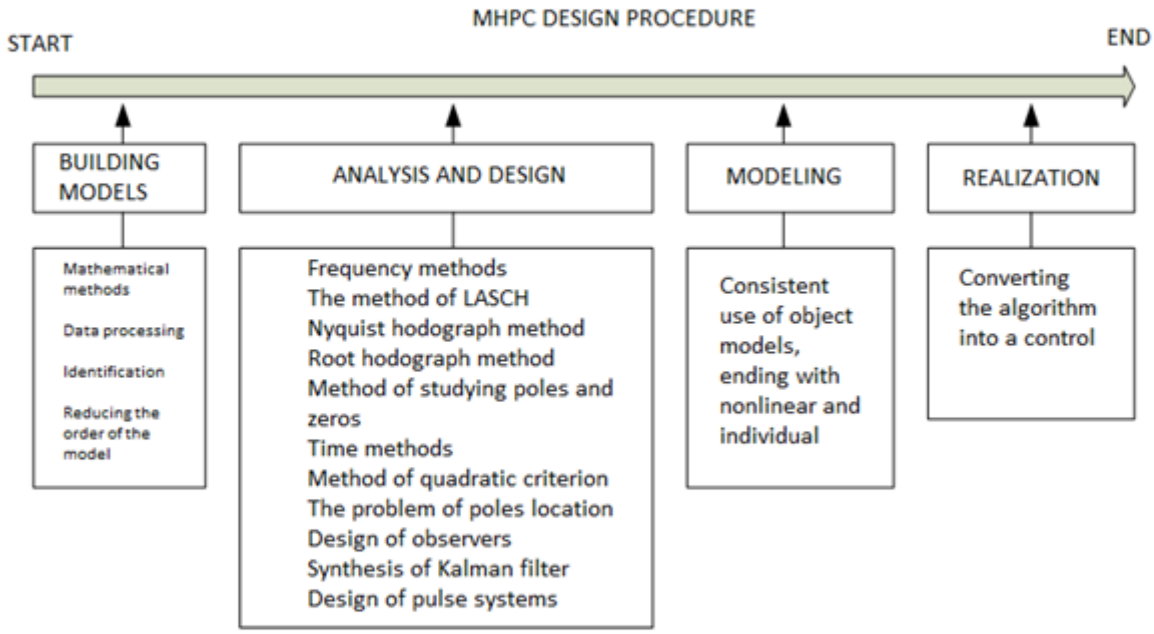


Fig. 1.9 Scheme of the procedure for computer-aided design of the MHCP

Automated synthesis consists in determining the properties and studying the performance of the next version of the automatic control system according to its intermediate description, that is, during the synthesis, the projects of the constructed automatic control system are created, and during the analysis, the projects of the constructed automatic control system are evaluated.

The basis of computer-aided design is that the procedures of automated analysis are divided into procedures of monovariant and multivariant analysis. In monovariant analysis, the values of internal and external parameters are set, it is necessary to determine the values of the initial parameters of the object. The task is reduced to a single solution of the equations that make up the mathematical model of the designed object.

Multivariate analysis is the study of the properties of an object in some region of the space of internal parameters. Such analysis requires multiple solutions of systems of equations (multiple execution of monovariant analysis).

Synthesis procedures are divided into structural and parametric synthesis procedures. The purpose of the structural synthesis is to determine the structure of the object - the list of elements that make up the object and the way the elements are connected to each other within the object.

Parametric synthesis consists in determining the numerical values of the parameters of the elements at the given structure and operating conditions for the initial parameters of the object, that is, in parametric synthesis it is necessary to find the area in the space of internal parameters. In Fig. 1.10 shows a typical sequence of design procedures for automated synthesis at one of the design stages.

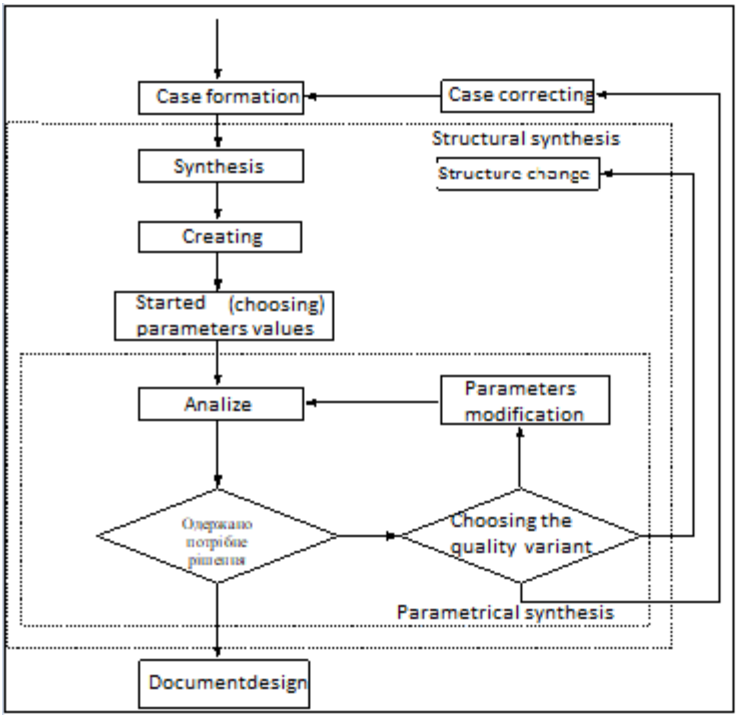


Fig. 1.10 Typical sequence of design procedures for automated synthesis

The design of an automatic control system begins with the synthesis of the initial version of its structure. To evaluate this option, a mathematical model (MM) is created. After selecting the initial values of the parameters of the elements of the automatic control system, the analysis of the variant is performed, the results of which make its evaluation possible.

Usually, the evaluation consists in checking the fulfillment of the performance conditions formulated in the TOR. If the performance conditions are fulfilled to the proper extent, the resulting design solution is accepted, the system of this design level is described in the accepted form and the technical specifications for the design of elements of this level are formulated. If the resulting design solution is unsatisfactory, one of the possible ways to improve the system is selected.

Of course, the easiest way to change the numerical values of the parameters of the elements that make up the vector of output parameters.

The set of procedures for modification, analysis and evaluation of the results of analyses is the procedure of parametric synthesis. If the modifications are purposeful and subordinate to the strategy of finding the best value of some quality indicator, then the parametric synthesis procedure is an optimization procedure. If parametric synthesis fails to achieve an acceptable degree of fulfillment of all performance conditions, then the structure of the system is changed.

A new version of the structure of the designed object is synthesized, and the procedures of model formation and parametric synthesis are repeated for it. If it is not possible to obtain an acceptable design solution on this way, then the question of adjusting the TOR formulated at the previous stage of design is raised. Such adjustment may require repeated execution of a number of procedures of its hierarchical level, which determines the iterative nature of the design.

1.4 Basic components of computer-aided design

The basic components of the provision of computer-aided design of the MHPC are shown in Fig. 1.11.

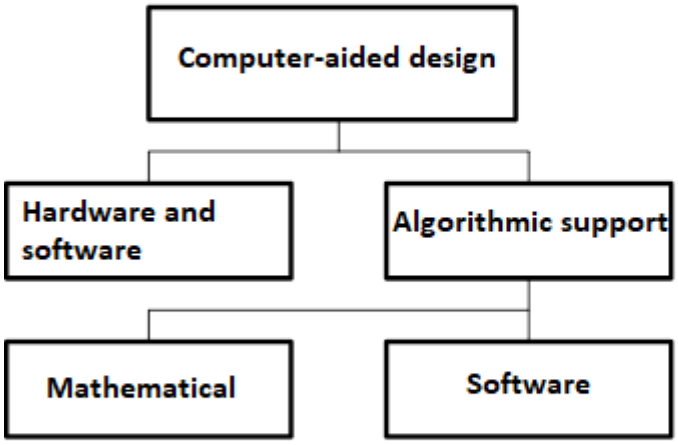


Fig. 1.11 Basic components of computer-aided design of the MHCP

Mathematical support is a set of mathematical models, methods and algorithms for solving computer-aided design problems.

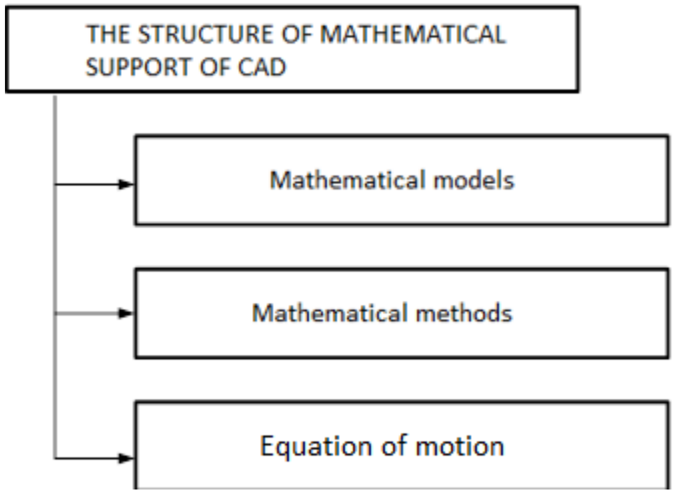


Fig. 1.12 Structure of mathematical support

Mathematical model is a group of mathematical objects and relations between them that reflects some properties of the modeled product or process.

This definition implies that the mathematical model does not have to be completely identical to the original, as its purpose is to enable the study of the dynamics of the phenomenon and process by simplifying its representation.

It can be argued that the higher the degree of identity of the model to the original, the more difficult it will be to compile and study. Therefore, when designing, as a rule, they resort to mathematical models that reflect only to some extent and only some properties of the original. However, as the description of the original is detailed and expanded, the level of mathematical models used for its study should objectively increase. Thus, during the design of processes and technical systems, mathematical models of different levels of complexity can be used.

As a rule, the following components are taken as significant in mathematical modeling:

- equations of motion that take into account the expected operating conditions of the object;
- uniqueness conditions, i.e. relations that take into account the influence of physical constants (e.g. free fall acceleration, material properties), product dimensions, initial and boundary conditions;
- equations describing the physical processes of interaction of the object with the environment;

• equations of stress state of the product elements;

• equations describing the relationship of the economic efficiency criterion with physical properties.

The numerical expression of the properties of a mathematical model is its parameters, the values of which cannot go beyond the limits set by the conditions of performance.

The main components of design automation - application packages (APP) are built on mathematical support as the foundation (Fig. 1.13).

Representing the entire scope of work on the creation of PPP in the form of a pyramid, mathematical models and methods are placed at its lower level. At the next level - algorithms, then - computational algorithms, at the very last level - programs. Programming is a record of the accepted programming language of the computational algorithm. A sufficiently experienced programmer combines the two upper stages of the program, developing a computational algorithm convenient for him, and then writing it in an algorithmic programming language. Therefore, usually 70% of the labor intensity of creating a software product is mathematical software and 30% is the compilation of the programs themselves.

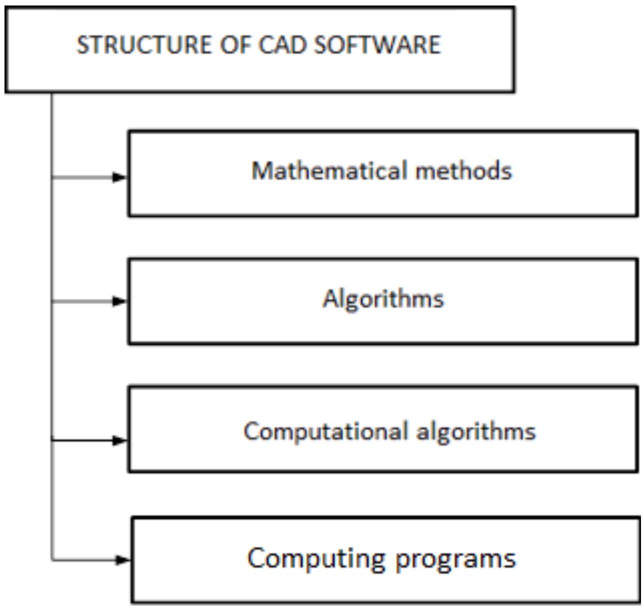


Fig. 1.13 Software structure

The operating system usually includes a control program, a linguistic processing program and a service program.

Controlling - exercises control over all processing programs. The linguistic processing program facilitates the input of tasks into the computer by translating the original application program into a form acceptable to the computer. The maintenance program provides standard maintenance procedures, such as system compilation, sorting, merging of data set elements, editing of inter-program links, file operations.

SECTION 2
FORMATION OF THE DESIGN ALGORITHM MOBILE COMPLEX

2.1 Selection of basic components of the complex

The mobile high-precision complex should ensure timely arrival to the area of remote support of forced avalanches and delivery of the necessary charges and means of their movement to the avalanche, preparation in the shortest possible time of the control and launch of the charge delivery device to the avalanche, launching of this device and controlling it in flight, monitoring the results of the charge, the possibility of launching the second and subsequent charges.

According to the purpose of the MHCP, its main basic components are the launcher, charge delivery device, sighting device, automatic control system of the charge delivery device.

Studies have shown that it is advisable to use an unmanned aerial vehicle (UAV) - a drone - as a device for delivering a charge to an avalanche.

The use of drones allows remotely, without human intervention and without exposing them to danger, to carry out the operation of forced avalanches in hard-to-reach areas at their relative cheapness.

According to the principle of flight, all drones can be divided into 5 groups:

- with a rigid wing (aircraft type);
- with a flexible wing;
- with a rotating wing (helicopter type);
- with a flapping wing;
- aerostatic.

Fig. 2.1 Drone options

In addition to the drones of the listed groups, there are also various hybrid subclasses of vehicles, which, according to their flight principle, can hardly be unambiguously attributed to any of the listed groups. An example is the drones presented in the classification in Fig. 2.2.

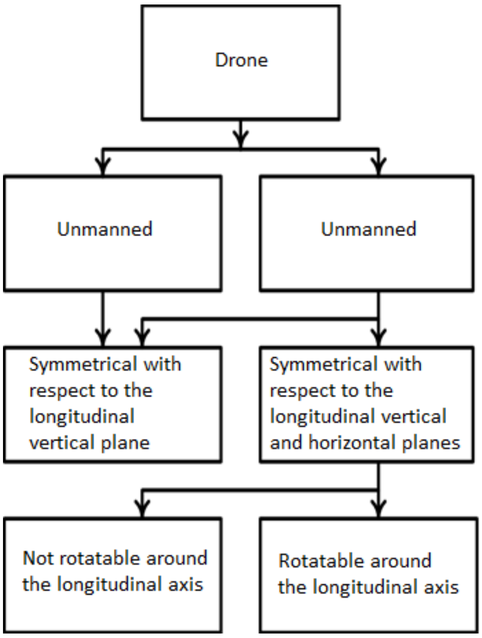


Fig. 2.2 Classification of drones

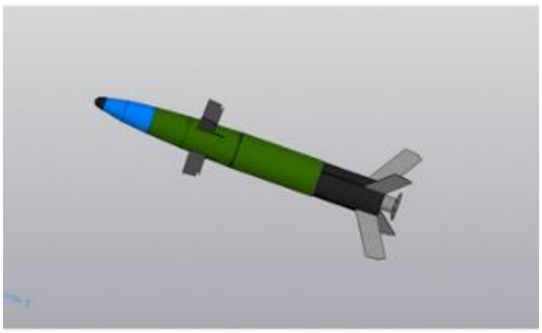


Fig. 2.3 Symmetrical rotating drone

The analysis of literature sources showed that it is structurally easier to place a control system and a high-power combat charge on symmetrical rotating drones.

In this regard, the aim of this paper is to describe, investigate and analyze the effectiveness of such drones as part of the MHCP.

Drone control system (DCS) is a combination of a control object - a drone with a charge, devices and algorithms that allow to ensure the preparation for launch and launch of the drone, and most importantly, to control the flight so that the drone performs its task.

While remaining within the control limits of the active trajectory section (ATS), the control system shall:

- to generate somehow the program trajectory;
- stabilize the actual flight trajectory relative to the programmed one;
- to find the moment of the end of the ADT, when the conditions of the task are satisfied: the trajectory of the passive trajectory section (PTS) will pass through the target point.

This is the basis of the basic structure of the SCS. The control system should contain stabilization and guidance subsystems.

The guidance system solves the first and third tasks. Stabilization of a solid body in space involves controlling and maintaining near the program values of all six kinematic parameters (phase coordinates): three linear and three rotational. Therefore, the stabilization system usually has six channels: three channels of center of mass stabilization and three channels of angular stabilization.

Note that, without taking into account the disturbances, the ballistic (passive) part of the trajectory is uniquely determined by the parameters of the end of the AST. But it is possible to reach a given point on the Earth's surface by different trajectories that differ from the calculated one. And the guidance channel should thus process information about the parameters of the actual trajectory of the active section in order to terminate it at the moment when the trajectory of the passive section, which began at this point, passes through the target point.

As you can see, in the description of the control system channels there are expressions "eliminate mismatch" - in the stabilization channels - and "stop AST" - in the guidance channel. This means that the stabilization channels are closed control loops.

Closed-loop stabilization channels seek to reflect the disturbances acting on the drone so that the actual trajectory is close to the programmed one.

According to the type of control system, drones can be remotely piloted, remotely controlled, automatic:

• remotely piloted are controlled directly by the operator in the line of sight through a ground station;

• remotely controlled operate autonomously, but can potentially be controlled by a pilot or operator using only feedback through other control subsystems;

• automatic operate autonomously.

To solve the problems of ensuring the forced avalanches, a remote-controlled drone guidance system can be fully applied in the MHCP.

The drone is controlled by automatic guidance systems. It can be launched from an autonomous launcher. The peculiarity of launches by guided drones is that the object does not fly along a ballistic trajectory, but after some time after the launch it is automatically brought to the target line, on which it is subsequently held with a certain accuracy. In principle, a controlled drone can fly above the target line with the transition to it in the immediate vicinity of the target.

Drone control - keeping on the target line, begins from the moment it appears in the field of view of the sighting devices. Before that, it makes an uncontrolled flight. In the uncontrolled section, the control wheels of the "drone" are automatically brought to a state that ensures its withdrawal to a given trajectory. With certain assumptions, it can be assumed that the uncontrolled section of the drone flight determines the minimum range of its flight. Dmin depends on the ballistic parameters of the aircraft, its initial speed, the characteristics of the instruments and control systems.

The drone is controlled by the operator using special automation devices (Fig.2.4). The main functional elements of the guidance systems are: a sighting device (SD), a control panel (CP), a command generation device (CGD), command transmission lines (CTL) and flight control lines (FCL), actuators (drives) of the drone rudders (DR).

