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

ADMIT TO DEFENSE
Head of department
Viktor M.Sineglazov
“____” ______________ 2022

# MASTER’S THESIS

**(EXPLANATORYNOTE)**

**GRADUATE OF EDUCATION AND QUALIFICATION LEVEL “MASTER”**

**THEME <u>Flight Control System of a Cargo Quadcopter</u>**

**Executor:Huliuk V Y.**

**Supervisor:Ph.D., Professor Filyashkin M.K.**

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

**Advisoron labor protection:Senior LecturerKozlitinO.O.**

**Normsinspector: Ph.D., Professor Filyashkin M.K.**

**Kyiv 2022**

**МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ**
**НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ**
**КАФЕДРАКОМП'ЮТЕРНО-ІНТЕГРОВАНИХ КОМПЛЕКСІВ**

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
В.М. Синєглазов
"_____"____________2022 р.

# ДИПЛОМНА РОБОТА
## (ПОЯСНЮВАЛЬНА ЗАПИСКА)

**ВИПУСКНИКА ОСВІТНЬО-КВАЛІФІКАЦІЙНОГО РІВНЯ "МАГІСТР"**

**Тема: Система управління польотом вантажного квадрокоптера**

**Виконавець: Гулюк В.Я**

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

**Консультант з екологічноїбезпеки:к.т.н., доцент ЯвнюкА.А.**

**Консультант з охоронипраці:старший викладачКозлітінО.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**

Освітній ступінь: бакалавр

Спеціальність 151 “Автоматизація та комп'ютерно-інтегровані технології”

Освітньо-професійна програма "Комп’ютерно-інтегровані технологічні процеси і виробництва"

ЗАТВЕРДЖУЮ
Завідувач кафедри
Синєглазов В.М.
“ ____ ” __________2022 р.

**ЗАВДАННЯ**

**на виконання бакалаврської роботи студента**

Гулюка Василя Ярославовича

1. **Тема проекту (роботи):** “ Система автоматичного управління польотом вантажного квадрокоптера ”

2. **Термін виконання проекту (роботи):** з 19.08.2022р. до 15.11.2022р.

3. **Вихідні данні до проекту (роботи):** Розробку системи автоматичного управління проводити для квадрокоптера типу Airborg H8.

4. **Зміст пояснювальної записки (перелік питань, що підлягають розробці):** 1. Класифікація БПЛА та квадрокоптерів. 2. Аналіз відмінностей управління польотом квадрокоптера й гелікоптера. Особливості динаміки управління вантажного квадрокоптера. 3. Обґрунтування необхідності автоматизації процесів управління. Структурна схема інформаційно-керуючого комплексу. 3. Математичні моделі вантажного квадрокоптера, як об’єкта керування. 4. Синтез контурів автоматичного управління поздовжнім рухом квадрокоптера. 5. Дослідження контурів автоматичного управління.

Перелік обов’язкового графічного матеріалу: 1. Існуючі квадрокоптери. 2. Плакат, що ілюструє принципи управління польотом квадрокоптера та гелікопткра. 3. Структурна схема інформаційно-керуючого комплексу квадрокоптера. 4. Математичні моделі квадрокоптера. 5. Синтез контурів автоматичного управління поздовжнім рухом квадрокоптера. 6. Результати дослідження контурів автоматичного управління.

Дата видачі завдання ________________________________________

Керівник к.т.н., професор Філяшкін М.К.

(підпис)

***Завдання прийняв до виконання*** ____________________ Гулюк В. Я.

(підпис)

## 6. Календарний план-графік

| № п/п | Завдання | Термін виконання | Відмітка про виконання |
|---|---|---|---|
| 1 | Аналіз актуальності проблеми | 09.08.2022-26.08.2022 | |
| 2 | Аналіз характеристик безпілотних літальних апаратів та їх застосування | 26.08.2022-02.09.2022 | |
| 3 | Дослідження інформаційного забезпечення систем управління безпілотними літальними апаратами | 02.09.2022-16.09.2022 | |
| 4 | Дослідження систем, що входять до складу інтегрованого навігаційного комплексу | 16.09.2022-23.09.2022 | |
| 6 | Розробка та дослідження контурів управління польотом | 07.10.2022-21.10.2022 | |
| 6 | Моделювання контурів управління рухом квадрокоптера в просторі | 21.10.2022-04.11.2022 | |
| 7 | Висновки по роботі та підготовка презентації і роздаткового матеріалу | 04.11.2022-15.11.2022 | |

## 7. Консультанти зі спеціальних розділів

| Розділ | Консультант (посада, П. І. Б.) | Дата, підпис | |
|---|---|---|---|
| | | Завдання видав | Завдання прийняв |
| Охорона праці | Старший викладач, Козлітін О.О, | | |
| Охорона навколишнього середовища | к.б.н., доцент, Явнюк А.А. | | |

**8. Дата видачі завдання** ______________________________

Керівник: ______________________ Філяшкін М.К.

(підпис)

Завдання прийняв до виконання: ______________________ Гулюк В.Я.

(підпис)

**NATIONAL AVIATION UNIVERSITY**

**Faculty of aeronavigation, electronics and telecommunications**

**Department of Aviation Computer Integrated Complexes**

**Educational level:** master

Specialty 151 “ Automation and computer-integrated technologies”

Educational and professional program “Computer-integrated technological processes and production”

**APPROVED BY**

Head of department

Victor M. Sineglazov

“_____”_____________ 2022

**Graduate Student’s Diploma Thesis Assignment**

**Huliuk Vasil Yaroslavovcih**

**1. Topic of the project (work):** "Automatic flight control system of cargo quadcopter"

**2. The term of the project (work)**: from August 19, 2022. until 15.11.2022

**3. Initial data for the project (work):** Development of an automatic control system for the Airborg H8 type quadcopter.

**4. Contents of the explanatory note (list of issues to be developed):** 1. Classification of UAVs and quadcopters. 2. Analysis of the differences between quadcopter and helicopter flight control. Features of cargo quadrocopter control dynamics. 3. Justification of the need to automate management processes. Structural diagram of the information and management complex. 3. Mathematical models of cargo quadrocopter as a control object. 4. Synthesis of the contours of the automatic control of the longitudinal movement of the quadcopter. 5. Study of automatic control circuits.

List of mandatory graphic material: 1. Existing quadcopters. 2. A poster illustrating the principles of controlling the flight of a quadcopter and a helicopter. 3. Structural diagram of the information and control complex of the quadcopter. 4. Mathematical models of the quadcopter. 5. Synthesis of the contours of the automatic control of the longitudinal movement of the quadcopter. 6. Results of the study of automatic control circuits.