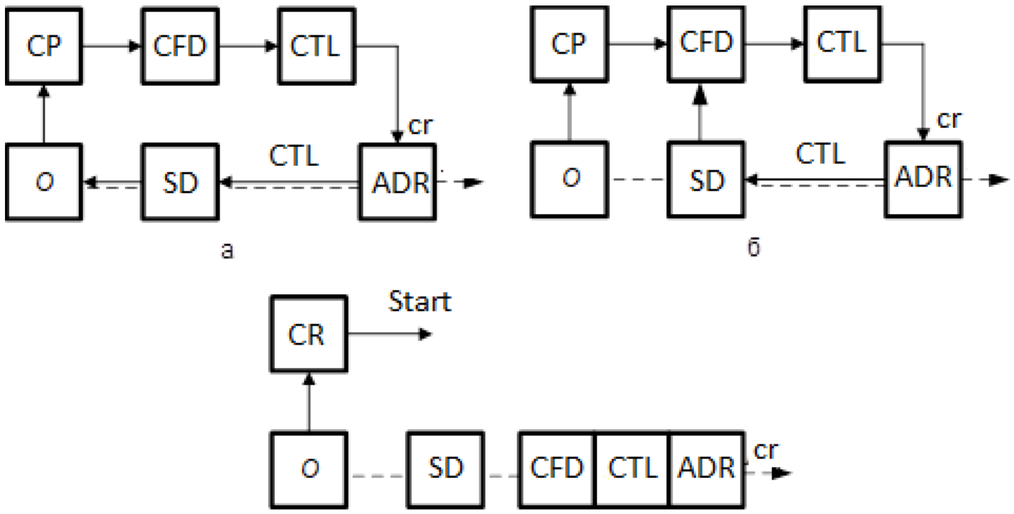


Fig. 2.4 Control systems:
a - manual, b - semi-automatic, c - automatic

Wired communication lines, radio channels, directional laser radiation can be used as STL. When implementing STL by radio, special radio transmitters and directional antennas are used. Laser command transmission lines are formed by optical systems that direct a modulated beam to an object along the entire flight path of the drone.

Flight control lines are usually optical - tracers are installed on them, the radiation of which is recorded through sighting devices.

Based on the degree of automation, all drone control systems in flight are divided into three types: manual, semi-automatic and automatic.

In the manual control system (Fig. 2.4a), the operator O through the sighting devices of the SD visualizes the target object - sets the direction of the LD in space and launches the drone. Observing through the sight the image of the tracer (the line of the FCL), he estimates its position and, acting on the SD console, generates control commands in the CFD to bring it to the target line. The control commands on the FCL are transmitted to the actuators of the CTL - the drone flies along a given trajectory. Thus, in manual control systems, the gunner is in the control loop of the "drone" and provides observation of the target, determining its true position relative to the target line and controlling it in flight. Thus, the quality of control processes and their compliance with the requirements of technical specifications in manual control systems is ensured not only by the perfection of their design, but also personal qualities of a person (operator), his qualifications, skills and abilities.

In semi-automatic systems (Fig. 2.4b), the operator is excluded from the control loop. His role is to set the direction of the LD by holding the sighting mark on the target. The drone is guided automatically. At the same time, the CGD performs the functions of controlling its position on the flight path and generating control commands.

In automatic systems (Fig.2.4 c), the operator provides only the initial aiming and launches the drone. In the future, the instrumentation complex, including homing heads, provides its automatic control and guidance to the target. Thus, automatic systems do not require human intervention in controlling the drone after its launch. He should only periodically monitor their combat capability and, if necessary, make the necessary adjustments. Regardless of the degree of automation of drone guidance systems, the formation of forces that control the drone in flight is based on the same principles.

So, having analyzed the options for drone control systems, we see that all of the considered methods have their advantages, but also have disadvantages. For example, the manual guidance system (Fig.2.4 a) has low accuracy and quality of the guidance system, as they depend on the personal qualities of the person. The automatic guidance system (Fig. 2.4 c) is expensive, which is its main disadvantage, while the semi-automatic system (Fig. 2.4 b) is more attractive, because the gunner is excluded from the control circuit, his role is to set the direction of the LD by holding the sighting mark on the target. Guidance of the drone is automatic and it is cheaper than the automatic system.

In this project for the MHCP it is proposed to transmit information and control the drone by laser beam. It is advisable to use a semi-automatic control system shown in Fig. 2.5a. If the CFD is placed directly on the drone, then there is no need for a separate line of sight - the FLC command generation device will automatically control the position of the drone relative to the direction set by the operator - the target line (LD). Since in semi-automatic systems the operator only monitors the direction of flight, and the drone is controlled automatically, the quality of the control processes of these systems is determined by their parameters and the correctness of operational adjustments.

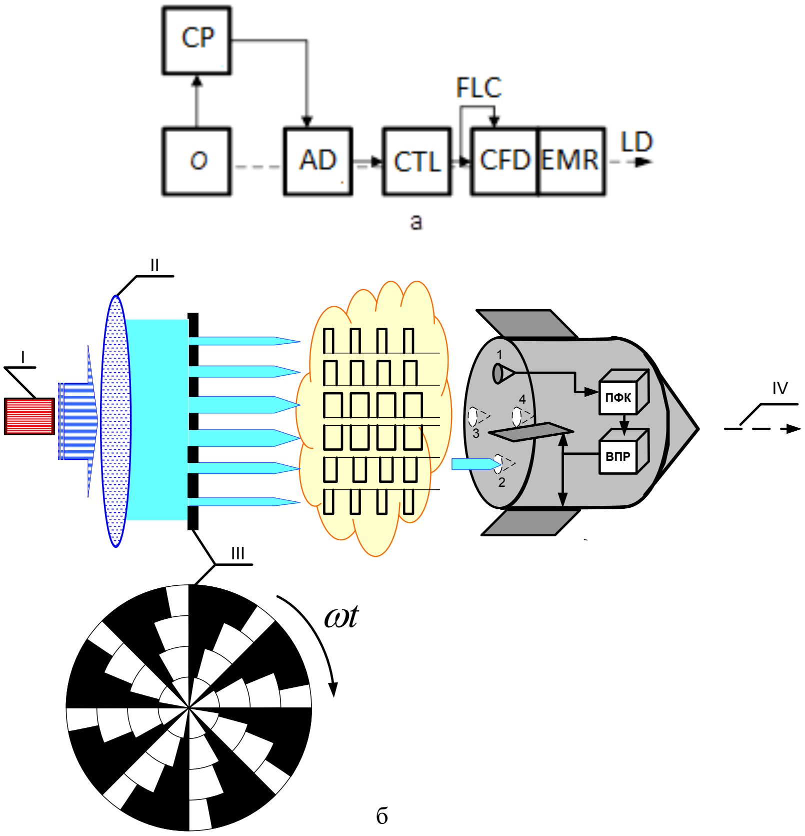


Fig. 2.5 Control by laser beam:
a - semi-automatic control system; b - control principle
I - laser; II - optical system; III - modeling disk; IV - target line; 1 - PFC receiver

Controlling the drone in flight involves the formation of a control signal proportional to the deviation of the drone along the course Δz and pitch Δy from the target line

$$U_y = f(\Delta z, \Delta y)$$

with its subsequent transformation into rudder angles and control forces. Control signals are formed in CFD - devices (Fig.2.5b) of command formation.

Structurally, the laser control system is usually placed in the observation and targeting devices.

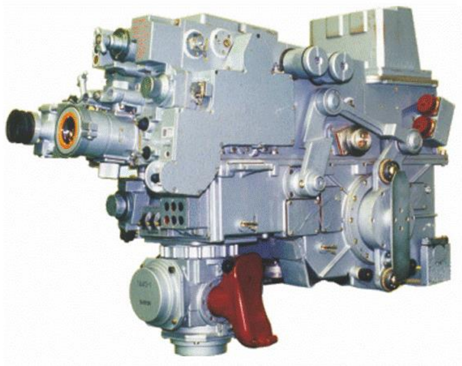


Рис Fig. 2.6 Sight rangefinder

In Fig. 2.6 shows the device - sight rangefinder observation device type 1G42, which is proposed to the CFD.

2.2 Mathematical support of drone design

To mathematically describe the drone as a charge carrier, first of all, we considered its longitudinal and lateral motion.

Longitudinal motion is a motion in which the velocity vector of the center of mass coincides with the plane of symmetry (for aircraft schemes) or with the vertical plane of symmetry (for rocket schemes).

Consider the movement of the charge carrier shown in Fig. 2.7. We will assume that there is no rotation of the carrier around the longitudinal axis.

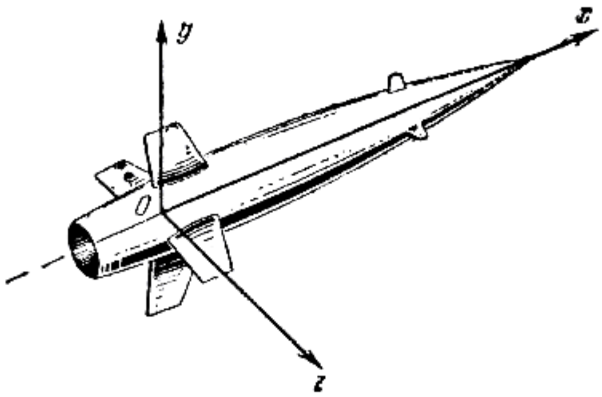


Fig. 2.7 Drone as a charge carrier

The equations of motion can be obtained from the equations of longitudinal

$$(p+n_{22})\boldsymbol{\alpha} - p\boldsymbol{\vartheta} = f_2$$

$$(n_0 p + n_{33})\boldsymbol{\alpha} + (p^2 + n_{33}p)\boldsymbol{\vartheta} = -n_v\,\boldsymbol{\delta}_v + f_3$$

$$\boldsymbol{\alpha} - \boldsymbol{\vartheta} + ph = v_y$$

and lateral

$$(p+n_{11})\beta - p\psi = f_1$$
$$(p^2+n_{33}p)\psi + n_{31}\beta = -n_{3p}\delta_p + f_3$$

movements of the aircraft.

Using the fact that the drone has two planes of symmetry, we can conclude that its plane motion in the vertical plane, described by the first group of equations, is similar to the plane motion in the horizontal plane, described by the second group of equations. Consequently,

$$\begin{aligned}(p+n_{22})\alpha - p\vartheta &= f_2\\ (n_0 p+n_{32})\alpha + (p^2+n_{zz}p)\vartheta &= -n_v\delta_v\end{aligned} \quad (2.1)$$

$$\begin{aligned}(p+n_{22})\beta + p\psi &= f_2'\\ (n_0 p+n_{32})\beta - (p^2+n_{zz}p)\psi &= n_p\delta_p\end{aligned} \quad (2.2)$$

Let's introduce the concept of complex angles of attack

$$\gamma = \beta + i\alpha \quad (2.3)$$

Orientation of the longitudinal axis

$$\theta = -\psi + i\vartheta \quad (2.4)$$

and deviation of control surfaces

$$\delta = -\delta_p + i\delta_v \quad (2.5)$$

where, $i=\sqrt{-1}$.

Multiplying each of the equations (2.1) by and and adding to equation (2.2), we obtain the following equations of motion of the drone with two planes of symmetry

$$\begin{aligned}(p+n_{22})\gamma - p\theta &= F_{12}\\ (n_0 p+n_{32})\gamma + (p^2+n_{zz}p)\theta &= -n_y\delta + F_3\end{aligned} \quad (2.6)$$

where, $F_2 = f + if_2$, $F_3 = f_3 + if_3$.

These equations are similar in form to the original equations of the first and second groups. But they describe a complex spatial motion of the drone, while each of the groups describes a plane motion.

The roll motion, i.e. the motion about the x-axis of the drone with two planes of symmetry, can be assumed to be almost independent of the yaw and pitch motion.

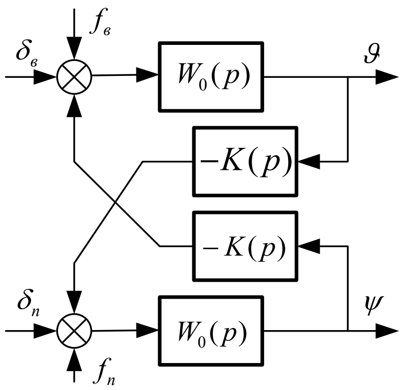
Since the wing areas are relatively small, the damping moment of the roll is also small, so the roll equation can be represented as

$$J_x \frac{d^2\varphi}{dt^2} = M_{kr}$$

were, $\varphi = \int_0^t \omega_x dt$ – roll angle, M_{kr} – moment generated by the roll control system.

Let us take the pitch and yaw channels of the drone to be identical, and the cross-couplings between the channels to be antisymmetric.

Using the assumption of channel identity, we present the structural diagram of the charge carrier as



Pic. 2.8 Block diagram of the drone

Here $W_0(p)$ — transmitting functions of channels, $K(p)$ — transfer functions of communication circuits between channels, f_v i f_n— excitations acting on pitch and yaw channels.

Thus, the applied method of transforming the equations of motion of the drone has the advantage that in fact both channels are identical, so the same control principles can be used for each channel.

2.3 Modeling of the control system

Since the drone is a two-channel identical dynamic system, this allows us to conclude that it is expedient to use an identical two-channel control system with antisymmetric connections. The structural diagram of such a control system is as follows:

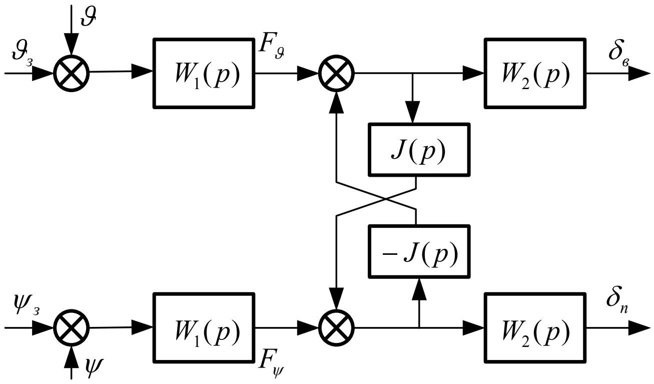


Fig. 2.9 Two-channel control system

If such a control system is connected to the drone, we get a two-channel system, shown in Fig. 2.10.

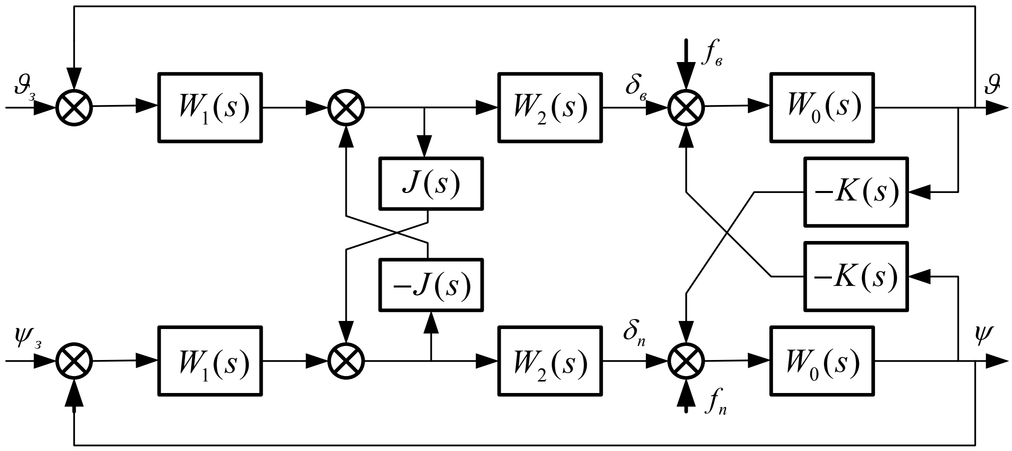


Fig. 2.10 Block diagram of the two-channel drone control system

The structural diagram of the drone (Fig.2.9) can be described by the following equations:

$$\boldsymbol{\vartheta} = W_0\left(\boldsymbol{\delta}_v + f_v - K\boldsymbol{\psi}\right) \tag{2.7}$$

$$\boldsymbol{\psi} = W_0\left(\boldsymbol{\delta}_p + f_p - K\boldsymbol{\vartheta}\right) \tag{2.8}$$

From these equations we obtain:

$$\boldsymbol{\vartheta} = \frac{W_0}{1+K^2W_0^2}\left[\boldsymbol{\delta}_v + f_v + KW_0\left(\boldsymbol{\delta}_p + f_p\right)\right] \tag{2.9}$$

$$\boldsymbol{\psi} = \frac{W_0}{1+K^2W_0^2}\left[\boldsymbol{\delta}_p + f_p - KW_0\left(\boldsymbol{\delta}_v + f_v\right)\right] \tag{2.10}$$

From here we find transfer functions for different input signals:

$$\left.\begin{aligned}\frac{\vartheta}{\delta_v}=\frac{W_0}{1+K^0W_0^2},\frac{\vartheta}{\delta_p}=\frac{KW_0^2}{1+K^2W_0^2},\\ \frac{\psi}{\delta_p}=\frac{W_0}{1+K^2W_0^2},\frac{\psi}{\delta_v}=\frac{-KW_0^2}{1+K^2W_0^2}\end{aligned}\right\} \quad (2.11)$$

In order to obtain the complex transfer function we multiply the equation (2.7) on $i=\sqrt{-1}$ and add to the equation (2.8).

We get

$$\psi+i\vartheta=W_0\left[\delta_p+i\delta_v+f_p+if_v-iK(\psi+i\vartheta)\right],$$

or by entering the notation $\theta=\psi+i\vartheta$, $\delta=\delta_p+i\delta_v, f=f_p+if_v$,

$$\theta=\frac{W_0}{1+iKW_0}(\delta+f). \quad (2.12)$$

The complex transfer function will look like

$$\frac{\theta}{\delta}=\frac{W_0}{1+iKW_0}. \quad (2.13)$$

Comparing the algebraic and complex transfer functions, we can see that their denominators are different: the order of the denominator of the algebraic transfer function is equal to the square of the order of the denominator of the complex transfer function. This circumstance facilitates the study of two-channel systems.

For the control system, we can write:

$$\delta_v=W[\vartheta_z-\vartheta-J(\psi_z-\psi)] \quad (2.14)$$

$$\delta_p=W[\psi_z-\psi+J(\vartheta_z-\vartheta)] \quad (2.15)$$

where $W=W_1W_2$.

Let us write these equations in complex form. If we multiply (2.18) by and add to equation (2.19) we have

$$\delta=W(1-iJ)(\theta_z-\theta) \quad (2.16)$$

where $\theta_z=\psi_z+i\vartheta_z$.

Having the equations of the drone and the control system, we can obtain the equations of the closed-loop system. Solving equations (2.9) - (2.12) together, we find

$$\left[1+\frac{W_0W(1+KJW_0)}{1+K^2W_0^2}\right]\vartheta=\frac{W_0W(1+KJW_0)}{1+K^2W_0^2}\vartheta_z+\frac{W_0W(KW_0-J)}{1+K^2W_0^2}\cdot$$

$$\cdot(\psi_z-\psi)+\frac{W_0}{1+K^2W_0^2}(f_v+KW_0p) \quad (2.17)$$

$$\left[1+\frac{W_0W(1+KJW_0)}{1+K^2W_0^2}\right]\psi=\frac{W_0W(1+KJW_0)}{1+K^2W_0^2}\psi_z-\frac{W_0W(KW_0-J)}{1+K^2W_0^2}(\vartheta_z-\vartheta)$$

$$+\frac{W_0}{1+K^2W_0^2}(f_p-KW_0f_v). \quad (2.18)$$

From here, transfer functions can be obtained for the controlled quantities ϑ and ψ for various input signals.

Symmetric drone control systems are often based on the principle of invariance, that is, on the principle of independence of each channel. In this case, mutual influences of the channels on each other are excluded, which contributes to improving the quality of the transient process. From equations (2.17) and (2.18) we can see that the channels will be invariant with respect to mutual influence, if the condition

$$KW_0=J. \quad (2.19)$$

The technical realization of this condition is carried out by choosing the desired value of the transfer function J(p) of the cross-antisymmetric coupling in the control system. The physical meaning of invariance is that the mutual coupling between the channels in the control object is compensated by the mutual coupling in the control system.

Under the invariance condition, equations (2.17) and (2.18) are simplified and take the form:

$$\left.\begin{aligned}(1+W_0W)\vartheta&=W_0W\vartheta_z+\tfrac{W_0}{1+K^2W_0^2}\left(f_v+KW_0f_p\right)\\(1+W_0W)\psi&=W_0W\psi_z+\tfrac{W_0}{1+K^2W_0^2}\left(f_p-KW_0f_v\right)\end{aligned}\right\} \quad (2.20)$$

The choice of optimality of the control system parameters can be made by well-known methods, for example, by the method of function approximation or by the frequency method.

The choice of optimality of the control system parameters can be carried out by known methods, for example, by the method of functional approximation or frequency method.

To do this, solve equations (2.12) and (2.16) together:

$$\left[1+\frac{W_0 W(1-iJ)}{1+iKW_0}\right]\theta = \frac{W_0 W(1-iJ)}{1+iKW_0}\theta_z + \frac{W_0}{1+iKW_0}f. \tag{2.21}$$

We will get it from here:

$$\frac{\theta}{\theta_z} = \frac{W_0 W(1-iJ)}{1+iKW_0+W_0 W(1-iJ)} \tag{2.22}$$

When the invariance condition (2.19) is satisfied, equation (2.22) takes the form

$$\frac{\theta}{\theta_z} = \frac{W_0 W}{1+W_0 W} \tag{2.23}$$

The use of complex transfer functions allowed to reduce the study of two-channel control system to a single-channel complex system. At the same time, the possibility of mathematical replacement of two channels by one complex channel indicates the possibility of implementing a single-channel pitch and yaw control system. In order to show the possibility of implementing a single-channel system, consider a two-channel system with a carrier frequency, the scheme of which is given in Fig. 2.11.

The input of the system is the values of ϑ_z and ψ_z, from which the output values of and are subtracted. The mismatch signals generated by

$$\Delta\vartheta = \vartheta_z - \vartheta \text{ i } \Delta\psi = \psi_z - \psi \tag{2.24}$$

are fed to the modulator (multiplying device), at the output of which a signal is received:

$$u = \Delta\vartheta \sin\Omega t + \Delta\psi\cos\Omega t = \Delta\theta\sin(\Omega t + \phi) \tag{2.25}$$

where $$\Delta\theta = \sqrt{\Delta\vartheta^2 + \Delta\psi^2}, \quad tg\varphi = \frac{\Delta\psi}{\Delta\vartheta}.$$

As can be seen from the diagram (Fig. 2.12), the signal $\Delta\vartheta$ is multiplied by $\sin\Omega t$, and the signal $\Delta\psi$ is multiplied by $\cos\Omega t$. The signals $\Delta\psi$ and $\Delta\vartheta$, if viewed as components of a vector (complex quantity), are shifted in space one relative to the other by $\frac{\pi}{2}$.

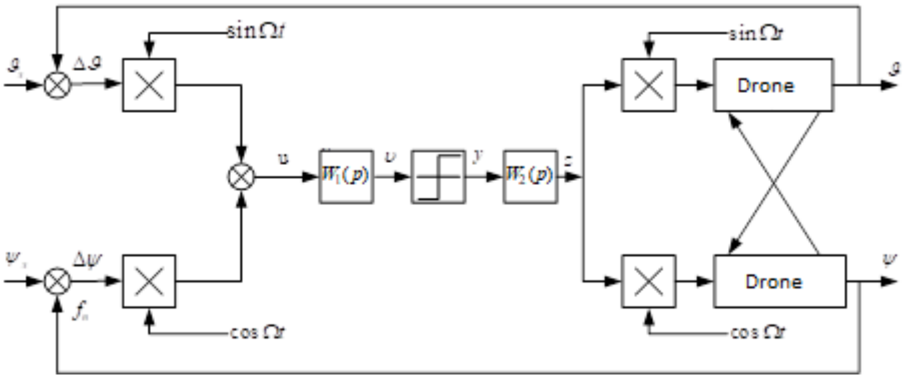


Fig. 2.11 Single channel drone control system

The phase shift between them after multiplication in the detector is also equal to $\frac{\pi}{2}$. This circumstance indicates that the modulation of signals $\Delta\vartheta$ and $\Delta\psi$ can be performed not only by multiplication by sinΩt and cosΩt in the modulator, but also by rotation with angular velocity of the measuring device that produces the angles ϑ and ψ. Since the charge carriers under consideration have rotating or fully rotating main parts, the realization of a rotating ϑ and ψ angle meter is not difficult.

Therefore, to create a single-channel control system for a rotating drone, it is necessary that the angle meter ϑ and ψ the actuating devices are placed on the rotating part, while the carrier circular frequency of the system should be equal to the angular speed of rotation.

CHAPTER 3

DESIGN OF AN AUTOMATED CONTROL SYSTEM

3.1 Study of forces and moments acting on the drone

The drone (Fig. 3.1) flies in space *x, y, z* with a $\bar{V}$ speed under the action of the thrust force T of the marching engine. The linear velocity vector deviates from the longitudinal axis of the charge carrier in the course (horizontal) and pitch (vertical) planes by angles $\alpha_к, \alpha_т$, called angles of attack

As a result of the interaction of the drone with the oncoming air flow, an aerodynamic force $\bar{R}(\alpha)$ arises, which is applied at the center of pressure CP of the drone. For a drone with tail feathers, the CP is located behind the center of mass CM.

The vertical components of aerodynamic R_y force and thrust T_y form the moments that rotate the drone relative to the center of mass in the pitch plane:

$M_{pm} = T_y l_{py}$ — rudder torque; $M_{am} = R_y l_{ay}$ — aerodynamic moment,

where l_{py}, l_{ay} — shoulders of force action T_y, R_y relative to the center of mass.

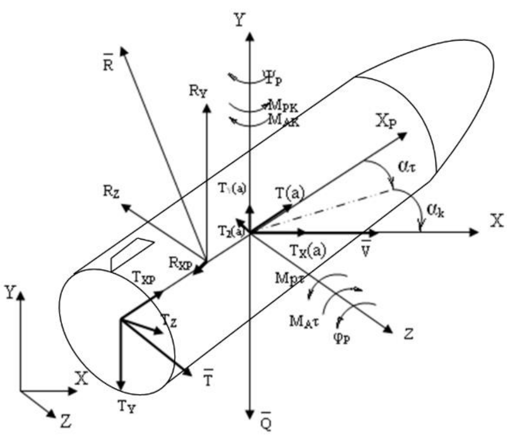


Fig. 3.1. Diagram of forces and moments acting on the drone

In turn, the horizontal components R_z T_z of these forces create similar moments $M_{\text{р}\kappa} = T_z l_{\text{p}z}$, $M_{\text{а}\kappa} = R_z l_{\text{a}z}$ of rotation of the drone in the course area.

The drone's flight trajectory will depend on the ratio of forces acting on it in the corresponding planes.

Thus, equality to zero of the algebraic sum of vertical components of forces

$$F_y = R_y - Q - T_y + T_y(\alpha) = 0 \qquad (3.1)$$

where Q — drone weight force; $T_y(\alpha)$— vertical component of the total force $(T_{\text{p}x} + R_{\text{p}x})$, acting along the axis of the drone,

and mutual balancing of the moments formed by them

$$T_y l_{\text{p}y} = R_y l_{\text{a}y} \qquad (3.2)$$

will provide horizontal flight with a constant angle of attack $T_y + \Delta T_y$ the rudder torque will be greater than the aerodynamic torque. Under the action of the differential torque

$$\Delta M = (T_y + \Delta T_y) l_{\text{p}y} - R_y l_{\text{a}y} \qquad (3.3)$$

the drone will start turning in the pitch plane, increasing the angle of attack α. This will lead to an increase in aerodynamic force $R(\alpha)$, and therefore the moment it shapes. As soon as the aerodynamic torque reaches the value of the rudder torque:

$$(T_y + \Delta T_y) l_{\text{p}y} = (R_y + \Delta R_y) l_{\text{a}y} \qquad (3.4)$$

drone rotation around the center of mass will stop and the angle of attack will stabilize.

Note that the algebraic sum of the vertical components of the forces acting on the drone

$$F'_y = (R_y + \Delta R_y) - (T_y + \Delta T_y) - Q + T_y(\alpha) + \Delta T_y(\alpha) \qquad (3.5)$$

will be greater than zero. According to (3.1) - (3.3) we obtain:

$$F'_y = \left(\frac{l_{\text{p}y}}{l_{\text{a}y}} - 1 \right) \Delta T_y + \Delta T_y(\alpha) > 0. \qquad (4.6)$$

So under the influence of force, the drone will gain altitude.

Reduction of the vertical component of thrust $\left(T_y - \Delta T_y\right)$ will cause the drone to rotate under the prevailing aerodynamic momentum in the direction of decreasing the angle of attack. The resulting force acting along the y-axis

$$F_y = \left(1 - \frac{l_{\text{p}y}}{l_{\text{a}y}}\right)\Delta T_y - \Delta T_y(\alpha) < 0, \quad (3.7)$$

will become negative - the flight altitude will decrease.

Similarly, the ratio of forces acting on the charge carrier determines its flight in the plane of the course.

In case of mutual equality of aerodynamic moment and rudder moment

$$M_{\text{a}k} = R_z l_{az} = T_z l_{\rho z} = M_{\text{p}k}, \quad (3.8)$$

seeking to rotate the drone around the vertical axis, and zero sum of forces acting along the z-axis

$$F_z = T_z - R_z + T_z(\alpha) = 0, \quad (3.9)$$

where $T_z(\alpha)$ - horizontal component of the total force $\left(T_{\text{p}x} + R_{\text{p}x}\right)$

the drone makes a frontal flight with a constant angle of attack $\alpha_{\text{к}}$.

Change of the transverse component $(T_z \pm \Delta T_z)$ thrust forces will lead to a change in the angle of attack, which is stabilized only when the moments are equal

$$(R_z \pm \Delta R_z) l_{\text{a}z} = (T_z \pm \Delta T_z) l_{\text{p}z}, \quad (3.10)$$

and disruption of the balance of power components

$$F_z' = \pm\left(1 \mp \frac{l_{\text{p}z}}{l_{\text{a}z}}\right)\Delta T_z \pm \Delta T_z(\alpha), \quad (3.11)$$

which will ensure the movement of the charge carrier to the right or left..

Thus, the change in the spatial position of the thrust force T marching engine - change of its components T_y, T_z provides the ability to spatially change the velocity vector $\bar{V}$ (angles of attack α), that is, control both pitch and heading.

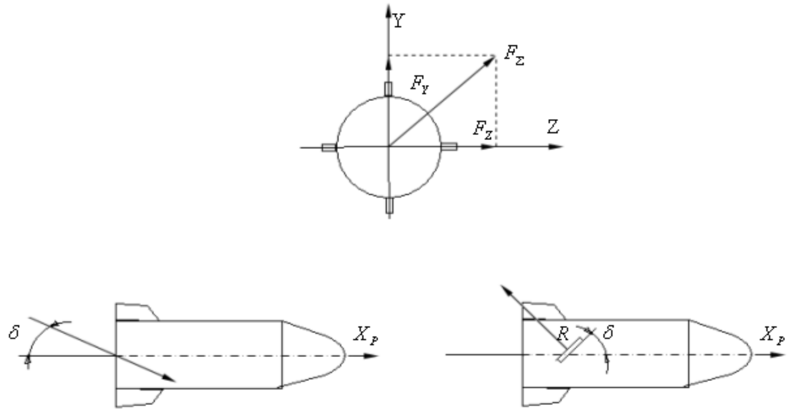
In general, the drone is under the influence of the forces of weight Q, thrust T and aerodynamic *R*:

$$\bar{F}_z = \bar{Q} + \bar{T} + \bar{R}. \quad (3.12)$$

So, to change the ratio between them, and hence to control the drone - to form the control forces on the course F_z and pitch F_y, can be influenced not only by the traction force, but also by other components.

This task is solved with the help of rudders - gas-dynamic or aerodynamic, moving relative to the body of the charge carrier. In the first case, the spatial position of the force *T* of the thrust of the marching engine changes, and in the second - the aerodynamic force *R*. Both control methods are widely used in technology.

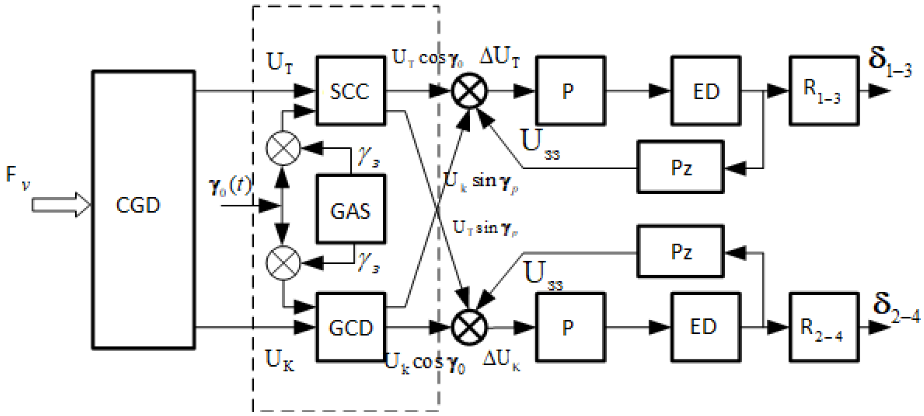
The drone can be equipped with either one or two pairs of rudders. As a rule, drones with gas-dynamic rudders have one pair, and two - with aerodynamic rudders.



Pic. 3.2 Drone control steering wheels

3.2 Determining the composition of the onboard equipment of the drone

Controlling the drone by smoothly changing the rudder angles can be implemented using the functional diagram of the onboard equipment, which is shown in Fig. 3.3.



Pic. 3.3 Control of smooth change of steering angles

Control signals from the course U_k and pitch U_T, are allocated by the command generation device (DFC) from the modulated light flux Φ_v laser.

The principle of determination (Fig. 3.4) of drone deviations from the target line at semi-automatic control by the laser beam and the formation of control signals from the course and pitch is as follows.

A modulating disk - a raster (Fig.2.5b) is placed in the drone observation device. Its rotation with angular frequency allows to split the continuous light flux of the directed laser radiation into ring fluxes, providing their pulse width modulation (each ring has its own pulse width).

The raster is oriented in the drone tracking device so that its center determines the direction of the target line.

During the flight of a rotating drone along the target line (Fig.3.4a), the receiver of the DFC command formation device at its right and left horizontal positions fixes a sequence of pulses of one laser light flux gap.

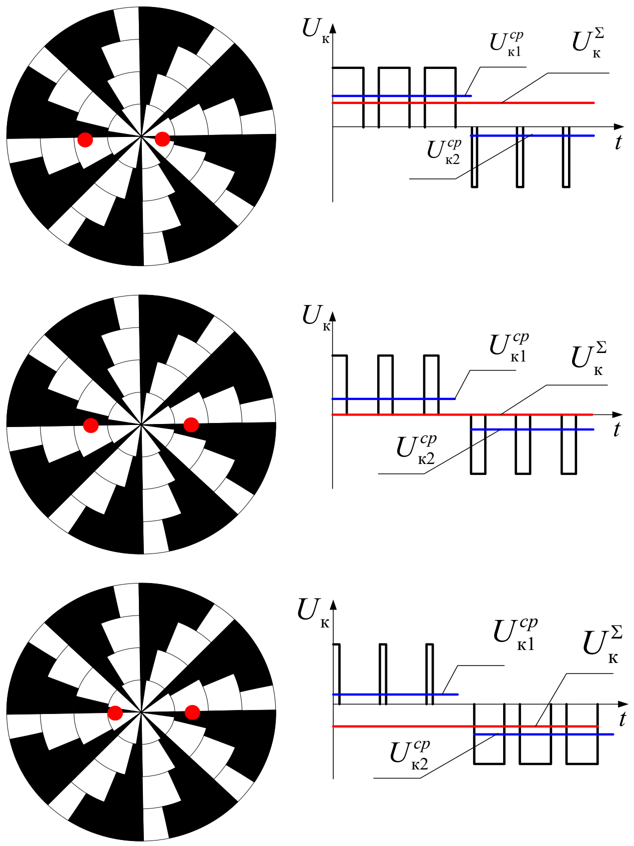


Fig. 3.4 Principle of determining drone deviations on course

and formation of the control signal:

a - on the target line; b - course deviation to the left; c - course deviation to the right

In this case, the average values of control signals on the course at the angles of rotation of the drone $\gamma_р = 0^0$ and $\gamma_р = 180^0$ will be the same

$$U_{к1}^{ср} = U_{к2}^{ср} = \gamma_0 U_0 .$$

Therefore, the total control signal on the course will be zero

$$U_к^{\Sigma} = U_{к1}^{ср} - U_{к2}^{ср} = 0 .$$

The deviation of the drone relative to the target line to the left (Fig.3.4b) will lead to the appearance on the CSD of laser light flux pulses of different γ_1 and γ_2 of the sparsity. Suppose that $\gamma_1 > \gamma_2$.

Then the total control signal is defined as

$$U_к^{\Sigma} = U_{к1}^{ср} - U_{к2}^{ср} = (\gamma_1 - \gamma_2) U_0 > 0,$$

and a control command will be generated to turn the drone to the right.

The deviation of the drone relative to the target line on the right (Fig. 3.4c) will also lead to the appearance of laser light flux pulses of different γ_1 and γ_2 of the gap.

At the same time, we have $\gamma_1 < \gamma_2$ and

$$U_{\kappa}^{\Sigma} = U_{\kappa 1}^{cp} - U_{\kappa 2}^{cp} = (\gamma_1 - \gamma_2) U_0 < 0.$$

A control command is generated to turn the drone to the left.