## 6. Planned schedule:

| № | Task | Deadline | Performance note |
|---|---|---|---|
| 1 | Analysis of the relevance of the problem | 09.08.2022-26.08.2022 | |
| 2 | Analysis of characteristics of unmanned aerial vehicles and their application | 26.08.2022-02.09.2022 | |
| 3 | Research of information support of control systems of unmanned aerial vehicles | 02.09.2022-16.09.2022 | |
| 4 | Research of systems included in the integrated navigation complex | 16.09.2022-23.09.2022 | |
| 6 | Development and research of flight control circuits | 07.10.2022-21.10.2022 | |
| 6 | Modeling of quadcopter motion control contours in space | 21.10.2022-04.11.2022 | |
| 7 | Conclusions on the work and preparation of the presentation and handout | 04.11.2022-15.11.2022 | |

## 7. Special chapters' advisors

| Chapter | Advisor (position, name) | Date, signature | |
|---|---|---|---|
| | | Assignment issue date | Assignment accepted |
| Labor protection | Senior lecturer, Kozlitin O. O. | | |
| Environmental protection | Ph.D, Associate Professor, Iavniuk V.F. | | |

## 8. Date of task receiving: ____________________

Diploma thesis supervisor: ____________________ Mykola K. Filyashkin
(signature)

Issued task accepted: ____________________ Vasiliy Y. Huliuk
(signature)

# ABSTRACT

The purpose of the work is to develop a system of automatic control of the flight of a cargo quadcopter and to study the influence of the inertia of the change in the speed of rotation of the propellers.

In the work, for the tasks of synthesis and analysis of automatic control circuits, a mathematical model of the cargo quadcopter as a control object was modernized and verified, which takes into account the inertia of the change in the rotation speed of the propellers and the influence of the flight parameters on the aerodynamic characteristics of the propellers.

The paper proposes a correction of the quadcopter angular motion control law by introducing a forced component into the signal chain of the angular velocity sensor.

**CONTENT**

## KEYWORDS

Quadcopter - (from the English Quadcopter - "helicopter with four propellers"), an unmanned aerial vehicle with four propellers

The engineering and control complex is a means of navigation and control of an unmanned aerial vehicle

Inertia is a property of the body, which consists in the fact that it takes time to change the speed of movement of the body due to interaction

Pitch - angular movement of the aircraft relative to the main transverse axis of inertia.

The regulator is a device that produces a control signal for changing (adjusting) the output parameter.

# INTRODUCTION

The development of systems using unmanned aerial vehicles (UAVs) is a modern trend in aerospace research. An unmanned aerial vehicle is a moving object, on board of which there is no person during the flight. Such UAVs can be controlled remotely or autonomously follow a pre-programmed path. UAVs are mainly used in military operations. However, they also find application in civil needs, such as firefighting. In general, unmanned vehicles are preferred when performing missions unsuitable for manned vehicles. There is a wide range of geometric configurations, means of control and general functioning of UAVs. Aircraft with blade motors have a number of advantages over variants with fixed wings. They primarily include the ability to take off and land vertically, as well as the ability to hover over a fixed point. In addition, helicopter-type UAVs can move in the range of low speeds. One of the possible configurations of helicopter motors is represented by the so-called quadrocopter (Fig. 1).

A quadcopter is a cross-shaped flying device with motors located at the ends of the device's ribs. The motors are fixed.

Fig. 1. Quadrocopter.

Unlike a helicopter, in which an inclined washer is used for control, which changes the direction of thrust of the rotor, as well as the common pitch and, aQCordingly, the amount of thrust of the rotor, in quadcopters, the direction of thrust relative to the body and the pitch of the rotor blades do not change, but only the amount of thrust by due to the change in the speed of rotation of the four supporting screws.

Currently, quadcopters are used quite widely and in a variety of ways, but this use is limited mainly to "manual" remote control modes from the operator's remote control. The task of developing a control system that allows autonomous flight of a quadcopter along a given route is urgent

Changing the direction of movement of the quadcopter is associated with a change in the magnitude and direction of thrust of the propellers. To change the flight height of the quadcopter, the speed of rotation and, aQCordingly, the amount of thrust of all propellers changes synchronously. And to move the quadcopter in the horizontal plane, the thrust of the main propellers changes its angular orientation. To change the angles of roll and pitch, corresponding control moments are created by changing the rotation speeds of various screws. To compensate for the reactive moments of the bearing screws, the opposite direction of rotation of individual pairs of screws is used. Changes in the speed of rotation of these pairs violates the condition of compensation and creates a yaw control moment that turns the quadcopter.

Thus, the control of the quadcopter is reduced to the control of the speed of rotation of the propellers, which significantly simplifies the design of the control system. When studying the dynamics of the movement of miniature quadcopters, the inertia of the change in the speed of rotation of the propellers is usually neglected. However, "heavy" quadcopters, the total weight of which is about 15 ... 20 kg, have massive propellers with a large span (length) of the blades. For example, the Airborg H8 quadcopter has a propeller span of almost two meters. Naturally, the inertia of changing the speed of rotation of such propellers (inertia of control) can significantly affect the quality of the control processes of the quadcopter.

This work is devoted to the study of the dynamics of the movement of a heavy quadcopter controlled by an automatic control system (ACS). In order to synthesize the laws of automatic control of the ACS, it is necessary to develop a mathematical model of the quadcopter and investigate the influence of the inertia of the change in the speed of rotation of the propellers on the dynamics of the automatic control circuits of the quadcopter.

# CHAPTER 1.

# CLASSIFICATION OF UAVS AND QUADROCOPTERS

- The main classification features of UAVs are:
- by type of control system,
- by mass,
- by the scale of tasks,
- aQCording to the fuel system,
- by wing type,
- by flight duration,
- at the practical flight ceiling,
- by type of aircraft,
- based on
- aQCording to flight rules,
- by the number of uses,
- by type of fuel tank,
- by radius of action,
- at maximum flight speed,
- by the number of engines,
- by use,
- by the direction of lift/landing,
- by type of lift/landing,
- by the time of receiving the collected information.

The type of control system determines the type of UAV. Remotely piloted aircraft are controlled directly by the operator within line of sight via a ground station. Remotely operated operate autonomously but can be controlled by a pilot using only feedback via other control subsystems. Automated flying machines perform pre-programmed actions. Remotely piloted aviation systems are controlled by embedded systems.

The mass of UAVs divides them into small-sized ones - up to 200 kg, medium-sized ones - 200-2000 kg, large-sized ones - 2000-5000 kg, heavy ones - more than 5000 kg.