Thus, changing the spatial position of the drone leads to a change in the magnitude and sign of the control signal.

Smooth adjustment of the steering angles δ according to the change of the control signal

$$\delta = k_n U_y,$$

where k_n – transmission coefficient of on-board equipment, is achieved by using tracking position drives in its composition (Fig.3.3).

The named drives usually include: amplifier (P) of control signal, executive drive (ED) of rudders (R), feedback potentiometer (Pzz). The independence of the formation of control forces F_y, F_z from each other is achieved by equipping each pair of rudders with its own drive, which monitors

Control signals from the course U_k and pitch U_T, (Fig.3.3), are input to the amplifiers (P) of the tracking systems. From the outputs of the amplifiers, which have gains k_y, control voltages are supplied to the executive drives (ED), which turn pairs of interconnected rudders P_{1-3}, P_{2-4}. Movable contacts of potentiometers move simultaneously with the steering wheels Pzz, providing at the input P the increase of the feedback signal:

$$-U_{zz} = k_{zz}\delta,$$

where k_{zz} – transfer ratio of the potentiometer P_{zz}.

Rudder movement under the influence of control signals U_k, U_T, will cease when the tension U_{zz} will reach their value.

Thus, the presence of rigid negative feedbacks allows you to get the angles of rotation of the rudders, and hence the control forces, proportional to the specified values of the control signal. In general, for the counter-parallel connection of the links of the tracking drives, we obtain:

$$F(F_y, F_z) = \eta\delta = \frac{k_u k_y k_{ed}}{1+k_y k_{ed} k_{zz}} \eta U_y \quad (3.13)$$

where k_y, k_{ed}, k_{zz} – transmission coefficients of the tracking drive elements; - aerodynamic coefficient of rudders; k_u – transmission ratio of the elements preceding the drive.

Compliance of the regulating characteristics with the requirements of technical specifications is ensured by the selection of parameters of the element base of the drives.

Due to the rotation of the drone around the longitudinal axis, its rudders periodically change places, changing their functions: pitch rudders, for example 1-3, when turning the charge carrier to $\boldsymbol{\gamma} = 90^0$ will become the rudders of the course; in turn, the rudders of the 2-4 course will begin to perform the functions of pitch rudders. As a result of such movements, the spatial position of the control force changes. Consequently, the flight trajectory of the drone will change.

It is possible to exclude the influence of rotation on the maneuver only by ensuring that both the magnitude and the direction in the space of the vector are unchanged $\overline{F}_\Sigma$. To do this, when the control signal is constant U_y (U_k, U_T) so change the angles of rotation of the drone's rudders depending on $\boldsymbol{\gamma}_\text{д} = \boldsymbol{\omega}_\text{д} t$, so that the new components $\overline{F}_y' + \overline{F}_z' = \overline{F}_\Sigma$ of the controlling force would ensure the fulfillment of this condition. The laws of change of the controlling forces can be found from Fig. 3.5,б:

$$F_z' = F_\Sigma \cos(\psi - \gamma_d) = F_z \cos\gamma_d + F_y \sin\gamma_d$$

$$F_y' = F_\Sigma \sin(\psi - \gamma_d) = F_y \cos\gamma_d - F_z \sin\gamma_p \quad (3.14)$$

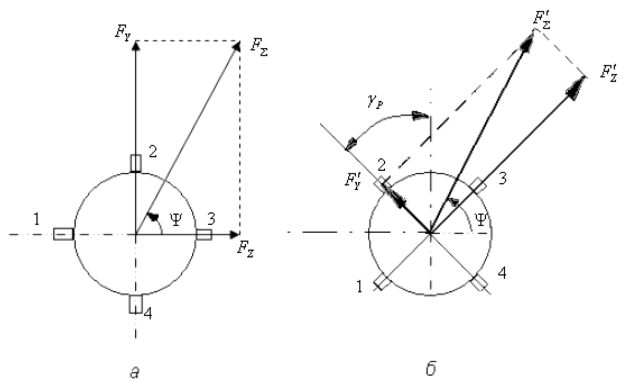


Fig. 3.5 Principle of drone rotation control with two pairs of rudders

a - initial position of the drone, b - the drone is rotated by an angle $\gamma_д$

Taking into account the equation, we obtain:

$$F_z' = kU_k \cos\gamma_d + kU_T \sin\gamma_d$$
$$F_y' = kU_T \cos\gamma_d - kU_k \sin\gamma_d \quad (3.15)$$

where $k = \frac{k_U k_y k_{un}}{1 + k_y k_{un} k_{oc}} \eta$ – rudder drive ratio.

Thus, the continuous change of control forces according to the equation allows to exclude the influence of drone rotation on its flight.

Conversion of signals U_k, U_T controlling the operation of the tracking drives, according to the drone's rotation, is carried out by a special device - a gyroscopic command decoder GSL, which is part of the on-board control equipment. The GSL contains an GAS angle sensor and two sine-cosine converters.

GAS is based on a three-stage gyroscope, the outer frame of which is oriented along the axis of the charge carrier. When starting the drone, the gyroscope is set to a certain position γ_a, relative to which its rotation is measured $\gamma_d(t)$.

Functional potentiometers can be used as SCC, the rotors of which stop on the axis of the outer frame of the GAS, and the stators are connected to the drone body. The inputs of the converter are supplied with signals U_k and U_T, which, when the stators rotate together with the drone body relative to the fixed rotors connected to the outer frame *GAS*, will be converted to harmonic. The control signals are summed at the input of the amplifiers *P* drives that monitor.

3.3 Development of the design algorithm

The algorithm for the design of the MHCP drone control system is shown in Fig. 3.6 - 3.7.

The purpose of this algorithm is to help researchers acquire the practical knowledge necessary for independent work with CAD.

The presented methodology allows to divide the design procedure into appropriate stages, each of which solves an independent subtask. This makes it possible to focus efforts on solving a subtask implemented as a separate procedure or function. Connections between stages are carried out by means of appropriate references to them (conditions), then information is transferred from one stage to another.

The full formation of an action requires the sequential passage of stages, some of which are preliminary, and some - the main ones.

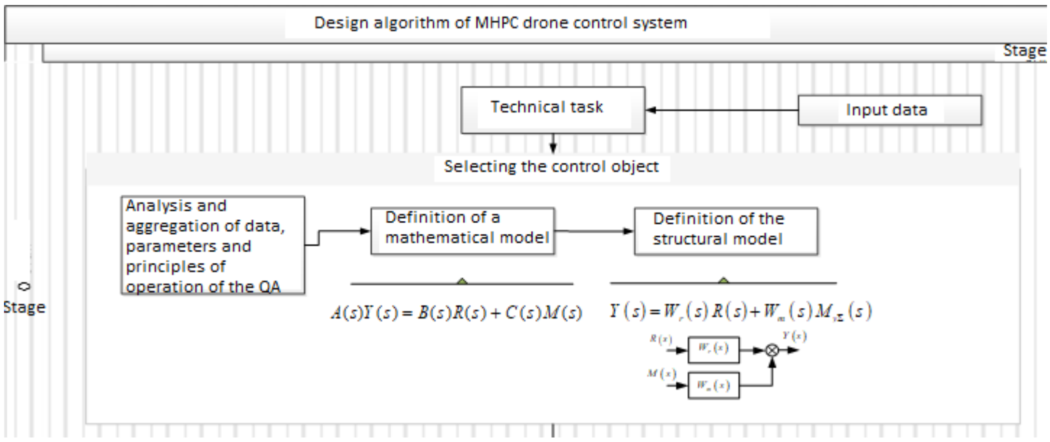
Preliminary stages are designed to create the necessary conditions for the action, and the main stages describe the course of the action itself.

The previous stages of the algorithm include:

- selection of the control object;
- preliminary selection of the control system;
- study of external disturbances acting on the control object.

The main stages of the algorithm include:

- development of the structural diagram of the drone;
- development of the structural diagram of the control system;
- selection of the control principle;
- study of the control system;
- calculation of correction devices.



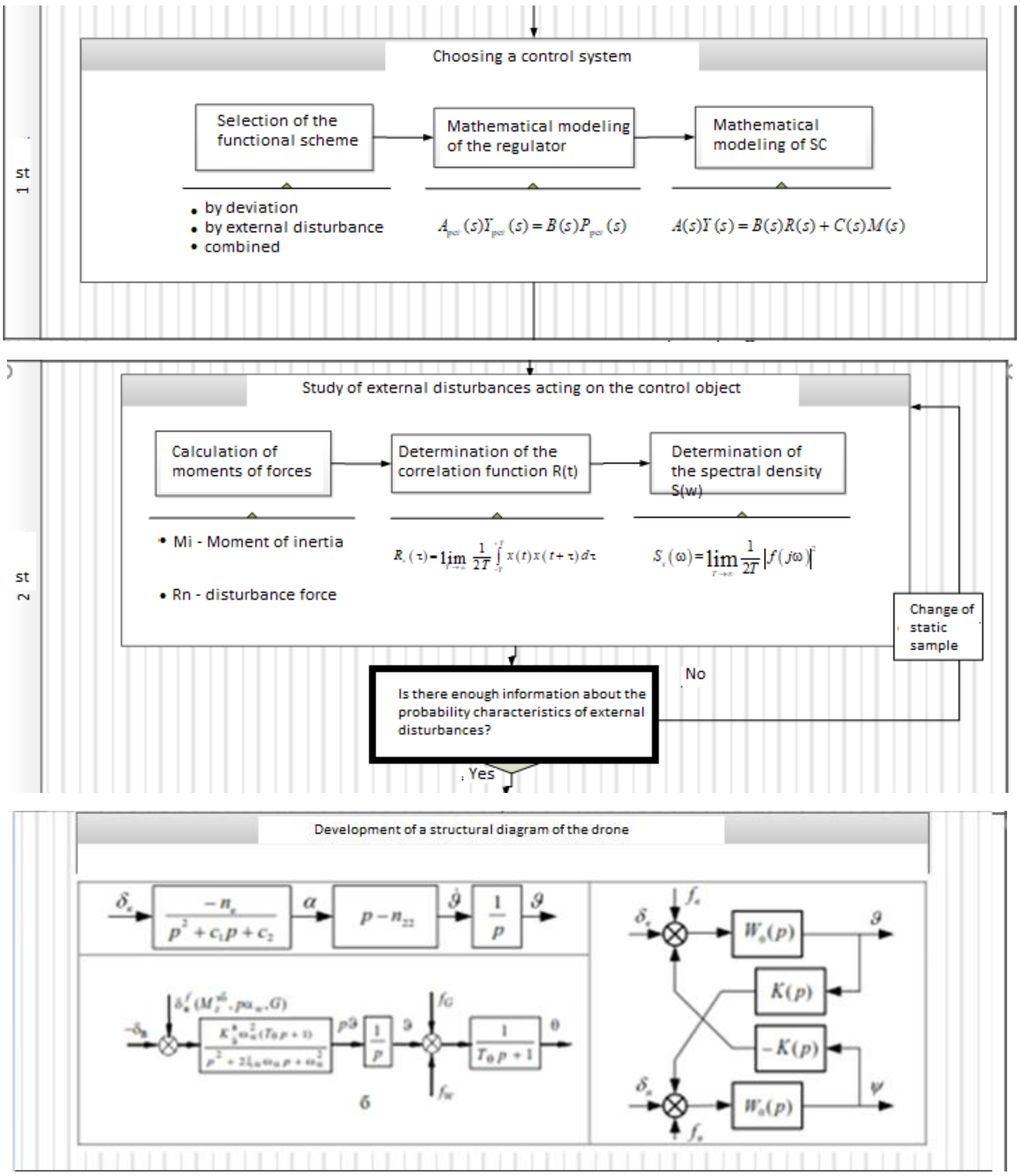
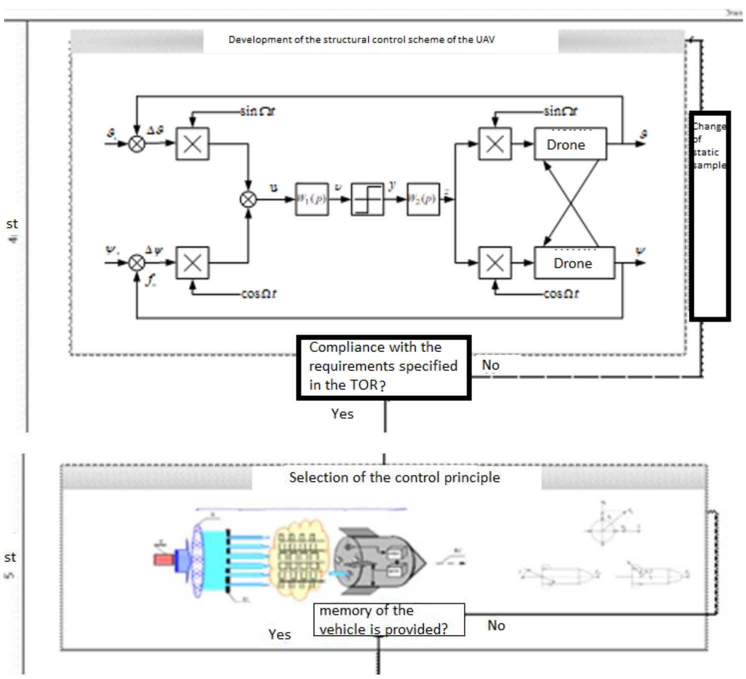


Fig. 3.6 MHCP drone control system design algorithm, stage 0 - 3



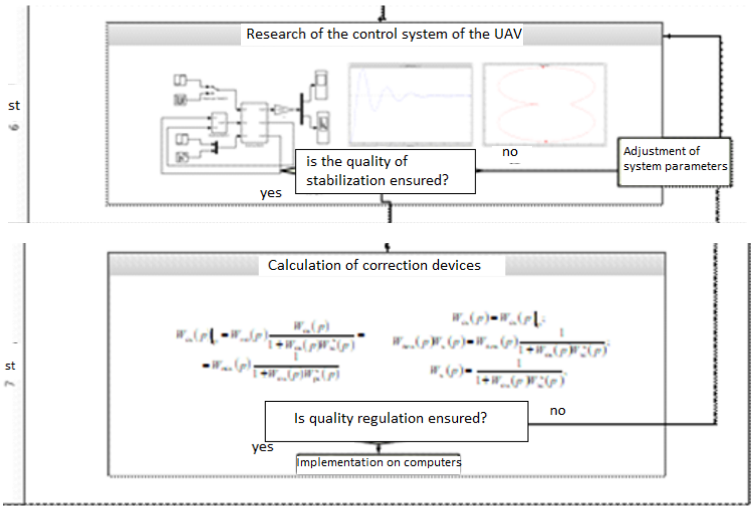


Fig. 3.7 MHCP drone control system design algorithm, stage 4 – 7

The main stage of the computer-aided design system is to build a model that best reflects the properties of the real object. When creating a mathematical model, we strive to leave only the most essential parameters for consideration, to make the mathematical description of the process as simple as possible. The model is created by comparing theory and experiment. This comparison is usually iterative, which can be reflected in the form of an algorithm. At each iteration step, the corresponding model and the corresponding process are refined.

The final stage of computer-aided design is, directly, the design of the optimal controller for the control system.

Thus, CAD was developed and implemented:

- ✓ reduces the design time of the object;
- ✓ creates a real object in the virtual space of the PC;
- ✓ improves the quality and accuracy of its functioning;
- ✓ improves the quality and accuracy of its functioning..

An obligatory component of effective CAD is its implementation on a computer, in our case it is software and methodological support for experimental research during design.

CHAPTER 4
SOFTWARE AND METHODOLOGICAL SUPPORT OF EXPERIMENTAL RESEARCH DURING DESIGN

In engineering practice, especially in the automated selection of the best design solutions, mathematical methods of analysis and synthesis of complex technical systems are increasingly used. This became possible due to the appearance of high-speed computers. However, the wide possibilities of computer technology are realized only with appropriate methodological support, because the use of methods of modeling and optimization of complex technical systems is associated with the difficulties of implementing mathematical methods in practice, and above all, with the difficulties of developing and implementing algorithms and programs for computers.

In this regard, the author in the thesis proposed two ways to solve the problem of software and methodological support for design automation:

• modeling and synthesis based on basic application packages;

• development of software for analysis and synthesis methods.

One of the most important issues in solving the second task was the question of the programming language in which to implement mathematical algorithms. The author chose the C++ programming language, because this language provides an effective description of complex algorithms for calculations over large sets of data represented in various forms; in addition, it is often used in engineering practice.

4.1 Structural modeling of the control system

The mathematical model of the controlled drone and the algorithms for building an automated control system are described in Section 3. They describe the operation of the system with a sufficient degree of accuracy for engineering calculations and allow for its research.

In real working conditions, drone control commands and disturbing signals act simultaneously. So, the response law is determined on the basis of the superposition method:

$$\varphi_0(t)=\sum_{i=1}^{N} W_i(p)\cdot Y_i(t), \tag{4.1}$$

where $W_i(p)$- is the transfer function of the system on the channel of the *i*-th input influence on it; $Y_i(t)$ - *i*-th control signal or disturbing influence.

The control system may include elements of different physical nature and design. However, the uniformity of structural diagrams of elements, nodes, blocks and subsystems included in it allows us to talk about some typical control channel, for example, on the course, and to build its structural image (Fig. 4.1):

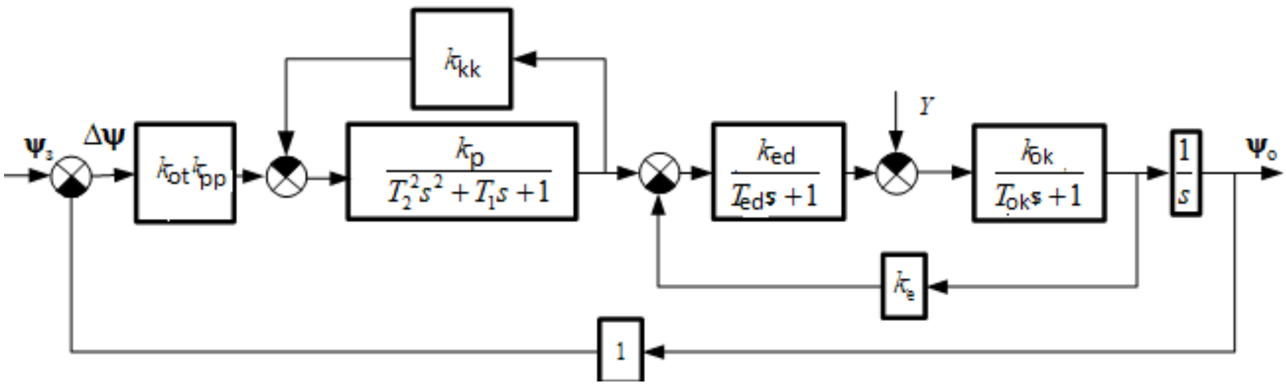


Fig. 4.1 Block diagram of the course control system

The following notations are used in the diagram:

$\frac{k_{ок}}{T_{ок}s+1}$ – transmitting function of the drone (control object);

T_{ed}, k_{ed}, k_e – time constant and static gains of the command generation device (actuator);

k_{pp} – static gain of the preamplifier;

$\frac{k_p}{T_2^2 s^2+T_1 s+1}$ – transmitting function of the CFD amplifier;

k_{ot} – static transfer coefficient of the circuit of the main gear ZZ - receiver of the CFD.