AQCording to the scale of the tasks to be solved, UAVs are divided into tactical, that is, their flight range does not exceed 80 km, operational-tactical - up to 300 km, operational-strategic - up to 700 km.

The UAV fuel system divides them into the following types: mono-refueling - one-time refueling of the fuel system, which is carried out in industrial conditions by the manufacturer at the factory, multi-refueling - multiple refueling, which can, in turn, be ground - performed on the ground, platform - sea (on board sea vessel) and onboard (on board a manned aircraft).

AQCording to the type of wing, UAVs are divided into fixed - aircraft (ensures a flight speed of about 50-60 km/h) and helicopter (ensures a flight speed of about 100 km/h) types, floating - used in convertibles (allows vertical takeoff/landing and has the ability physically turn engines or propellers 90 degrees to create vertical lift or horizontal thrust).

The duration of the UAV flight is different and divides them into short duration - less than 6 hours, medium duration - 6-12 hours, long duration - more than 12 hours.

The practical flight ceiling of UAVs is divided into low-altitude - less than 1 km, medium-altitude - 1-4 km, high-altitude - 4-12 km, stratospheric - more than 12 km.

By type, aircraft are divided into airplane and helicopters aerodynamics and lighter than air.

Based on their base, UAVs are divided into land-based, which move on the earth's surface, marine, oriented to work in the water environment, and space-oriented, oriented to space.

AQCording to flight rules, UAVs are divided into visual ones, if they are located and fly within the line of sight of the pilot who controls and controls them during daylight hours (5 km); instrument, if the flight is performed in automatic mode not only within the visible zone, but also in blind zones in the dark time of day (more than 150 km); visual instrument, when visual and instrument methods are used during the flight (5 - 150 km).

AQCording to the number of uses, UAVs are divided into disposable, if no landing system is provided, and reusable, which are used a large number of times (more than 10 times) and can solve various tasks.

The range of UAVs varies widely. There are five main types: short range - up to 40 km, small - up to 70 km, medium - up to 300 km, long range - up to 1500 km, long range - at least 1500 km.

AQCording to the maximum flight speed, UAVs are divided into low speed - up to 100 km/h, low speed - from 100 to 300 km/h, medium speed - from 300 to 600 km/h, supersonic - exceeding the speed of sound up to 5 times.

AQCording to the number of engines, UAVs are divided into single-engine, twin-engine, multi-engine, and single-engine.

UAVs are widely used in all spheres of human activity, which can generally be divided into: military and civilian.

UAVs are divided into horizontal and vertical aQCording to the direction of takeoff/landing.

By type of lift/landing: multilift/descent, airfield, deck, water.

UAV at the time of receiving collected information: in real time, periodically during communication sessions, after landing [3].

## 1.1UVS International classification

The International Association for Unmanned Aerial Systems UVSI (Association for Unmanned Vehicle Systems International, until 2004 it was called the European Association for Unmanned Systems - EURO UVS) proposed a universal classification of UAVs (Table 1), which combines many of the mentioned criteria.

*Table* 1

| Group | Category | Take-off mass, kg | Flight range, km | Flight height, m | Flight duration, hours |
|---|---|---|---|---|---|
| Small UAVs | Nano UAV | < 0,025 | < 1 | 100 | < 0,5 |
| | Micro UAV | < 5 | < 10 | 250 | 1 |
| | Mini UAV | 20 - 150 | < 30 | 150 - 300 | < 2 |
| | Light UAVs to control the front edge of defense | 25- 150 | 10 - 30 | 3000 | 2 - 4 |
| | Light UAVs with a short flight range | 50 – 250 | 30 -70 | 3000 | 3 - 6 |
| | Medium UAVs | 150-500 | 70 - 200 | 5000 | 6 - 10 |
| Tactical | Medium UAVs with a long flight duration | 500-1500 | >500 | 8000 | 10 - 18 |
| | Low-altitude UAVs for penetration into the depth of the enemy's defenses | 250 2500 | >250 | 50 - 9000 | 0,5 - 1 |
| | Low-altitude UAVs with a long flight duration | 15 - 25 | >500 | 3000 | >24 |
| | Medium-altitude UAVs with a long flight duration | 1000-500 | > 500 | 5000-8000 | 24 - 48 |
| | High-altitude UAVs with a long flight duration | 2500-5000 | > 2000 | 20000 | 24 - 48 |
| Strategic | Combat (strike) UAVs | >1000 | 1500 | 12000 | 2 |
| | UAVs equipped with a warhead | • | 300 | 4000 | 3 - 4 |
| | false targets UAVs | 150–500 | 0 - 500 | 50 - 5000 | < 4 |

The above classification currently applies to both existing and future models of UAVs under development. Basically, this classification was formed before 2000, when drones were just gaining popularity, but since then it has been revised many times. It can be considered established even now. In addition, many special types of devices with non-standard combinations of parameters are difficult to attribute to any of the types of UAVs.

## 1.2 Classification of UAVs by design

As you know, today there are a large number of types of UAVs, of different designs, designed for many different tasks.

In this section, we will look at the most famous of them, which have gained the most popularity and proved their superiority over other types.

There are the following types of UAVs, which differ in design and principle of operation, take-off / landing and purpose:

- Aircraft-type UAV
- Multirotor UAVs
- Aerostatic UAV
- Unmanned convertibles and hybrid models

Let's consider each of these types below.

### 1.2.1 Aircraft-type UAV

This type of apparatus is also known as fixed-wing UAV. The lifting force in them is created aerodynamically due to the pressure of the air that hits the fixed wing. Devices of this type, as a rule, are distinguished by long flight duration, high maximum flight height and high speed.

There is a wide variety of aircraft-type UAV subtypes, differing in the shape of the wing and fuselage. Practically all aircraft layout schemes and types of fuselages that are found in manned aviation are also applicable in unmanned.

Figure 1.1 shows the experimental Proteus multipurpose aircraft developed by the American company Scaled Composites. Both manned and unmanned versions of this aircraft have been developed. A feature of the design is the tandem layout of the wings. Its length is 17.1 m, rear wing span 28 m, ceiling height 16 km (with a load of 3.2 t), take-off weight 5.6 t, maximum speed 520 km / h (at an altitude of 10 km), flight duration up to 18 h. Power plant - two turbojet engines with a thrust of 10.2 kN.

Fig. 1.1 - Proteus aircraft


Figure 1.2 shows the RQ-4 Global Hawk reconnaissance UAV, developed by the American firm Teledyne Ryan Aeronautical, a subsidiary of Northrop Grumman. It is distinguished by an unusual shape of the fuselage, in the nose part of which radar, optical and clear equipment is placed. The device is made of composite materials based on carbon fiber and aluminum alloys, has a length of 13.5 m, a wingspan of 35 m, a take-off weight of about 15 tons, and is capable of carrying a payload weighing up to 900 kg. The RQ-4 Global Hawk can stay in the

air for up to 30 hours at an altitude of up to 18 km. The maximum speed is 640 km / h. The power plant is a turbojet engine with a traction force of 34.5 kN.