The study and synthesis of the literature allowed us to accept the following values of the coefficients of the system model:

$$k_{\text{e}} = 0{,}1,\ k_{\text{pp}} = 2,\ k_{\text{ot}} = 40,\ \frac{k_{\text{ok}}}{T_{\text{ok}}s+1} = \frac{0{,}2}{0{,}9s+1},\ \frac{k_{ed}}{T_{ed}s+1} = \frac{0{,}8}{0{,}1s+1}, \tag{4.2}$$

$$\frac{k_p}{T_2^2 s^2+T_1 s+1} = \frac{4}{0{,}002s^2+0{,}01s+1} \tag{4.3}$$

The availability of the structural diagram of the control system and the parameters of its constituent elements allows to develop new and modernize existing systems, to conduct their comprehensive experimental studies by methods of both machine modeling and mathematical programming.

In accordance with the obtained structural scheme, in the MatLab environment, based on the Simulink6 application package, a calculation model of the control system for the course channel was built, which is shown in Fig. 4.2.

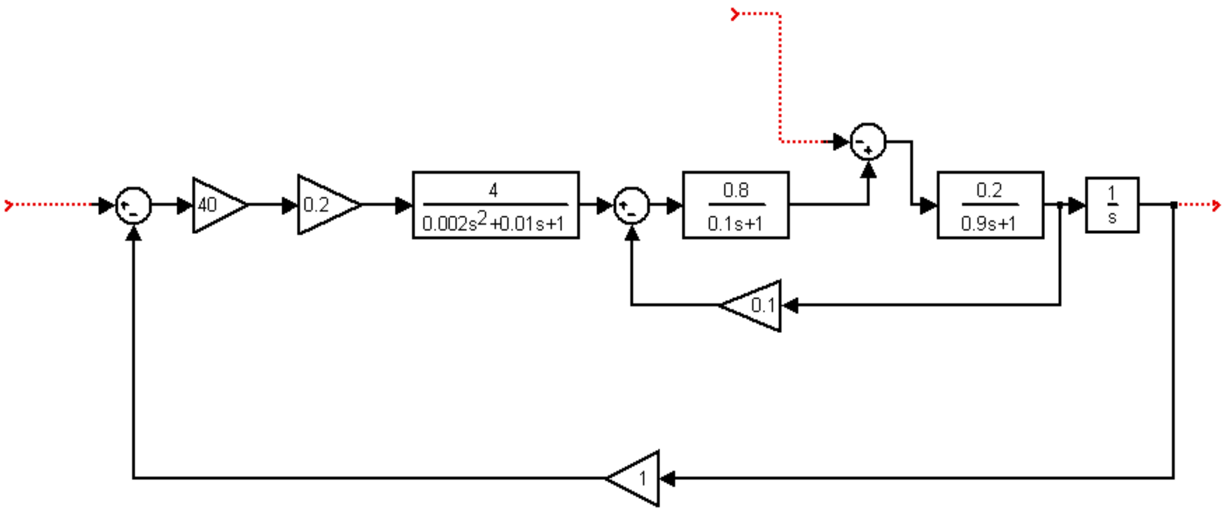


Fig. 4.2 Model of the course control system

During the synthesis of the system, corrective devices and additional elements that provide optimization of control processes were introduced into the model.

After verification and debugging, the model was reduced to the Subsystems level in order to simplify its perception with dedicated channels for the formation of dynamic errors and placed blocks of signal supply and registration (Fig.4.3).

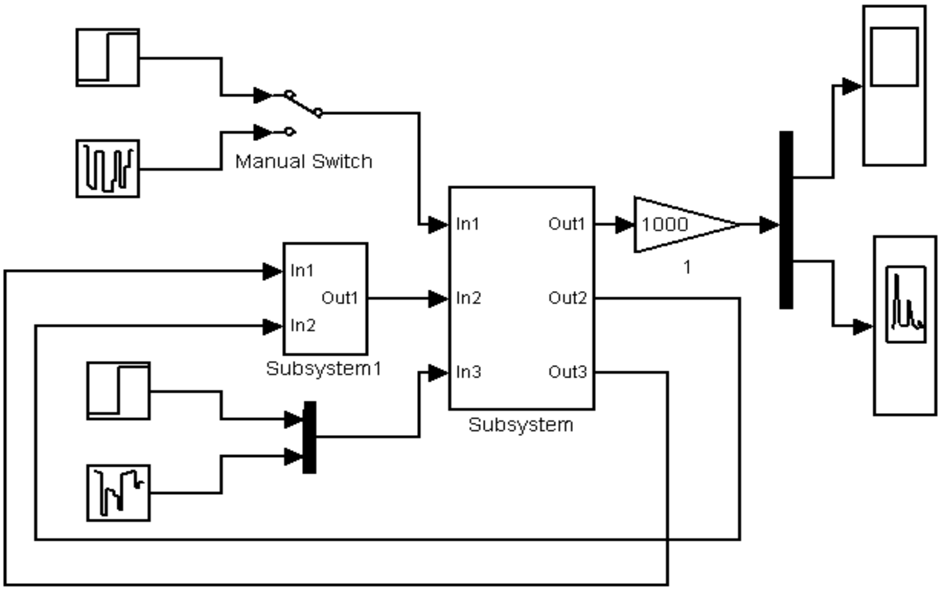


Fig. 4.3 Model of the automated control system

The studies were conducted both under typical (standard) signals of influence on the UAV and random disturbances.

4.2 Designing on the basis of basic application packages

Design is understood as a directed calculation with the ultimate goal of finding a rational structure of the system and establishing the optimal values of the parameters of its individual links.

In the thesis, using the Simulink 6 application package, the transient characteristics of the system by the control signal, the amplitude-phase frequency response of the open system and its logarithmic amplitude-frequency response were determined. The simulation results are shown in Figs. 4.4 - 4.5.

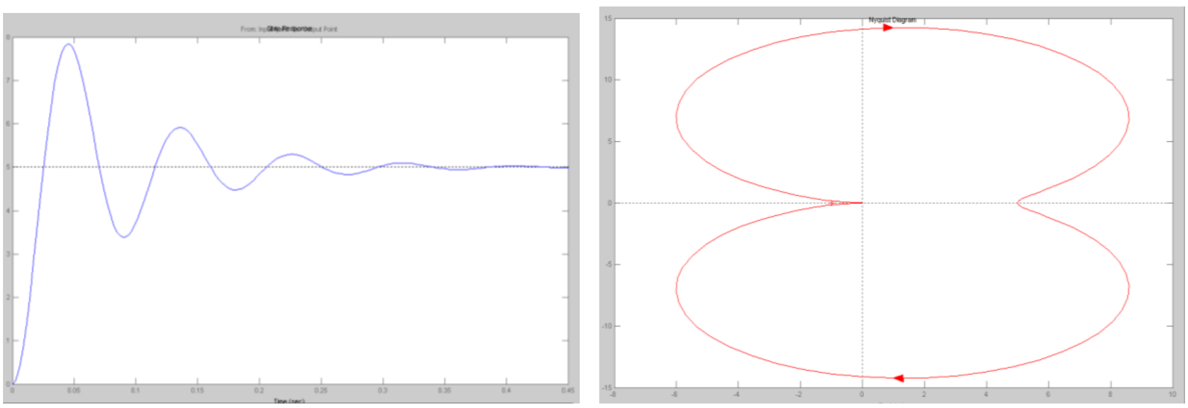


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Fig. 4.4 Results of modeling the drone control system a - transient response; b - amplitude-phase frequency response

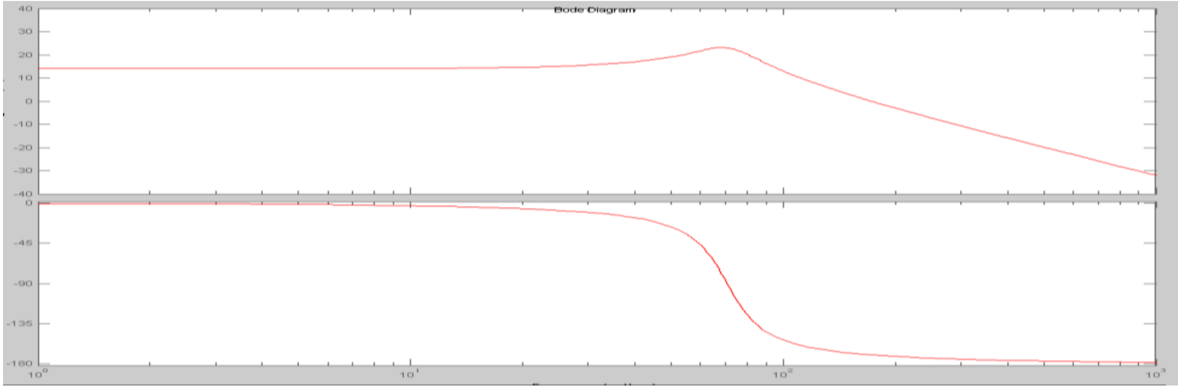


Fig. 4.5 Logarithmic amplitude-frequency response
control systems

The analysis of the simulation materials, in accordance with the selected criteria, allowed to establish that the control time, system oscillation (overshoot, number of overshoots), safety margins by module h and phase γ do not fully meet the requirements proposed by the technical specifications for control systems, which can ultimately lead to the drone leaving the control line.

In order to optimize the parameters of the designed system, the procedure of synthesis of corrective devices by the method of logarithmic amplitude characteristics was carried out.

To correct the quality of the design model, the method of parallel inclusion of correction loops was chosen.

With parallel correction, the transfer function of the open-loop corrected system is defined by the expression

$$W_{\text{sk}}(s)|_p = W_{\text{no}}(s)\frac{W_{\text{ox}}(s)}{1+W_{\text{ox}}(s)W_{\text{zz}}^k(s)} = W_{\text{вих}}(s)\frac{1}{1+W_{\text{ox}}(s)W_{\text{zz}}^k(s)},$$

where $W_{\text{no}}(s)$ and $W_{\text{ox}}(s)$ - respectively, the transferred functions of the chain of links not covered and covered by the corrective feedback;

$W_{\text{zz}}^k(s)$- transmitting feedback function that corrects.

The feedback parameters are defined as follows: since the transfer function of the corrected system $W_{\text{sk}}(s)$ must be the same at any type of correction, then, equaling the transfer functions of the corrected systems at successive $W_{\text{sk}}(s)$ and parallel $W_{\text{sk}}(s)|_r$ corrections, we obtain the transfer function of the correcting device

$$W_{\text{sk}}(s) = W_{\text{sk}}(s)|_r;$$

$$W_{\text{out}}(s)W_k(s) = W_{\text{out}}(p)\frac{1}{1 + W_{\text{ox}}(p)W_{\text{zz}}^k(s)};$$

$$W_k(p) = \frac{1}{1 + W_{\text{ox}}(p)W_{\text{zz}}^k(s)},$$

where $W_k(s)$ - transfer function of the sequential correction loop.

The frequency response of the corrector is obtained by introducing the substitution $s = j\omega$:

$$W_{\text{k}}(j\omega) = \frac{1}{1 + W_{\text{ox}}(j\omega)W_{\text{zs}}^k(j\omega)}$$

For the frequency range when $W_{\text{ox}}(j\omega)W_{\text{zz}}^k(j\omega) << 1$, the frequency response of the correction device is equal to $W_{\text{к}}(j\omega) \approx 1$, and the logarithmic amplitude-frequency response $L_{\text{k}}(\omega) = 0$, i.e. no correction is required in this range.

For the frequency range when $W_{\text{ox}}(j\omega)W_{\text{zz}}^k(j\omega) >> 1$, the frequency response of the correction device is equal to $W_k(j\omega) \approx \frac{1}{W_{\text{ox}}(j\omega)W_{\text{zz}}^k(j\omega)}$.

Turning to the logarithmic frequency characteristics, we obtain

$$L_k(\omega) = -L_{\text{ox}}(\omega) - L_{\text{zz}}^k(\omega) .$$

Where from,

$$L_{\text{zz}}^k(\omega) = -[L_{\text{ox}}(\omega) + L_k(\omega)].$$

Thus, the logarithmic amplitude-frequency response of the parallel correction loop is equal to the sum of the LFR of the links covered by this loop and the LFR of the serial correction device taken with the reverse sign.

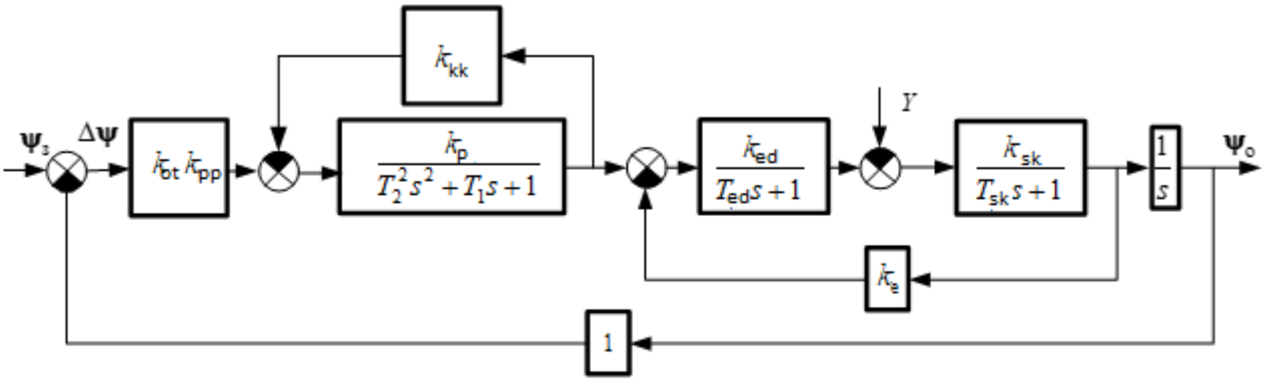
The latter is easily defined as the difference between the LFR of the system with the required quality indicators (the desired system) and the LFR of the original system

$$L_{\text{k}}(\omega) = L_{\text{bh}}(\omega) - L_{\text{out}}(\omega).$$

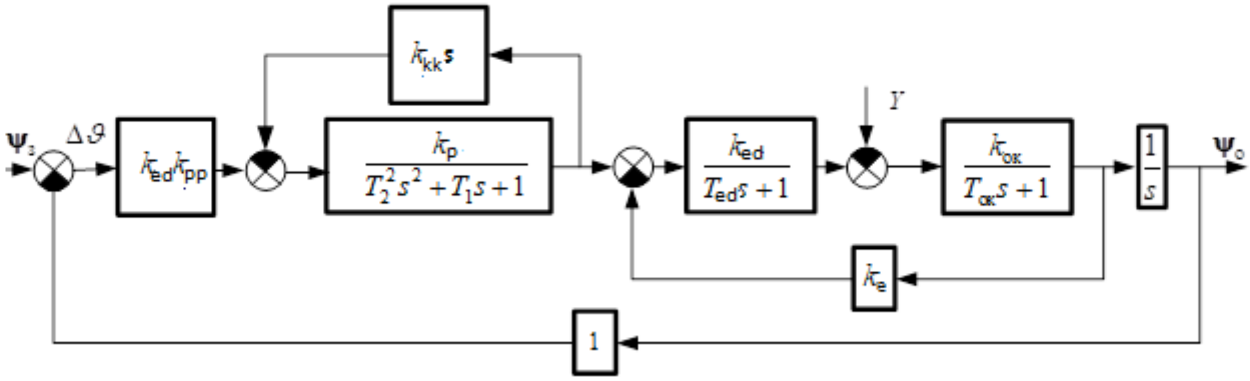
Then the frequency response of the parallel correcting loop will be defined as:

$$L_{\text{zz}}^k(\omega) = -[L_{\text{ox}}(\omega) + L_{\text{bh}}(\omega) - L_{\text{out}}(\omega)].$$

In the course of research, the possibility of using rigid -k_{kk} and flexible -$k_{\text{kk}}s$ negative feedbacks. They were supposed to cover the main CFD amplifier of the control system (pic. 4.6).