Fig 1.2 - БПЛА RQ-4 Global Hawk

Figure 1.3 shows the promising Kh-47B combat deck UAV, which is being developed by Northrop Grumman (USA). It has the shape of a wide curved letter "V" without a tail part. The wings can be folded, which is important for the limited deck area of an aircraft carrier. For flight control, the UAV is equipped with 6 working planes. Turbojet engine of the Canadian company Pratt amp. Whitney provides high speed flight of the drone and is located in the rear part of the device. The drone consists of four parts assembled from composite materials and connected approximately in the middle of the body. The aircraft has a length of 11.6 m, a wingspan of 18.9 m (9.4 m in the folded state), a weight of 6.3 t, a maximum take-off weight of 20.2 t. The cruising speed is 900 km / h. The radius of action is 3900 km The ceiling is 12.2 km. Presumably, the device will be adapted for refueling in the air. At the same time, the UAV will be ready, if necessary, to continuously perform the assigned combat task for 80 hours, which is an order of magnitude longer than the flight duration of combat aircraft with pilots.

Fig. 1.3 - Kh-47B UAV

Propellers that pull or push, as well as Impellers (bladed machines enclosed in a cylindrical casing - English: impeller, ducted fan, shrouded propeller) or jet engines are usually used as engines of aircraft-type devices.

Aircraft-type devices usually require a runway or launch catapults (Fig. 1.4). There are also aircraft UAVs of a light class that are launched "by hand". When landing, a runway, parachute or special catchers (cables, nets or stretchers) can be used

Fig. 1.4 - starting catapult

Take-offs and landings of traditional aircraft-type UAVs is a rather time-consuming and expensive process that requires the presence of special auxiliary means (airstrips, launch and landing devices), so developers of new equipment are increasingly turning to non-traditional aircraft UAV schemes, which allows for the creation of airfield-free unmanned systems. First of all, we are talking about vertical take-off and landing (VTOL) aircraft. Today, there are many types of ZPS devices. Many of these are hybrids of airplanes and helicopters, and are discussed in the next section. The same LVZP, which to a greater extent have the properties of an airplane than a helicopter, usually have a jet engine, an impeller, or small-sized propellers as a propellant. They can be conventionally divided by the position of the fuselage during takeoff and landing into machines with a vertical position of the fuselage (tailsitters, from English - tailsitter)

### 1.2.2. Multirotor (helicopter) systems

One of the most popular UAVs is a multicopter. UAVs with more than two main rotors belong to this group. Reactive moments are balanced by rotating the supporting screws in pairs in different directions or tilting the thrust vector of each screw in the desired direction. Unmanned Multicopters, as a rule, belong to the classes of mini- and micro-UAVs.

The main purpose of the Multicopter is photo and video recording of various objects, so they are usually equipped with controllable camera hangers. Multicopters are also used as devices for operational monitoring of the situation, carrying out agricultural work (for example, spraying), for the delivery of light cargo.

Fig. 1.5 – “Tricopter”

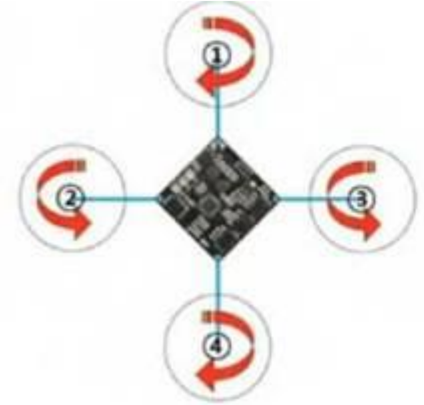

Fig. 1.6 - "+Copter"

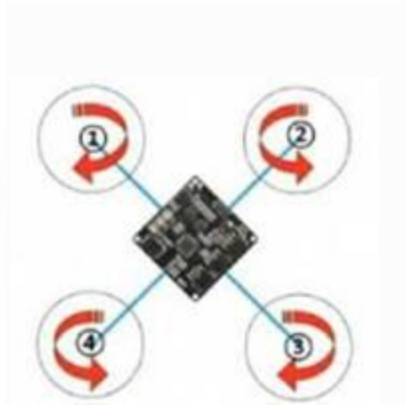

Fig. 1.7 - "XCopter"

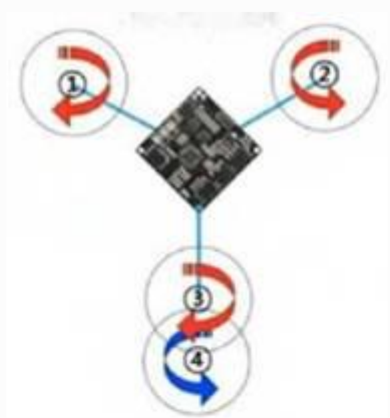

Fig 1.8 - “Y4Copter”

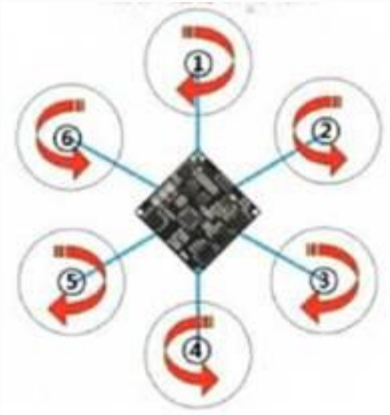

Fig 1.9 - “HexaCopter”

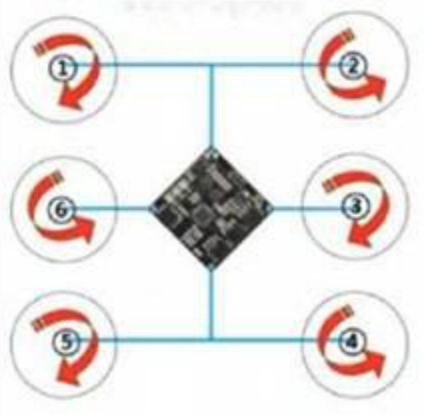

Fig 1.10 - “H6Copter”

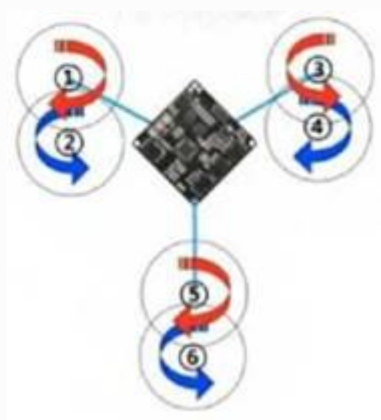

Fig. 1.11 - “Y6Copter”

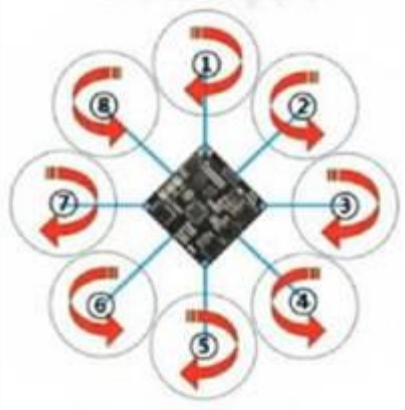

Fig. 1.12 - “OctoCopter”

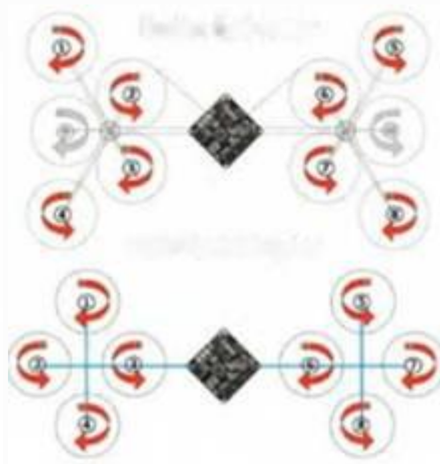

Fig. 1.13 -“ButterflyCopter”

Tricopter - the simplest scheme for building a Multicopter (Figure 1.14). Usually, a tricopter moves with two forward propellers, and the third is tail. The first two propellers have opposite directions of rotation and mutually compensate for the reactive twisting moments, the tail propeller does not have a couple, therefore, to compensate for its reactive moment, the axis of rotation of this propeller is slightly tilted in the direction opposite to the direction of twisting. This is done with the help of a special servo drive and traction, which are used to stabilize or control the position of the device along the course.

Fig. 1.14 - Example of a Tricopter

A quadcopter is the most common scheme for building a multicopter. The presence of four rigidly fixed rotors makes it possible to organize a fairly simple movement organization scheme. There are two such schemes of movement: scheme "+" and scheme "x". In the first case, one of the rotors is the front one, the opposite one is the rear one, and two rotors are the side ones. In the "x" scheme, the front two rotors are at the same time, the other two are the rear ones, and displacements in the lateral direction are also implemented simultaneously by a pair of corresponding rotors (Figure 1.15). The algorithm for controlling the rotation frequencies of the screws for the "+" scheme is somewhat simpler and clearer than for the " scheme x ", but the latter is used more and more often due to design advantages: with this scheme, it is easier to place the fuselage, which can have an elongated shape, the on-board video camera has a freer view.

Fig. 1.15 - Geoscan 401

Hexacopters and octocopters with 6 (figure 1. 16) and 8 (figure 1. 17) motors, respectively, have a much larger carrying capacity compared to a quadcopter. They are also able to maintain stable flight in case of failure of one engine. Such devices are also characterized by a much lower level of vibrations, which is especially important for video recording.

Fig. 1.16 - Octocopter Fig . 1.17 - Hexocopter

**1.3 Heavy quadrocopters**

Quadcopters with a large cargo capacity are called aircraft that can take off with additional weight to solve specific tasks. The main advantage is the ability to shoot in real time and get to hard-to-reach places.

The main characteristics that a cargo drone must meet are flight time and load capacity. These parameters affect the price of the device, so such quadcopters are used only in specific areas to perform certain tasks.

### 1.3.1 Features of heavy quadrocopter

In order for a quadcopter to be considered cargo, it is necessary to meet certain criteria:

- load capacity from 5 kg;
- cargo attachment device for attaching or capturing cargo (hook, chains, slings, cargo compartments, manipulators, etc.);
- increased number of engines to ensure greater stability and power of the quadcopter;
- appropriate sizes to ensure versatility;
- increased requirements for the quality and capacity of the battery to increase the duration of the flight;
- the inertia of the change in the speed of rotation of the propellers.

Some models may have a parachute for soft landing in case of emergency situations (engine failure, low battery charge).

### 1.3.2 Difficulties of operation of a heavy quadrocopter

Increasing the carrying capacity of aircraft, one has to face the technical difficulties of ensuring safety and flight duration:

- weight restrictions - the large capacity of the drone complicates the maneuverability of the device and its duration of flight, which forces the use of lighter but stronger materials;
- battery capacity - the flight time depends on the weight of the cargo;
- buoyancy of the device - the ability to resist the air flow and maintain balance;
- weather conditions - quadcopters are unable to cope with precipitation and strong wind, and low temperatures drastically reduce the battery charge;
- flight duration - the greater the weight, the faster the quadcopter consumes

energy;

- security - difficulties in tracking the location of the device increase the interception of valuable cargo by criminals;
- reliability - flights are conducted far from mass gatherings of people, as there is no 100% guarantee that the drone will not fall on your head;
- territorial restriction - flight locations are limited to private territories where the drone can be shot down

### 1.3.3 Areas of appliaction

When using a quadcopter with a large carrying capacity for professional purposes, it is necessary to take into aQCount the skill of piloting, which allows you to perform various maneuvers.

The greatest demand among the areas of application of cargo drones is:

- Delivery - the possibility of transporting fragile cargo.
- Filming - use of heavy equipment (for films, clips, commercials).
- Medical transportation - automation of the process of delivery of analyzes to the laboratory with the possibility of notifying recipients.
- Agriculture - treatment of agricultural land with chemical preparations.
- Help in rescue operations - copters allow you to inspect hard-to-reach areas and conduct search operations.

### 1.3.4 Main representatives

The cargo copter market is constantly expanding, presenting models with increased payload and flight duration. The most common and reliable cargo quadcopters are:

DJI Matrice 600 Pro (Fig. 1.18) is a device compatible with various cameras. Comes with 6 batteries that provide 16 minutes of flight with a maximum weight of 15 kg. The device is able to develop a speed of up to 65 km / h. A good bonus is a folding case.

Fig. 1.18 DJI Matrice 600 Pro

Freefly ALTA 8 (Fig. 1.19) is a copter with good maneuverability, equipped with a carbon fiber frame. The device with a carrying capacity of up to 8 kg can fly about 1.5 km. The package includes a special container for transportation. Cameras are attached to the copter from above and below.