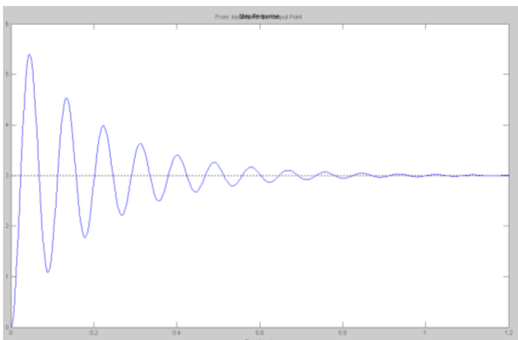
a



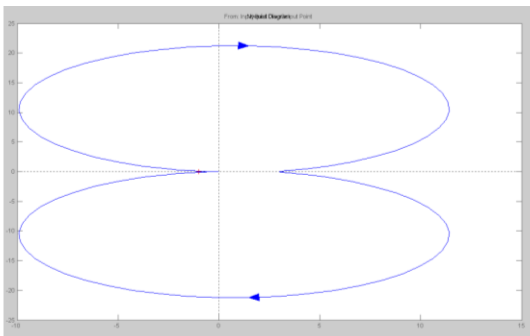
b

Fig. 4.6 Block diagram of the control system in the presence of correction loops:
a - rigid negative feedback; b - flexible negative feedback

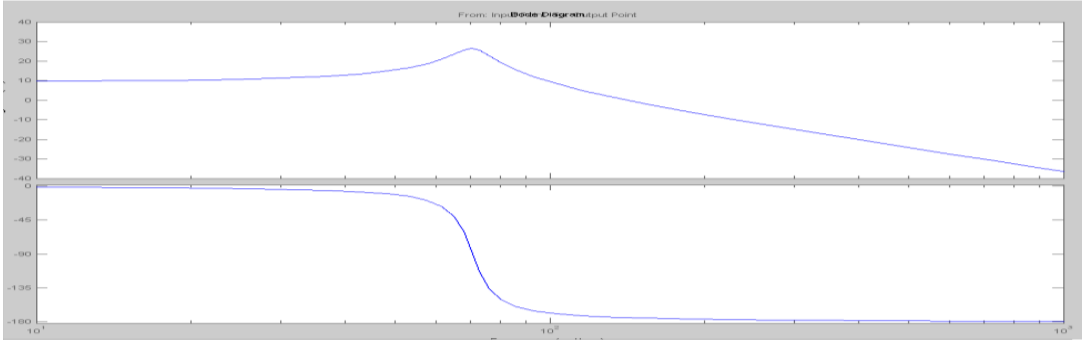
The transient, amplitude-phase frequency and logarithmic amplitude-frequency characteristics of the synthesized system with rigid negative feedback are shown in Fig. 4.7, and at flexible negative feedback - in Fig. 4.8.



a

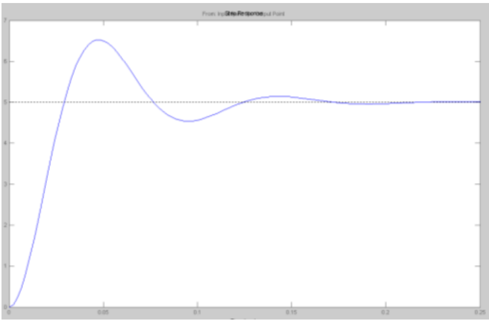


b

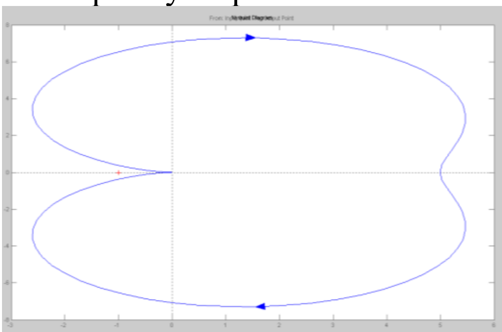


c

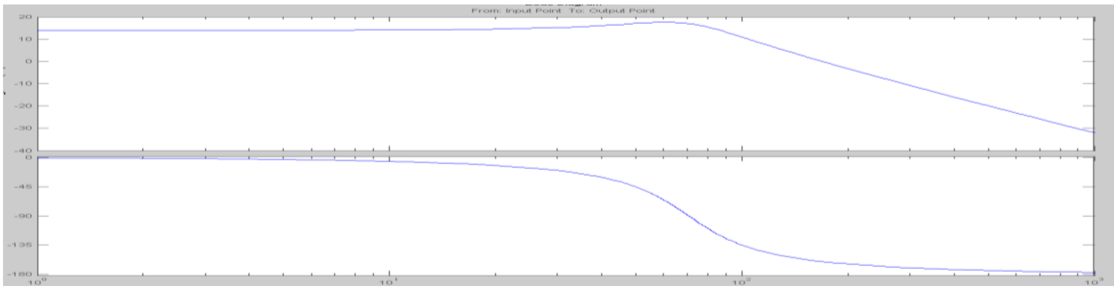
Fig. 4.7 Characteristics of the synthesized system
with rigid negative feedback:
a - transient response; b - amplitude-phase frequency response;
c - logarithmic amplitude-frequency response



a



b



c

Fig. 4.8 Characteristics of the synthesized system
with flexible negative feedback:
a - transient response; b - amplitude-phase frequency response;
c - logarithmic amplitude-frequency response

The analysis of the results allows us to draw conclusions::

- correction of the drone control system by means of hard negative feedback:
- improves system performance - the time for working out inconsistencies is reduced $(t'_0 < t_0)$;
- increases the fluctuation;
- reduces the maximum value of the regulated value $(Z'_{st} < Z_{st})$;
- reduces the reserves of stability.
- correction of the drone control system using flexible negative feedback
- slightly increases the working time $(t''_0 > t'_0)$;

- significantly reduces the adjustment time ($t''_r < t'_r$) ;
- reduces system oscillation (dampens vibrations);
- does not change the steady state value of the regulated value;
- increases the reserves of stability.

Since the introduction of rigid negative feedback is accompanied not only by a decrease in the system gain, but also by a decrease in its stability margin, it is more expedient to introduce flexible feedback into the control system.

By increasing the stability margin in the system, flexible feedback does not affect the gain, and therefore does not require an additional increase in the gain of the preamplifier to ensure a given control accuracy. In this case, the system scheme is simplified, and the possibility of its implementation is greatly facilitated.

4.3 Software implementation of pulse control

The reaction of the automatic control system to a single step signal is called a transient function.

The reaction of the automatic control system to a single step signal is called a transient function $z_o(t) = C_1 e^{\lambda_1 t} + C_2 e^{\lambda_2 t} + ... + C_n e^{\lambda_n t}$, and is determined by the type of roots λ_i of the characteristic equation of the system:

$$A(s) = a^n s^n + a^{n-1} s^{n-1} + ... + a_1 s + a_0 = 0.$$

The roots of the characteristic equation depend only on the ratio of the design parameters of the automatic system and do not depend on the type of external influences or initial conditions. Consequently, in the synthesis of systems by the type of their transient characteristics it is possible to determine the necessary coefficients of the characteristic equation, and by them - the necessary parameters. If necessary, the reverse problem can be solved.

The developed software allows to solve both direct and inverse problem - to study the influence of automatic system parameters on its dynamics or to select parameters based on the quality of control processes.

The program is written in C++.

The input data are the values of the coefficients a_i of the characteristic equation of the drone control system. The output is the transient response..

The user interface of the program is shown in Fig. 4.9.

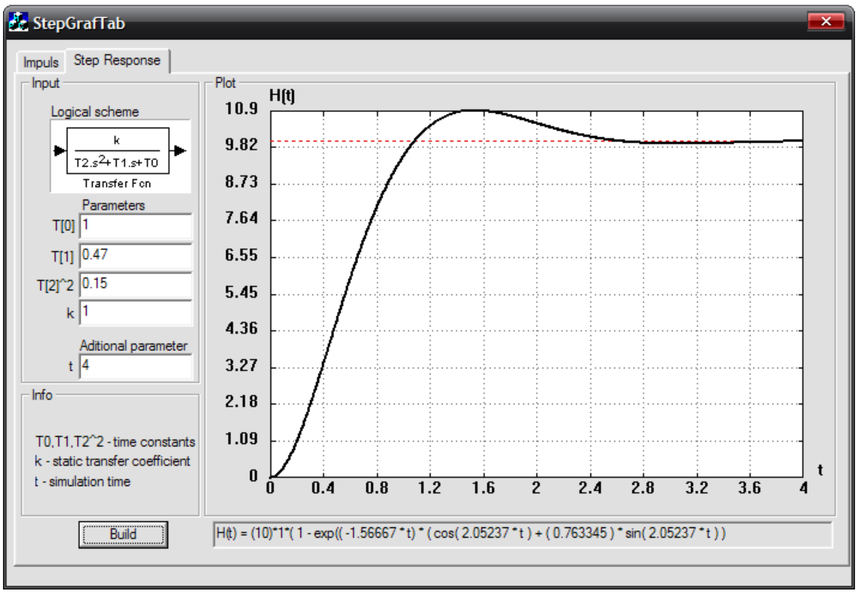
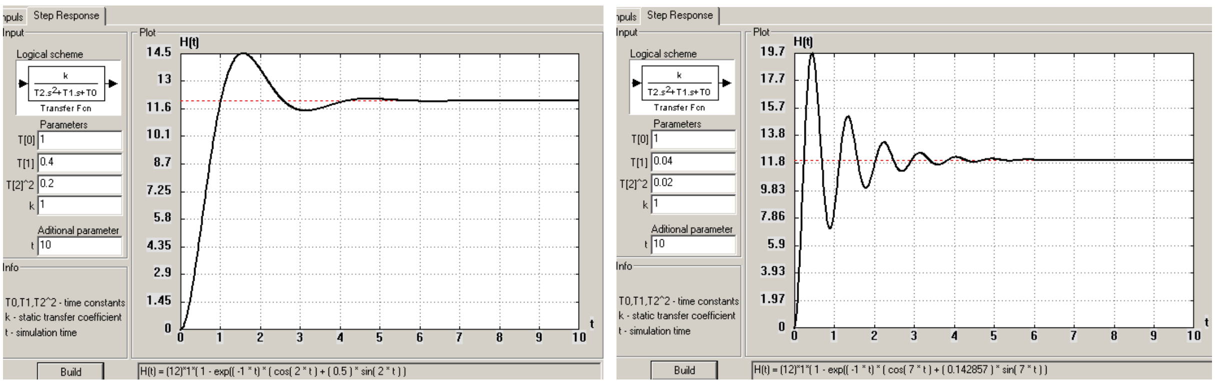


Fig. 4.9 User interface

On the left side of the user interface there are fields in which the time constants are set (T_i) and the gain of the equivalent transfer k function of the control system (input block). To set the value of any parameter, just move the cursor to its field, click the left mouse button and enter the desired value.

On the right side of the interface there is an oscilloscope with which we can see the transient function.



a b

Fig. 4.10 Transient characteristics of the system
a - $T_2^2 = 0{,}2s, T_1 = 0{,}4s$; b - $T_2^2 = 0{,}02s, T_1 = 0{,}04s$

At the bottom of the interface is the solution field. By pressing the "build" button, we get the answer in the solution field, and the graph of the transient function will be plotted.

Fig. 4.10 illustrates the change of transient characteristics of the control system at different values of its parameters. A fragment of the program listing is given below.

```
     // StepGrafTab.h : main header file for the STEPGRAFTAB application

//

#if !defined(AFX_STEPGRAFTAB_H__FAEBA9FD_053D_4691_AC60_B2683116065B__INCLUDED_)
#define AFX_STEPGRAFTAB_H__FAEBA9FD_053D_4691_AC60_B2683116065B__INCLUDED_

#if _MSC_VER > 1000
#pragma once
#endif // _MSC_VER > 1000

#ifndef __AFXWIN_H__
      #error include 'stdafx.h' before including this file for PCH
#endif

#include "resource.h"         // main symbols

/////////////////////////////////////////////////////////////////////////////
// CStepGrafTabApp:
// See StepGrafTab.cpp for the implementation of this class
//

class CStepGrafTabApp : public CWinApp
{
public:
      CStepGrafTabApp();

// Overrides
      // ClassWizard generated virtual function overrides
      //{{AFX_VIRTUAL(CStepGrafTabApp)
      public:
      virtual BOOL InitInstance();
      //}}AFX_VIRTUAL

// Implementation

      //{{AFX_MSG(CStepGrafTabApp)
            // NOTE - the ClassWizard will add and remove member functions here.
            //    DO NOT EDIT what you see in these blocks of generated code !
      //}}AFX_MSG
      DECLARE_MESSAGE_MAP()
};


/////////////////////////////////////////////////////////////////////////////

//{{AFX_INSERT_LOCATION}}
// Microsoft Visual C++ will insert additional declarations immediately before
the previous line.

#endif //
!defined(AFX_STEPGRAFTAB_H__FAEBA9FD_053D_4691_AC60_B2683116065B__INCLUDED_)
```

```
// StepGrafTab.cpp : Defines the class behaviors for the application.
//

#include "stdafx.h"
#include "StepGrafTab.h"
```

The user interface of the software implementation of pulse control of the drone is shown in Fig. 4.11.

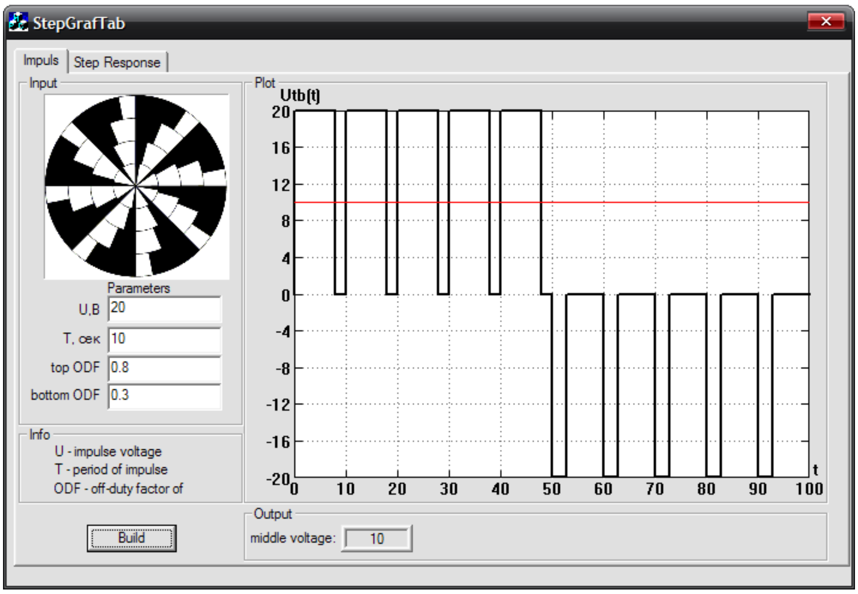


Fig. 4.11 User interface of the software implementation of pulse control

The input data of the program is a set of pulses received by the receiver of the command generation device, at the angles of rotation of the drone $\gamma_p = 0^0$ (top) and $\gamma_p = 180^0$ (bottom). The output is the average value of the heading (pitch) control signal.

On the left side of the interface there is a raster image of the control system and four windows for entering information:

reference voltage U,B;

pulse repetition period T, c.;

pulse duty cycle at the angle of rotation of the drone $\gamma = 0^0$ - top ODF;

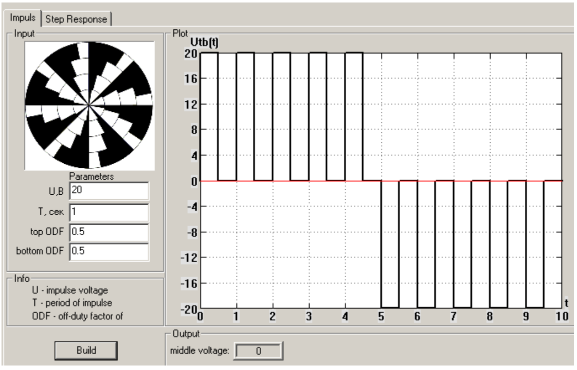
pulse duty cycle at the angle of rotation of the drone $\gamma = 180^0$ - bottom ODF.

In the right side of the interface there is an oscilloscope screen, with the help of which we can see the principle of control signal formation.

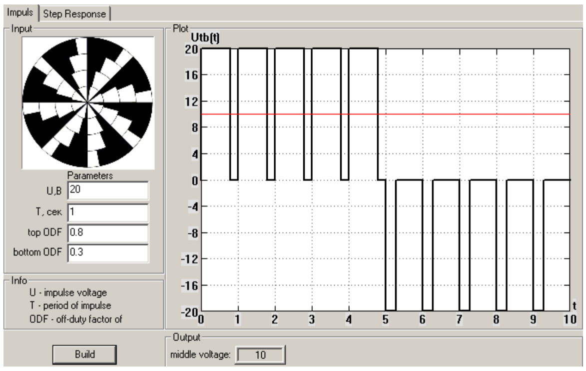
To set the value of any output parameter, just move the cursor to its field, click the left mouse button and enter the desired value.

To get the visualization of pulse control it is necessary to press the build button after setting the input data.

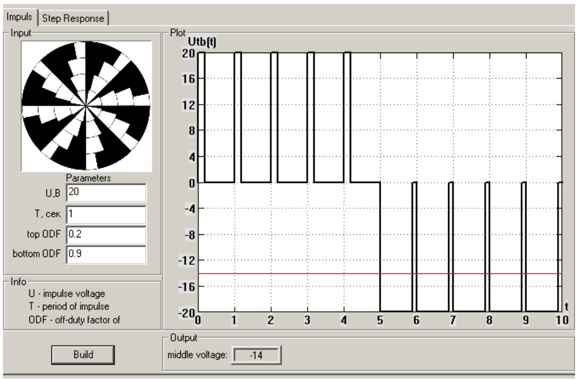
The oscilloscope builds the pulses and the line of the final control voltage. For example, in Fig. 4.12 shows the control pulses and the total control signal of the drone in the absence of its heading deviation, when the drone deviates to the right and when the drone deviates to the left.



a



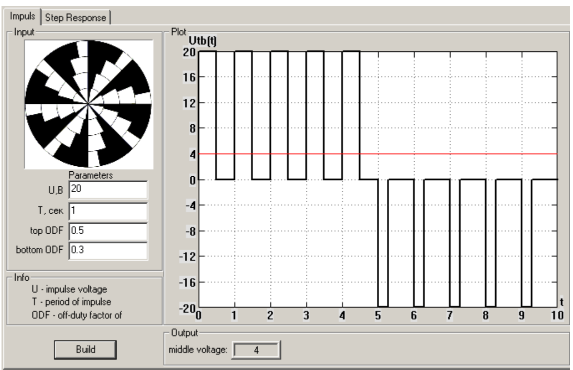
b



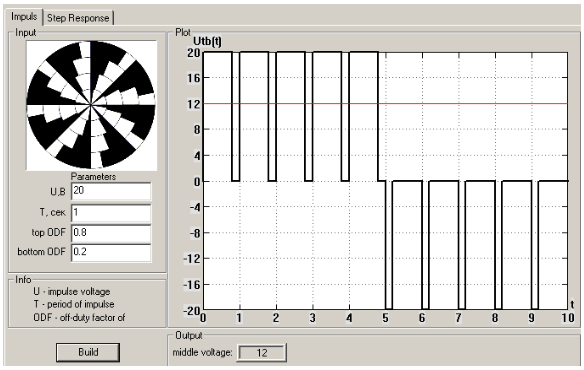
c

Fig. 4.11 Formation of control pulses and total control signal:
a - in the absence of drone deviation on course;
b - when the drone deviates to the right;
c - when the UAV deviates to the left

Fig. 4.12 illustrates the dependence of the control signal on the drone heading deviation on the right.



a



b

Fig. 4.12 Formation of control pulses and total signal control of the drone at its deviation on the course to the right: a – deviation 10^0; b – deviation 30^0 /

The developed programs can be used both in the design of drone control systems and in the training of operators.

CHAPTER 5

PROTECTION OF THE ENVIRONMENT

Environmental protection is the regulation of relations in the field of protection, use and reproduction of natural resources, ensuring environmental safety, prevention and elimination of the negative impact of economic and other activities on the environment, conservation of natural resources, genetic fund of wildlife, landscapes and other natural complexes, unique territories and natural objects associated with historical and cultural heritage.

Environmental pollution is an action that has introduced into the ecological system non-native living or non-living components, physical or structural changes that disrupt the processes of circulation and metabolism, as well as energy outflows, resulting in reduced productivity or destruction of the ecosystem.

Pollutants are usually grouped by their nature:

- physical pollution, these include: noise pollution and low frequency vibration, electromagnetic pollution, radioactive elements;
- chemical and biological pollutants, these include: synthetic organic substances, heavy metals, fluoride compounds;
- mechanical, these include: dust and solid particles.

The science of ecology is engaged in solving the issues in the field of environmental protection. Ecology is the economy of nature and the simultaneous study of all relationships of living things with organic and inorganic components of the environment.