Fig. 1.19 Freefly ALTA 8

AZ 4K UHD Camera Drone Green Bee 1200 (Fig. 1.20) is a classic copter with increased power, which has a wide frame and good maneuverability with 4 propellers. The device can stay in the air for about 20 minutes, while lifting up to 20 kg.

Fig. 1.20 AZ 4K UHD Camera Drone Green Bee 1200

Vulcan UAV Black Widow (Fig. 1.21) is a copter with a flexible modular system that allows you to install the chassis and adjust the battery compartment. It is available in OKTO (X8) and hexa (X6) configurations.

Fig. 1.21 Vulcan UAV Black Widow

DJI S1000 (Fig. 1.22) is a copter made on the basis of eight rotors made of carbon fiber, which is capable of lifting up to 6 kg. A feature is the ability to carry cargo almost automatically without landing to transfer the parcel (This information is based on Cargo Delivery technology). The device has a stable signal at a distance of up to 10 km and works on an 18-channel protocol in the field of FPV, which allows remote control. A powerful and light battery (22000 mAh) allows you to fly with a full load for 13 minutes. The control panel is equipped with Frsky technology, which makes it possible to program the device for actions in emergency situations.

Another feature is the ability to lay out a route on a three-dimensional map to pre-specified points with further adjustment of speed, altitude and flight course.

Fig. 1.22 DJI S1000

It is for a heavy quadcopter that it is proposed to develop a self-propelled aerial vehicle in flight, taking into aQCount the peculiarities of its dynamics.

## CHAPTER 2.
## ANALYSIS OF DIFFERENCES IN FLIGHT CONTROL OF A QUADROCOPTER AND HELICOPTER.

Despite the fact that initially drones were developed for military purposes, are used in reconnaissance operations and are active participants in hostilities, these rotorcraft have also found peaceful use.

Quadcopters have gained the most popularity. Mobile four-screw drones are often equipped with a video camera, so they are actively used by search and rescue teams, special services and the police, as well as when filming documentaries and feature films. Thanks to Bluetooth and Wi-Fi technologies, aircrafts, being tens or hundreds of meters from the pilot, can rise to a great height for photo and video shooting or surveying the surroundings inaQCessible to humans. Powerful quadcopter models, as well as their six-winged hexacopter counterparts, are already being used to transport cargo. For example, Amazon uses drones to deliver goods, is developing a project to create a tower that will be the starting point for courier drones, and is also working on creating a special design of flying transporters. The Swiss Post actively uses a similar delivery system. Thanks to drones, correspondence is delivered to hard-to-reach villages.

The fire service also appreciated the advantages of nimble and fast drones. The multicopter is used to detect and destroy fires. Such a "firefighter" will not lose control due to increased smoke or carbon monoxide poisoning.

Quadrocopter (QC) is an unmanned aerial vehicle with four lifting propellers. Unlike a helicopter, in which an inclined washer is used for control, which changes the direction of thrust of the lifting rotor, as well as the joint pitch and, aQCordingly, the amount of thrust of the main rotor, in KK the direction of thrust relative to the body and the pitch of the rotor blades are unchanged.

To change the flight height, the QC synchronously changes the rotation speed and, aQCordingly, the amount of thrust of all four rotors. And for horizontal movement, the QC changes its angular orientation (roll and pitch angles), while the horizontal components of the rotor thrust change, and the QC velocity vector rotates in the horizontal plane. To change roll and pitch angles, corresponding control moments are created by changing the rotation speeds of various rotors. To compensate for the reactive moments of the rotors, the opposite direction of rotation of individual pairs of rotors is used. A change in the rotation speed of these pairs distorts the compensation condition and creates a control moment of the search. Thus, the QC control is reduced to the control of the rotor rotation speed, which greatly simplifies the design of the control system.

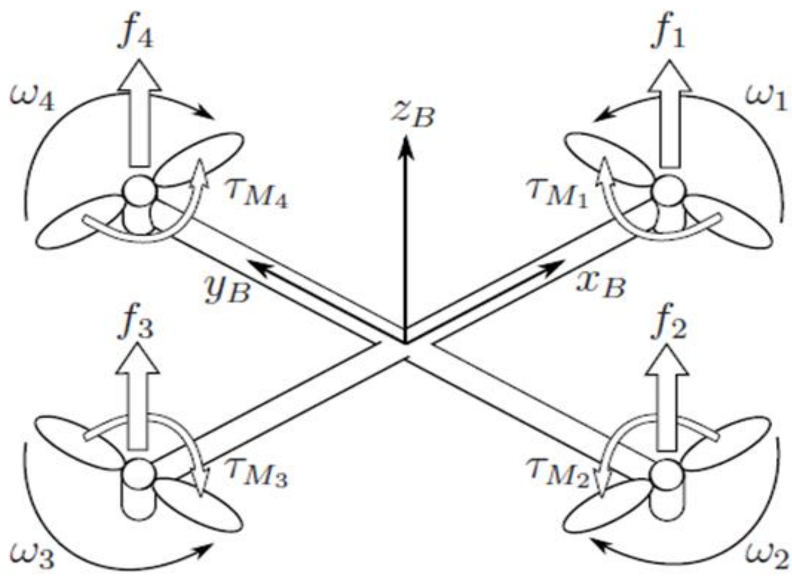


Fig. 2.1 structure of the quadcopter

The difficulty of controlling the drone depends on the flight mode. According to the most popular classification, several main types of drone control can be distinguished:

**Manual mode**. It is considered the most difficult, because every action of the quadcopter in flight is performed at the command of a person. That is why this mode is not suitable for beginners who are just learning the basics of controlling a copter. Despite the almost complete shutdown of automation, the drone still slightly adjusts human actions, but does not take away full control. Thanks to this, you can do various tricks that the system could consider dangerous for the equipment.

**A mode that uses built-in stabilization**, or Attitude. In this mode, the drone is controlled not only by the pilot, but also by the built-in system. Sensors, gyroscopes, accelerometers, etc. are used for this. They read the position of the quadcopter, and if something is wrong, they adjust the flight. This is especially useful if the camera is filming, and the unstable state of the copter can spoil the picture. True, this mode has its drawbacks - the control is so automated that it will be impossible to perform various tricks with the copter.

**GPS mode**. It works thanks to the satellite navigation system. In this case, the flight mode is set in advance, and there is no need to deal with the control as such. One of the advantages of this mode is the ability to call the drone in advance. Some quadcopters have a Return to home function. It will help you return the device home as soon as the signal is lost. GPS allows the equipment to hang at one point, even if you let go of the control panel. This is a great solution if the camera is shooting.

CareFree or HeadFree. A mode where the device flies relative to its location, not to the location of the person controlling it.

Currently, quadcopters are used quite widely and in a variety of ways, but this use is limited mainly to "manual" remote control modes from the operator's remote control. The task of developing a control system that allows autonomous flight of a quadcopter along a given route is urgent.

# CHAPTER 3.
# QUADROCOPTER INFORMATION AND CONTROL COMPLEX.

The on-board information and control complex is a full-fledged means of navigation and control of UAVs. The composition and structure of the information and control complex (IQC) may change depending on the type of aircraft and its functional purpose. However, they should all provide solutions to the following problems:

- determination of navigation parameters, orientation angles and UAV movement parameters (angular velocities and accelerations);
- navigation and control of the UAV when flying along a given trajectory;
- transmission of telemetric information about navigation parameters, orientation angles of the UAV to the transmission channel;
- stabilization of UAV orientation angles in flight;
- programmable payload management.

UAVs are known to have significant angular velocities and accelerations. This frequently updates the information in IQC and imposes strict requirements on the software and algorithms being developed. All modern navigation and orientation systems can be used with the most complete objects, such as inertial, satellite, aerometric, radiotechnical, etc.

Taking these characteristics into account leads to specific IQC properties in UAVs. In connection with the need to increase the accuracy and safety of navigation when solving target tasks, it is necessary to use a large number of navigation devices and navigation systems on moving objects.

Combining individual systems into navigation complexes and the joint use of information not only improves the accuracy and reliability of data on system parameters and conditions, but also improves road traffic safety. At the same time, the diversity of systems causes problems in the organization of connections in the complex and significantly complicates its structure.

An effective solution to these problems is possible through the creation of integrated equipment, with all the advantages of complex systems, but advantageously differs from them due to the wide use of common data transmission buses, a single technological base and a single structural design. Using the concept of integrated systems allows you to significantly improve the mass-dimensional characteristics of modern IQCs, reduce energy consumption and increase reliability.

The main advantages of integrated systems are listed in Table 2.1.

Table 2.1

| Factors | Quantitative changes |
|---|---|
| Precision | A significant increase |
| Mass | 30-70% reduction |
| Volume | 50-60% reduction |
| Power consumption | 25-50% reduction |
| Reliability | An increase of about 2 times |
| Reservation rate | An increase of 50% or more |
| Quality/cost | A significant increase |

Therefore, the UAV IQC usually includes three constituent elements:

- integrated navigation system;
- satellite navigation system receiver;
- autopilot module.

Such an IQC scheme can be presented in Fig. 3.1.

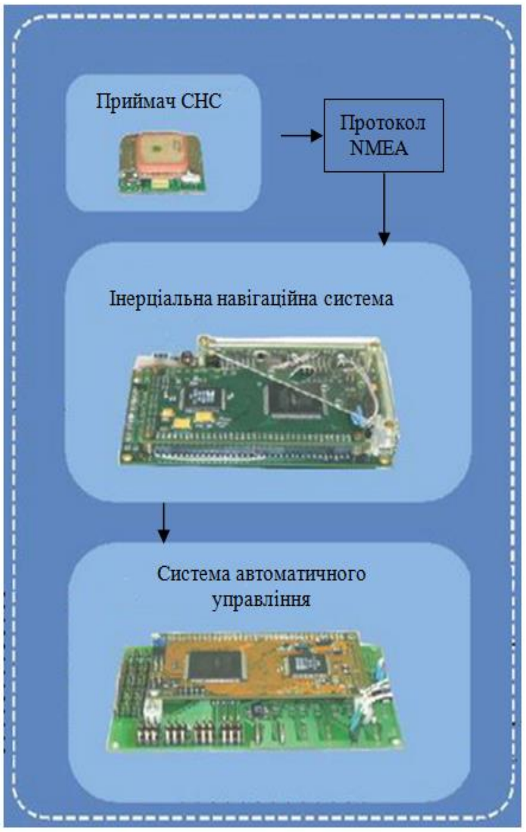


Fig. 3.1

The SNS receiver provides the determination of the coordinates of the location of the object, the height above sea level, the path angle and the path speed. The receiver transmits this data in NMEA format (text communication protocol) to the navigation system.

The integrated inertial navigation system includes sensitive elements integrated into a fully functional inertial navigation system, which is adjusted according to SNA data. The system measures pilotage and navigation parameters of the UAV movement and transfers these parameters to the autopilot module.

It is possible to give an example of operational parameters of UAV IQC according to the data of TeKnol LLC in the form of a table (table 2.2):

Таблиця 2.2

| | |
|---|---|
| Physical characteristics | |
| Hull size | 153×73×56мм |
| Waight | 320г |
| Working ranges | |
| Angular velocities | ±60º/сек |
| Normal acceleration | ±10g |
| pitch | ±50º |
| Heel | ±60º |
| Course | 0…360º |
| Height | 0…1000м |
| Electrical characteristics | |
| Supply voltage | 12…27В |
| Power consumption (max.) | 3,5Вт |
| Environment parameters | |
| Operating temperature range | -40ºC…+85ºC |
| Storage temperature | -40ºC…+85ºC |
| Humidity | 5%...98% |
| Physical influences | |
| Vibration/Shock | 2/20g |
| Peak acceleration | 4g (0,5м/сек) |
| Linear overloads | ±2g |

Technical and accuracy characteristics of the SNS receiver (table 2.3):

Table 2.3

| | |
|---|---|
| Receiver frequency | L1-1575,42 МГц |
| Number of channels | 12 |
| Receiver sensitivity | -170 dBW |
| Horizontal accuracy | 15м, 95% |
| Vertical accuracy | 30м, 95% |
| Coordinate update period | 1 sec. |
| Cold start | less than 45 seconds |
| Supply voltage | 10…30 В |
| Output ports | one RS-232 for issuing GPS data |
| Power consumption | no more than 1.5 W |

The exact characteristics of the inertial navigation system, which were obtained as a result of flight tests of the KompaNav-2 MINS, are presented in table 2.4:

Table 2.4

| | INS/SNS mode | Autonomous inertial mode |
|---|---|---|
| Coordinates | 6 м | 500 m (5 minutes after the GPS disappears) |
| Height | 2 м | 6 м |
| Road speed | 0,2 м/с | 5 м/с (5 хв. після зникнення GPS) |
| Vertical speed | 0,25 м/с | 0,3 м/с |
| Orientation angles (roll, pitch) | | |
| Straight flight | 0,2º…0,3 º | 0.3º...0.4º (unlimited time) |
| Maneuvering | 0,3º…0,5 º | 0,5º…0,7º ((unlimited time)) |
| **High** | 1,3º | 1,5º (unlimited time) |

| | | |
|---|---|---|
| **maneuverability flight** | | |
| Course (track angle) | 0,4º | 3.0º (10 min. after the disappearance of the GPS) |

The task of developing a control system that allows the autonomous flight of the quadcopter along a given route is relevant in the design of IQC UAV.