The main tasks of ecology are comprehensive diagnostics of the state of nature, development of forecasts for changes in the state of the environment, formation of preventive preventive measures for environmental protection.

In this section, the issues of environmental pollution by personal computers will be considered, and methods and measures will be proposed for the rational development of the use and disposal of equipment without harming the environment.

5.1 Impact of the research object on the environment

According to some UN researchers, to create one average personal computer, it takes 10 times more chemicals and fuel than the weight of the final product. Many raw materials used in the assembly of computers are toxic. Fossil fuels only add to the unsolved problem of global warming. Production waste also does not disappear, turning into landfills, or is recycled, having a bad impact on the environment. Many users and manufacturers make the mistake of believing that with the reduction and improvement of computers, their negative impact on the environment is reduced. Therefore, scientists emphasize the importance of recycling equipment. Before throwing the "gadget" in the trash, it is better to finally make sure that it is not subject to recovery and only then contact the computer configurator. Perhaps it will be partially useful in another build.

Currently, the most stringent of the existing global environmental standards for computer equipment is the TCO99 standard. Compared to the previous ones, it contains additional restrictions in terms of ecology, ergonomics, energy consumption and emissions of devices.

The most significant labels, such as the "Blue Angel", issued by the German certification organization as a sign of compliance with environmental standards, are very rare in the field of electronics. In contrast, the Energy Star logo, which is awarded to energy-saving devices, is widespread. However, in its case the problem is that each manufacturer has the right to independently label its products without undergoing inspections.

Given that this emblem does not carry any information about the actual power consumption of devices, it can be ignored.

Since 2006, the environmental protection organization Greenpeace has been evaluating electronics manufacturers by the amount of heavy metals and toxic substances, such as combustion inhibitors, used in their production (an inhibitor is a substance whose presence in small quantities prevents or slows down combustion or corrosion processes; inhibitors reduce the rate of chemical reactions or inhibit them). However, even the estimates of such an organization as Greenpeace cannot claim to be objective. After all, in some cases it uses verified information concerning, for example, waste disposal measures, and in others it relies only on the manufacturer's data. And if a company does not report any information, it automatically finds itself at the bottom of the rating. In addition, energy costs for production and transportation of products must also be taken into account when assessing environmental efficiency. After all, the times when equipment was manufactured only at one plant are long gone. Today, individual components are purchased at various enterprises around the world, after which the devices are assembled. Therefore, often even the companies themselves cannot know what harmful substances enter the atmosphere during the manufacture of their products and what metals or toxins they contain. LCD screens are one of the sources of greenhouse gases, which are much more harmful than carbon dioxide. Liquid crystal monitors quickly gained popularity, replacing bulky CRT models. And this is not surprising, because they have thin cases and consume much less electricity. In other aspects of environmental safety, displays based on liquid crystals were also considered a breakthrough, because they did not use gas containing lead. For quite a long time, no one paid attention to nitrogen trifluoride (NF3) used for cleaning LCD panels, and only in mid-2008 scientists proved the presence of this chemical in the atmosphere. The discovery was striking: compared to carbon dioxide (CO2), NF3 is 17,000 times more active greenhouse gas, and its atmospheric half-life can be from 550 to 740 light years (CO2 - from 30 to 40 years). There is no law that would limit the level of NF3 emissions yet. Identifying energy consumption is as problematic as determining the amount of recyclable materials and heavy metals contained in devices. A surprising result was obtained by Greenpeace during a comparative analysis of several models of identical laptops from different countries. In the touchpad Dell Vostro V13, available on the Chinese market, traces of bromine were found. In the model from Germany, this substance is also present, but not in the touchpad, but in the buttons. In a laptop purchased in the United States, bromine was found in the power supply. A similar picture is observed in other manufacturers: in the study of Apple products, experts found that the cable of the MacBook Pro 13 laptop from the USA and the Netherlands contains three times more bromine than in devices from the Philippines and Russia. When analyzing another cable, traces of bromine were found in devices from Russia and the Netherlands, and in the model from the United States they were not. Thus, only the level of power consumption remains a reliable indicator of environmental friendliness - among subnotebooks the championship belongs to only a few models, and the rest differ sharply from the leaders in their characteristics.

Mining operations destroy the Earth's surface and often pollute the surrounding air and water. The extraction of rare earth minerals is impossible or unprofitable without using processes that cause serious environmental damage. Polyvinyl chloride, commonly referred to by the abbreviation PVC, is a type of plastic used for a variety of purposes. The outer sheath of the cables that connect devices is made of it, it surrounds the electric wire of a laptop computer. PVC is present in the music collection of vinyl record lovers. Pipes and clothes are made of it. It is cheap, durable and very common material.

However, according to Greenpeace IT analyst Casey Harrell, "PVC is the worst of the plastics. It causes hormonal imbalances, reproductive problems and various forms of cancer. Polyvinyl chloride is almost impossible to dispose of properly. As a result, old material usually ends up in landfills or, even worse, is burned to extract copper cores and other valuable components. Its combustion produces extremely harmful carcinogenic dioxin. Landfills and chemical burials pollute water sources. The only way to properly dispose of PVC is to send it to a hazardous waste center.

Prolonged work of computers leads to a decrease in the concentration of oxygen in the air, the amount of ozone, on the contrary, increases. Ozone is a strong oxidant. Its concentration above the maximum permissible values leads to adverse metabolic reactions of the body. Monitors have a great influence on the ionic composition of the air in the working area. Changes in this balance, due to an increase in the number of positive ions, leads to negative consequences. It is established that the background spectrum of ions in rooms with monitors is characterized by an excess of negative ions.

During the operation of the terminal, the structure of the spectrum of the ionic composition of the air in the working area changes significantly. During 5 minutes of monitor operation, the concentration of light negative ions decreased by 8 times, and after 3 hours it decreased to a level close to zero. The number of medium and heavy negative particles significantly decreased. At the same time, the concentration of positive ions increased, and after 3 hours of monitor operation, positive particles prevailed in the air of the working area. It should be noted that in geopathogenic zones, the devices also register a sharp decrease in negatively charged oxygen ions, which emphasizes the fact of the same physical nature of the torsion fields of the Earth's zones and the torsion fields generated by monitors, televisions and other electronic equipment.

Personal computers, laptops and other information technology are widely used in scientific research, industry, as well as in everyday home use. But any technology is rapidly aging, it is replaced by new, more powerful, more modern PCs and office equipment. Gradually, the problem arises what to do with old equipment, obsolete or out of order for one reason or another, which clutters up utility rooms and warehouses.

Disposal of computers is a process that is carried out in several stages. The very first action is to write off the equipment directly from the enterprise. The second stage is the disassembly of equipment and sorting of the received materials. If the parts can serve as raw materials, for example, a kinescope, parts containing precious metals, they are sent for cleaning and then for reuse.

5.2 Calculation of the impact of the object of study on the environment

At the moment, it is believed that the entire IT sector accounts for about 2% of harmful emissions on a global scale. This is a significant figure, especially when you consider that this sector is developing and growing at a high speed.

According to the UN researchers, it is time to take coordinated international steps to reduce the environmental damage caused by computer equipment. According to them, when creating one average personal computer, the total weight of various chemicals and fossil fuels is 10 times higher than the weight of the final product. Moreover, many of these chemicals are toxic, and the use of fossil fuels worsens the process of global warming. This waste is then either dumped in huge landfills or recycled, often in poor conditions in developing countries, posing significant health risks.

It is impossible not to note the incredible energy efficiency of new devices. If we consider, for example, the products of the Mac Book product line of Apple Inc., which are considered to be one of the most environmentally friendly in the industry, we can find simply impossible before low power consumption.

Even the most inefficient of these products exceed three times the strict Energy Star 6.0 energy consumption standards of 25 kWh per year for a laptop. If you convert to watts, it turns out that the Mac Book consumes less than 1 watt of energy per hour - a hundred times less than a conventional 100 W incandescent light bulb. However, not everything is so simple. 75% of all energy (which is used during the entire life cycle of the device) goes to the production of Mac Book, not to its operation. It is the energy consumed when using the device that is taken into account by the Energy Star standard. And it is only 19%. The rest is processing and transportation.

The report of the same Apple company says that, for example, a 15-inch Mac Book Pro with retina display emits 690 kg of carbon dioxide into the atmosphere during its lifetime. In fact, this is the same energy consumption expressed in kilograms of CO2. With the help of a simple coefficient, these kilograms can be converted into kilowatt-hours of electricity produced at the power plant. Such coefficients are calculated by special organizations according to internationally approved protocols, such as the Green house Gas Protocol, and are widely used by businesses to calculate the environmental impact of their production.

It is clear that for different energy sources and different countries the coefficients are different. For example, in America, when receiving a kilowatt-hour of energy, about half a kilogram of carbon dioxide is produced. In China, where most of the electronics manufacturing plants are located, the coefficient is about 0.87 kg/kWh. In the world, the "average hospital temperature" is about 0.44 kg of CO2 per kWh.

If we convert 690 kg of CO2 into kilowatt-hours using these factors, even using conservative Chinese factors, we get 800 kWh. That's 200 kWh per year, almost 10 times more than the Energy Star standard. This may be surprising at first, but it is enough to consider the intricacies of processor production, which is one of the most harmful in the production of computer components. The production of microchips with submicron element sizes is one of the most complex processes in modern industry. This technology has absorbed a lot of physical and chemical processes and requires nanometer precision, which is achievable only with absolute sterility of the production room. In the workshop, where the work is carried out, the so-called "electronic hygiene" is observed: in the working area of semiconductor wafers processing and crystal growth operations, there should not be more than five dust particles of 0.5 microns in a liter of air. For comparison, the standards of cleanliness of surgical operating rooms allow the content of thousands of times more dust. A chip is not just a silicon wafer, but a complex multilayer semiconductor structure built on a silicon substrate. Chip production consists of more than three hundred operations, and one production cycle can last up to several weeks. At almost every stage, harmful chemicals, high-precision equipment and energy-intensive physical methods, such as radiation etching and ion implantation, are used. And these operations are repeated for each of the couple dozen layers that make up the processor. Plus the energy consumption for a heavy-duty ventilation and filtration system to ensure sterility.

Therefore, it is not surprising that the mass of fuel required to produce one processor is thousands of times greater than the mass of the chip itself (only a couple of grams). The total energy consumption is hundreds of thousands of times higher than in the conventional production of, say, plastic or metal, from which computer cases are subsequently made.

Today it is believed that the production of a processor weighing 2 grams requires 1.6 kg of fuel, 72 g of chemicals and 32 kg of water.

5.3 Ways to improve the situation, recommendations and mitigation measures

The composition of the computer includes many metals such as gold, silver, aluminum, copper and others. Success in the disposal of personal computers can be achieved through recycling.

Recycling of computers, electronic recycling - recycling of computers and any other electronic devices. This is a complete deconstruction of electronic devices in order to reduce the consumption of raw materials and save as much material as possible from old and broken equipment.

In 2009, 38% of computers and 25% of total e-waste were recycled in the United States, up from 5% and 3% respectively in 2006. Since its inception in the early 1990s, more and more devices are being recycled worldwide due to increased awareness and investment. Mostly electronic recycling takes place in order to recover valuable rare earth and precious metals, which are in short supply, as well as plastics. These will be resold or used in new devices after purification, eventually creating a closed-loop economy.

Recycling is environmentally friendly, as it prevents hazardous waste, including heavy metals and carcinogens, from entering the atmosphere or waterways, and from landfills. Although electronics make up a small proportion of the total waste generated, they are much more dangerous. There are strict laws aimed at enforcing and encouraging the recycling of household appliances, the most influential of which are the Electronic Waste and Electronic Equipment Directive of the European Union and the National Computer Recycling Act of the United States.

Obsolete computers and old electronics are a valuable source of recyclable materials for recycling, on the other hand they are a source of toxins and carcinogens.

Rapid advances in technology, low initial cost and predictable obsolescence have led to a rapidly growing surplus of computers and other electronic components around the world. Technical solutions are available, but in most cases, regulatory frameworks, collection systems, logistics, and other services must be implemented before a technical solution can be applied. The US Environmental Protection Agency estimates that 30 to 40 million PC residues are classified as "household hazardous waste". The National Security Council estimates that 75% of all personal computers ever sold are now e-waste.

Computer components contain many toxic compounds such as dioxins, polychlorinated biphenyls (PCBs), cadmium, chromium, radioactive isotopes and mercury. A typical computer monitor can contain more than 6% lead, much of it in the lead glass of the cathode ray tube (CRT). A standard 15-inch (38 cm) computer monitor can contain 1 kilogram (1.5 pounds) of lead, but other monitors can have up to 4 kilograms (8 pounds) of lead. Printed circuit boards contain significant amounts of lead and tin, solders that are likely to leach into groundwater. Recycling (e.g. incineration and acid treatments) should retain these precious compounds but can create or synthesize toxic by-products.

Exporting waste to countries with lower environmental standards is a major concern. The Basel Convention includes hazardous wastes but does not regulate quantity restrictions, such as CRT screens, which cannot be exported transcontinentally without the prior consent of both exporting countries to receive the waste. Companies may find it cost effective in the short term to sell obsolete computers to less developed countries with less stringent regulations. It is believed that most surplus laptops are sent to developing countries under the guise of "e-waste dumping". The high operating and reusable value of laptops, computers and components (e.g. RAM) can help pay for the cost of transporting many unwanted "goods".

Recycling methods:

- Consumer recycling. Consumer recycling options consist of selling, donating computers directly to organizations, sending devices directly to their manufacturers, or receiving components for refurbishment or recycling.

- Corporate recycling. Businesses are looking for cost-effective ways to recycle large quantities of computer equipment, but face more complex processes. Businesses are also considering selling or partnering with Original Equipment Manufacturers (OEMs) and recycling organizations. Some companies are taking back unwanted equipment from other companies, wiping the data from the systems and assessing the residual value of the product. For devices that have value, firms buy parts, repair and sell refurbished products to those looking for cheaper options than buying new.

Sale. Online auctions are an alternative for consumers who wish to resell an item for cash, subject to a commission, without risking additional costs, as the item may not be sold under a paid ad. Online classifieds can be risky due to fraud, forgery and user variability.

One of the innovations for the recycling of printed circuit boards was invented by employees from the National Physical Laboratory of Great Britain, demonstrated the possibility of a special solution that is dissolved in hot water. The action of which causes the detachment of electronic components.

Thus, 90% of the components of new printed circuit boards can be used again, while in the case of conventional methods - only 2%.

Almost no company can dispose of computers and office equipment on their own, as this process requires modern equipment and specific knowledge. Therefore, such work can be entrusted only to professionals who have extensive experience in this field.

The problem of disposal of used computers and peripheral equipment is becoming more acute every year. The volume of production of information and telecommunications technology products and the frequency of their replacement with new models make companies think about the problem of biodegradation. Researchers believe that more incentives should be given to both computer manufacturers and users to improve and reuse their equipment rather than throw it away. Success in this area will help, among other things, manufacturers to reduce the taxes they currently pay for the disposal of outdated models. The latter is all the more important as it makes greening economically profitable, thus attracting more and more research efforts and long-term investments. Thus, further spread of information technologies will not increase, but on the contrary - will reduce the technogenic load on the environment.

Thus:

The issues of environmental protection in the process of computer production arose long ago and are regulated now. In recent years, numerous regulations and standards (international NPR or TCO95, TCO99) have appeared around the world to reduce negative impacts.

For example, the TCO-95 NUTEK standard controls toxic emissions, working conditions, etc. According to TCO-95, the manufactured equipment can be certified only if not only the controlled parameters of the equipment itself meet the requirements of this standard, but also the production technology of this equipment meets the requirements of the standard.

A computer manufacturer these days usually advertises its product as meeting several environmental requirements. For example.:

- low electricity consumption;

- environmentally friendly production;
- non-use of freon, which destroys the Earth's ozone layer;
- production of containers, documentation and packaging from recycled materials, etc.

Often the manufacturer calls such a computer "green" ("Green PC"), although there is no single standard for a "green" computer yet. The buyer, if he is interested in preserving his own health and the health of the planet, should be interested in the process of buying not only functional but also environmental characteristics of the purchased computer.

Computer technology, being a great achievement of mankind, can have negative consequences for the environment. The technical level of modern monitors does not completely exclude the existence of harmful effects, but this impact must be minimized by regulating a number of parameters. To reduce the damage, it is necessary to comply with the established requirements and norms. The main purpose of their implementation is to protect flora and fauna from the harmful effects of computer and other electronic equipment.

The Greenpeace organization closely monitors how large companies treat the environment and regularly publishes the Greenpeace Guide to Greener Electronics report, in which manufacturers (HP, Sony, Toshiba, etc.) are rated in three main categories: rationality of operations, energy and climate, environmentally friendly products. It can be concluded that we can only hope that the time will come when technology will help people without causing irreversible damage to the health of the environment.

CHAPTER 6

LABOR PROTECTION

Occupational safety management has a targeted effect on the "man-production" system, which is the entire set of elements with which a person interacts in the process of work and which may have a corresponding impact on it. Occupational safety and health issues are regulated by the Labour Code of Ukraine, the Law of Ukraine "On Compulsory State Social Insurance against Accidents at Work and Occupational Diseases that Caused Disability", as well as a number of resolutions of the Cabinet of Ministers of Ukraine. One of the most important legal acts on labour protection is the Law "On Labour Protection".

The object considered in the thesis requires the use of a personal electronic computer (PC), which in turn are complex electronic devices characterized by the presence of certain hazardous sources of exposure to the designer and the environment in which he is.

6.1 Analysis of working conditions with electronic computers

According to the nature of labor activity, three professional groups are distinguished according to the current classifier of professions (DK - 003 - 95 and Amendment No. 1 to DK - 003 - 95):

- software developers (software engineers) - work mainly with video terminal and documentation if necessary and intensive exchange of information with computers and a high part of decision-making. The work is characterized by intensive mental creative work with increased visual strain, concentration of attention against the background of nervous and emotional stress, forced working posture, general hypodynamia, periodic load on the hands of the upper extremities. The work is performed in a dialogue mode with a computer at a free pace with a periodic search for errors in a time crunch;

- operators of electronic computers - perform work related to the accounting of information received from the TTR by prior request, or that comes from it, accompanied by breaks of varying duration, related to the performance of other work and characterized as work with visual strain, slight physical effort, moderate nervous tension and performed at a free pace;

- computer typing operator - performs monotonous work with documentation and keyboard and infrequent short switches of gaze to the display screen, with data entry at high speed, the work is characterized as physical labor with increased load on the upper extremities against the background of general hypodynamia with visual strain (fixation of vision mainly on documents), nervous and emotional stress.

The following intra-shift modes of work and rest when working with computers during an 8-hour day shift are established depending on the nature of work:

- for program developers using computers, a regulated rest break of 15 minutes should be assigned for every hour of work according to the VDT;

- for computer operators, regulated rest breaks of 15 minutes should be scheduled every two hours;

- computer typing operators should be assigned regulated rest breaks of 10 minutes after each hour of work according to the VDT.

In all cases where production circumstances do not allow the application of regulated breaks, the duration of continuous work with VDT should not exceed 4 hours.

In a 12-hour work shift, regulated breaks should be established in the first 8 hours of work similar to the breaks in an 8-hour work shift, and during the last 4 hours of work, regardless of the nature of the work activity, every hour for 15 minutes.

In order to reduce the negative impact of monotony, it is advisable to use the alternation of operations of conscious text and numerical data (change the content of work). Alternation of data entry and text editing.

To reduce nervous and emotional tension, fatigue of the visual analyzer, improve cerebral circulation, overcome the adverse effects of physical inactivity, prevent fatigue, it is advisable to use some breaks to perform a set of exercises given in Appendix 8.

In some cases - in case of chronic complaints of those working with computers and computers with visual fatigue despite compliance with sanitary and hygienic requirements for work and rest regimes, as well as the use of local eye protection - an individual approach to limiting the time of work with VDT, changing the nature of work, alternating with other activities not related to VDT is allowed.

Active recreation should consist in performing a set of gymnastic exercises aimed at relieving nervous tension, muscle relaxation, restoring the functions of physiological systems that are disturbed during the work process, relieving eye fatigue, improving cerebral circulation and performance.

Under the condition of high level of intensity of work with VDT, psychological relief during regulated breaks or at the end of the working day is shown.

6.2 List of harmful and dangerous production factors

The production environment refers to a set of physical, chemical, biological, psychophysiological factors at work that affect a person. All these factors are classified as hazardous and harmful.

Hazardous production factors are those whose impact on the worker leads to injuries, a sharp deterioration in health or death.

Harmful production factors - those whose impact on the employee may lead to illness and reduced ability to work.

Employees involved in work related to periodic or permanent work at a computer are exposed to occupational hazards, the main of which are:

Physical:

- increased voltage level in the electrical circuit, the short circuit of which can pass through the body of the worker;
- increased level of X-ray radiation;
- increased level of ultraviolet radiation;
- increased level of infrared radiation;
- the possibility of static electricity;
- dustiness of the working room air;
- increased content of heavy (+) air ions;
- uneven distribution of brightness in the field of view;
- increased level of light flux pulsation.

Chemical:

- Increased content of carbon dioxide, ozone, ammonia, phenol, formaldehyde, etc. in the air.

Psychophysiological:

- visual strain;
- memory voltage;
- attention span;
- prolonged static stress;
- relatively large amount of information processed per unit of time;
- monotony of work in some cases;
- irrational organization of the workplace.

When working with a PC, a person can be exposed to all harmful and dangerous factors. The harmful and dangerous factors that a designer faces when working with a PC are given in Table 6.1.

Table 6.1

List of harmful and dangerous production factors

Name of factors	**Possible sources of their occurrence**	**Nature of the action**
Danger of electric shock	Power supply network	Dangerous and harmful
Fire hazard of premises	Presence of materials that can catch fire and sources of ignition (electrical equipment)	Dangerous and harmful
Electromagnetic radiation including X-ray radiation	CRT (the display is a source of X-ray, radio frequency, ultraviolet, infrared and sound radiation)	Hazardous and harmful
Static electricity	CRT monitor and dielectric surface of the screen	Hazardous and harmful
Air ionization	Static electricity and X-ray radiation	Harmful
Increased noise level	Noise is created by the voltage converter of the computer, its technical periphery, as well as by people working in the classroom	Harmful
Unfavorable illumination	Insufficient artificial and natural lighting	Harmful

Unsatisfactory microclimate parameters	Unsatisfactory condition of ventilation and heating systems	Harmful
Psychophysiological stress	Monotony of work, overstrain of visual analyzers, mental tension, inconvenience and static postures	Harmful

Computers and telephones are also the main sources of noise in the premises. The noise level in the room should correspond to the optimal level according to DST 3.3.6.037-99.

6.3 Analysis of harmful and dangerous production factors acting in the workplace on the subject

The main harmful factors when working with a computer include: prolonged sitting position, electromagnetic radiation, eye strain, overload of wrist joints, the possibility of respiratory diseases, allergies, disruption of the normal course of pregnancy, etc. Prolonged sitting leads to tension of the muscles of the neck, head, arms and shoulders, osteochondrosis, in children - also to scoliosis. Prolonged sitting also leads to stagnation of blood in the pelvic organs and, as a result, to prostatitis and hemorrhoids. It is no secret that a sedentary lifestyle leads to obesity. Strain on eyesight. The human eye reacts to the smallest vibration of the text and the flickering of the screen. The eye muscles that control the lens are in constant tension, which necessarily leads to loss of visual acuity. Prolonged work at the computer is a huge strain on the eyes, because the image on the monitor does not consist of continuous lines, as on paper, but of individual dots that glow and flicker. The user's vision inevitably deteriorates, the eyes begin to water, headaches, fatigue, the image is doubled and distorted.

Chemical hazardous and harmful production factors include chemicals that are divided into toxic, irritating, sensitizing, carcinogenic and mutagenic by the nature of their action on the human body. These chemicals affect human reproductive function. According to the ways of penetration into the human body they are divided into penetrating through the respiratory system, gastrointestinal tract, skin and mucous membranes.

Biological hazardous and harmful production factors include pathogenic microorganisms (bacteria, viruses, rickettsia, spirochetes, fungi, protozoa) and products of their vital activity, as well as macroorganisms (plants and animals).

The psychophysiological hazardous and harmful production factors include physical (static and dynamic) and neuropsychic overloads (mental overstrain, overstrain of analyzers, monotony of work, emotional overload).

In order to objectively analyze the compliance of working conditions with current regulations, it is necessary to carry out a sanitary and hygienic characterization of working conditions, certification of the workplace in terms of harmful and dangerous factors of the production environment, the severity and intensity of the work process.

Computer work and stress. Stress is an emotional experience, internal tension caused by events in life. Stress occurs primarily when information is lost or damaged. Reasons: lack of backup copies, computer viruses, hard drive breakdowns, work errors. Working at the computer is one of the factors that cause stress (stressor). The body's reaction to stress is the launch of biochemical processes that are aimed at suppressing an extreme situation. Respiratory diseases when working with a computer in this context are mainly allergic in nature. This is due to the fact that during the long operation of the computer, the case and boards of the latter emit a number of harmful substances into the air, as well as the computer creates an electrostatic field around it, which attracts dust that settles in the lungs. Also, the computer deionizes the environment and reduces air humidity. The computer is a serious source of a number of allergens. For example, the monitor case, heating up to 50-55 ° C begins to emit triphenyl phosphate vapors into the air. In addition to the monitor, the motherboard, power supply, processor, video card are also heated, which can also emit harmful organic and inorganic substances (fluorine, chlorine, phosphorus) into the environment. In addition, there are many places in the computer where dust and dirt accumulate, microbes and fungi multiply. Dust receives a weak static charge from the monitor screen, which is enough for dust to settle on the user's body and in his respiratory tract.

6.4 Development of labor protection measures

On the basis of DNAOP 5.2.30-1.08-96 and VSN 4559-88 "Temporary sanitary norms and rules for employees of computer centers":

- persons over 18 years of age who have no contraindications according to the results of a preliminary medical examination and have undergone instruction, training and knowledge testing on occupational safety and have 1 qualification group for electrical safety are allowed to work on personal computers;

- admission to work on personal computers of persons under 18 years of age (trainees, students) is carried out under the guidance of experienced workers who have a qualification group for electrical safety not lower than 3.

To reduce and prevent the harmful effects of the above factors it is recommended

- to reduce the level of static electricity, place the display screen at a distance not closer than 550 - 700 mm. from the user's eyes;

- to reduce glare, the display screen should be located perpendicular to the light flux from window openings or from electric lamps;

To reduce eye fatigue:

- the illumination of the workplace should be at least 300 - 500 lux; the brightness of the screen should be at least 100 cd / sq. m;

- minimum luminous point size - no more than 0.6 mm

- contrast of the sign image - not less than 0.8;

- regeneration frequency - not less than 72 Hz.

To reduce the impact of hypodynamia and emotional overload, it is necessary to use technological breaks and perform a set of physical exercises.

For safety before starting work:

- leave street clothes, personal belongings in the wardrobe;

- remove from the workplace items that will not be used in work;

- it is forbidden to put paper, books, documents and other items on computer units;

- to avoid overloading the network, it is forbidden to connect the computer through tees together with other electrical appliances;

- turn on, if necessary, artificial lighting, table lamp;

- make sure that connecting wires, plug connectors, grounding bars and switches are in good condition, that protective covers and covers of computer units are securely fastened;

- check the absence of dust on the display screen. Do not allow clogging of ventilation holes for heat removal from computer units with dust and foreign objects;

- adjust the height of the chair seat and footrest. Adjust the position of the monitor screen relative to your field of view;

- in case of detection of malfunctions and other defects that create danger or significant inconvenience in work, report it to the head of the department, site.

For safety during work:

- when connecting personal computers and lighting to the mains, take only insulated parts of the plugs;

- observe the sequence of switching on the computer units specified in the operating instructions;

- to avoid static electricity discharges, do not touch the display screen;

- when entering data, editing programs, reading information from the screen, the continuous duration of work in front of the screen should not exceed 1 hour, followed by regulated breaks of 10 minutes for rest and performing a set of physical exercises, relaxation exercises and autogenic training.

- It is forbidden to use the computer when the power supply is not switched off:

- open protective covers and covers of computer units, adjust and clean internal parts, change fuses;

- switch the connecting cords of computer units;

- change the established configuration of the workplace, rearrange the computer units;

- do wet cleaning of computer surfaces;

- take food directly at the computer keyboard.

- It is strictly prohibited at the workplace of the computer operator:

- smoking, use of open fire;

- store flammable, explosive and chemically active products that destroy insulation. Signs of an emergency situation at the workplace of the computer operator are;

- appearance of failures in the computer, paper jam in the printer, disappearance of the image on the display screen;

- short circuit, sparking, burning smell, increased heating of the case, plug connectors, connecting wires, reduction or disappearance of voltage in the network, etc..

In an emergency situation it is necessary to :

- stop work, disconnect the computer from the network;
- in case of fire use carbon dioxide or powder fire extinguishers;
- take measures to evacuate people and provide first aid to the victims;
- report what happened to the head of the department, site;
- if necessary, call an ambulance, fire brigade.

Safety after the end of work:

- finish running programs, close all directories, prepare the computer for shutdown;
- disconnect the computer and local electric lighting from the network;
- arrange the workplace, take away the documents that were used;
- make sure there is no fire hazard.

6.5 Electrical safety and fire safety when working with electronic computers

The main cause of electric shock is violation of safety rules during the operation of electrical installations.

Electrical safety requirements in the premises where electronic computers and personal computers (hereinafter referred to as computers) are installed are reflected in DNAP 0.00-1.31-99. According to this normative document, during the design of power supply systems, installation of basic electrical equipment and electric lighting of buildings and premises for computers, it is necessary to comply with the requirements of the Rules for the Arrangement of Electrical Installations (PVE), GOST 12.1.006-84, GOST 12.1.019-79, GOST 12.1.030-81, GOST 12.1.045-84, PTE, PBE, VSN 59-88 "Electrical Equipment of Residential and Public Buildings. Design standards", SN 357-77 "Instruction for the design of power lighting equipment for industrial enterprises", Fire Safety Rules in Ukraine and other regulatory documents related to artificial lighting and electrical devices, as well as the requirements of the regulatory and technical operational documentation of the manufacturer.

The power supply line for power supply of computers, computer peripherals and equipment for maintenance, repair and adjustment of computers is performed as a separate group three-wire network by laying phase, neutral working and neutral protective conductors. The zero protective conductor is used for grounding (zeroing) of electrical receivers and is laid from the rack of the group distribution board, distribution point to the power outlets

In a room where more than five personal computers are operated or serviced simultaneously, an emergency backup switch is installed in a visible and accessible place, which can completely turn off the electrical power of the room, except for lighting.

It is unacceptable to connect computers, computer peripherals and equipment for maintenance, repair and adjustment of computers to a conventional two-wire power supply system, including the use of transition devices.

If up to 5 personal computers are located in the room outside its perimeter, using a three-conductor protected wire or cable in a sheath made of non-combustible or heavy-combustible material, it is allowed to lay them without metal pipes and flexible metal hoses.

Metal pipes and flexible metal hoses must be grounded. Grounding must meet the requirements of DNAP 0.00-1.21-98 "Rules for the safe operation of electrical installations of consumers". Grounded structures located in the premises (heating batteries, water pipes, cables with grounded open shield, etc.) must be reliably protected by dielectric shields or nets from accidental contact.

Are unacceptable:

- operation of cables and wires with damaged or lost protective properties during operation, insulation; leaving cables and wires with uninsulated conductors under voltage;

- use of home-made extension cords that do not meet the requirements of the PIE for portable electrical wiring;

- use of non-standard (home-made) electric heating equipment or incandescent lamps for heating the premises;

- use of damaged sockets, junction and junction boxes, switches and other electrical products, as well as lamps whose glass has traces of darkening or bulging;

- hanging lamps directly on current-carrying wires, wrapping electric lamps and lamps with paper, cloth and other combustible materials, operating them with caps (diffusers) removed;

- use of electrical equipment and devices in conditions that do not comply with the instructions (recommendations) of manufacturers.

6.6 Certification of workplaces

To objectively analyze the compliance of working conditions with the current regulations, it is necessary to carry out sanitary and hygienic characteristics of working conditions, certification of the workplace in terms of harmfulness and danger of factors of the production environment, the severity and intensity of the work process.

Certification of workplaces for working conditions at computers involves:

- comprehensive assessment of the factors of the production environment and the nature of work, compliance of their characteristics with labor safety standards, building and sanitary standards and regulations;

- identification of factors and causes of unfavorable working conditions;

- sanitary and hygienic study of the factors of the production environment;

- establishing the degree of harmfulness and danger of work and its nature according to the hygienic classification;

- justification of classification of the workplace as a category with harmful (especially harmful) working conditions;

- determination (confirmation) of the employees' right to benefits;

- analysis of the implementation of technical and organizational measures aimed at optimizing the level of hygiene, nature and safety of work.

The entire building must be electrified in accordance with all relevant regulations. All computers should be used only for their intended purpose, as they can be electrically dangerous if used incorrectly. It is desirable to use liquid crystal monitors, as X-ray radiation from them does not pose a danger to the user, since the intensity of such radiation is much lower than the maximum permissible level. The level of electromagnetic radiation should provide for a possible 12-hour stay in the radiation zone. The level of electrostatic field intensity should be within normal limits.

The room also has tables, chairs and cabinets for documents. All of them can be placed only in accordance with their functional purpose, and their number should correspond to the nomenclature of tools, content and features of the work performed.

The design of the desktop must meet modern ergonomic requirements and provide optimal placement on the working surface of the equipment used (display, keyboard) and documents.

The work chair should be lifting and swiveling, height adjustable, with a front rounded edge. The height of the seat surface shall be adjustable in the range from 400 to 500 mm, and the width and depth shall be 450 - 500 mm. The angle of inclination of the backrest is adjustable from 0° to 30° relative to the vertical position. To reduce the static tension of the muscles of the upper extremities, stationary armrests 250 mm long are installed. The seat surface meets all requirements.

The computer monitor should be at a sufficient distance from the user's eyes. The keyboard should be located on the surface of the table at a distance of 200 mm from the edge facing the worker. The design of the keyboard should include a support device that allows you to change the angle of inclination of the keyboard surface in the range from 5 to 15.

Thus, the ergonomic parameters of the workplace will meet the requirements for their organization and design and will ensure the maintenance of optimal working posture.

In the cold season, it is recommended to use its own independent heating system to heat the building. This has a positive effect on the well-being of employees, as it is possible to control the heating of the premises.

Ensuring meteorological working conditions and clean air in the room should be carried out using a system of supply and exhaust ventilation, regular ventilation, and wet cleaning.

It is necessary to use artificial and natural lighting. The normalized value of the natural light coefficient (NLC) for the fourth light zone, in which Ukraine is located, is 0.81. In addition, the room should be additionally illuminated with lamps with incandescent lamps with a power of 200 watts.

Thus, the working conditions of the employee will generally meet the existing sanitary and hygienic standards. But due to the fact that most of the time the employee takes a sitting posture and moves little, it is proposed to introduce five-minute industrial gymnastics, which must be carried out after every 60 minutes of sitting work, and which will be aimed at improving the physical and moral condition and well-being of the employee.

Thus:

Occupational safety is a system of legislative acts, socio-economic, organizational, technical, sanitary, hygienic and therapeutic and preventive measures and means that ensure the safety of health and human performance in the work process.

Working conditions are understood as a set of factors of the labor process and the production environment in which human activity is carried out, affecting health and performance.

The growth rate of the number of computer users is steadily increasing. At the same time, the possible danger to the health of those working on computers becomes more and more obvious. When working with a computer, the visual, musculoskeletal, neuropsychiatric systems and reproductive function in women are at greatest risk. In addition, the video display terminal disrupts the balance between positively and negatively charged ions in the air.

Personnel working on the computer must comply with the requirements of the instruction developed on the basis of Sanitary norms and rules SanPin 2.2.2.542-96

"Hygienic requirements for video display terminals, personal computers and work organization".

When working with a computer, the harmful and dangerous factors are: electrostatic fields; electromagnetic radiation; the presence of powerful ionizing radiation; local fatigue, general fatigue; eye fatigue; danger of electric shock; fire hazard.

In emergency situations, the computer must be immediately disconnected from the network: in case of power outage; in case of fire; in case of smoke smell.

The most stringent requirements in the world to computer equipment are imposed by the Swedes, who conducted the most complete studies of the impact of all types of radiation on human health. The countries of the European Union, when creating a single EU standard, were guided by the Swedish norms of TCO 92. Russian requirements for radiation from video monitors are still lower than in TCO 92, but in the near future the State Standard plans to raise the safety bar to the Swedish level.

CONCLUTIONS

A feature of reliable provision of forced avalanches from large distances with minimal damage to the rest of the territory is the use of mobile high-precision complexes.

The efficiency of its control system largely depends on how correctly the structure is chosen, the parameters of the complex are calculated and adjusted.

In the course of the diploma work it was:

- CAD of the mobile complex for remote control of forced avalanches was created for which:

- the basic components of the complex and their characteristics are determined;

- the design algorithm was substantiated and developed;

- mathematical support for the design of the drone and modeling of the control system was performed;

- the composition of the onboard equipment of the drone and the control method were determined.

- developed methods and defined algorithms for software and methodological support of experimental research during design:

- structural modeling of the control system;

- design based on basic application packages;

- software implementation of pulse control;

- the necessity of implementation and experimental studies were carried out in the interests of correct design. Theoretical and experimental studies of methods of calculation of regulators showed good agreement of results.

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