## 3.1. STRUCTURAL DIAGRAM OF THE AUTOMATIC QUADROCOPTER CONTROL SYSTEM

The task of controlling the flight of a quadcopter can be considered as a sequence of tasks of flying to the next set point of the route or moving along set sections of typical trajectories (for example, along a straight line or an arc of a circle). In this case, the automatic control system can be built as a feedback system that tracks a given route. At the same time, it is possible to distinguish the height control channel and the movement control channel in the horizontal plane. Stabilization and control in the vertical direction is provided by changing the total amount of thrust. the horizontal movement of the device occurs under the action of the horizontal projection of the total thrust vector deviated from the vertical. In this version, the deviation of the thrust vector occurs due to a change in the pitch and roll angles at a fixed position of the yaw angle. The change in angular position is achieved by differential control of the rotation speeds of the screws, which gives corresponding differences in their traction forces and moments. The subsystem that provides the necessary values of the angular parameters and height due to the change in thrust of the propellers can be called the orientation and stabilization system, and the subsystem that tracks the given trajectories is the trajectory control system. It should be noted that this option is not the most effective, but it most clearly implements division channel management.

The structure of the control system is shown in Fig. 3.2, where numbers indicate: 1 - setter; 2 - corrective devices of the trajectory control subsystem; 3 - coordinate converter; 4 - regulator of the orientation and stabilization subsystem; 5 - signal distributor; 6 - voltage limiter; 7 - propeller group; 8 - quadrocopter.

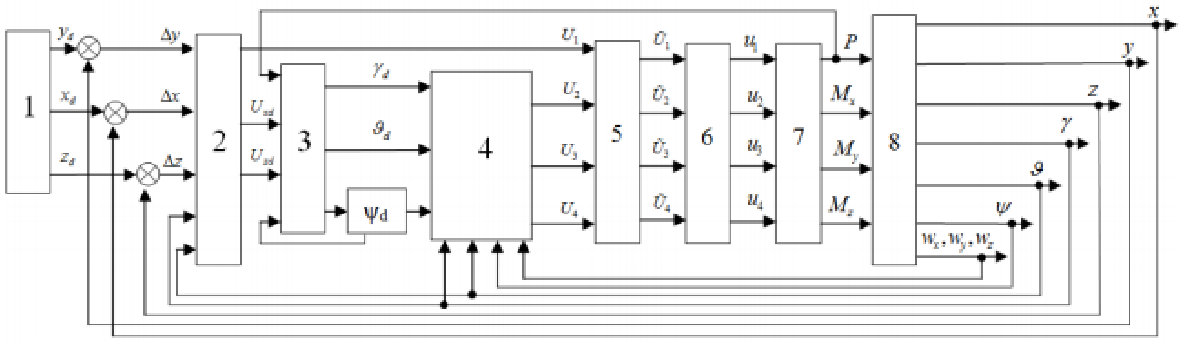

Fig. 3.2

The information system that measures the current movement parameters of the quadcopter is the inertial navigation system, which is corrected from the satellite system.

The control forces and moments of the quadcopter are formed with the help of four DC motors, which constantly rotate the propellers installed on their rotors. Control voltages to the motors are supplied through a signal distributor and voltage limiters. It is proposed to use direct current motors of type X22I2 KV980 in the ACS, which are most often used for multirotor systems (copters) and airplanes. For the selected engine. in the operating range of speeds, the input voltages are limited to values from 0 to 11.1 V.

It is suggested to calculate the work algorithms of the stabilization and trajectory control subsystems by one of the known methods, and it is better to choose those that are the simplest with comparable quality. Therefore, for each of the subsystems, the calculation of corrective devices in the form of PID regulators and the method known in the literature as "backstepping" (English backstepping) was carried out, after which, by comparing the results, the most suitable regulator was selected for each of the subsystems.

To avoid repetition in the presentation, the calculation of the regulators for each of the subsystems is shown on the example of one of the methods: "backstepping" - for the angular position stabilization algorithm; PID controllers - for the trajectory tracking algorithm.

As a technical toolkit for the system design process of the quadcopter flight control system, a corresponding mathematical model of the quadcopter flight under the control of the ACS is always used.

The work will consider a mathematical model of the controlled flight of a quadcopter in space, which allows to carry out design studies of the structure of the ACS, which takes into account the peculiarity of the closed loop of the flight control: the presence of a common executive body (a set of four traction electric motors) for the control loops of the flight along three mutually perpendicular axes.

## CHAPTER 4.
## MATHEMATICAL MODELS OF A QUADROCOPTER AS A CONTROL OBJECT.

The mathematical model of the quadcopter should be simple enough for research, so the following assumptions are made when obtaining it:

- quadrocopter is a solid body with constant inertial mass characteristics;
- the axes of the linked coordinate system (SC) of the quadcopter coincide with the main axes of inertia;
- The Earth is flat, does not rotate and does not move in inertial space;
- wind is taken into account as an external disturbance.

The equations of motion QC can be obtained from the basic laws of classical mechanics, which in vector form have the form:

$$m\frac{d\vec{V}}{dt}=\vec{F}; \tag{5.1}$$

$$\frac{d\vec{K}}{dt}=\vec{M}\ , \tag{5.2}$$

here m is the mass of the quadcopter; - air speed vector; - vector of forces acting on the quadcopter; - moment vector of the amount of motion; - moments acting on the quadcopter.

By projecting the vector equations (1 ... 2) on the axis of the connected SC, according to the rule of differentiation of the vector specified in the moving SC (Boer's rule), a system of differential equations is obtained that describes the spatial movement of the quadcopter as a rigid body with six degrees of freedom.

$$
\begin{aligned}
& m\left(\dot{V}_x+\omega_y V_z-\omega_z V_y\right)=F_x; \\
& m\left(\dot{V}_y+\omega_z V_x-\omega_x V_z\right)=F_y; \\
& m\left(\dot{V}_z+\omega_x V_y-\omega_y V_x\right)=F_z; \\
& \dot{K}_x+\omega_y K_z-\omega_z K_y=M_x; \\
& \dot{K}_y+\omega_z K_x-\omega_x K_z=M_y; \\
& \dot{K}_z+\omega_x K_y-\omega_y K_x=M_z,
\end{aligned} \tag{3}
$$

In the connected SC, the moment equations are simplified, because in this case the centrifugal moments of inertia Ixy, Iyz, Izx are equal to zero, and the projections of the moment of the amount of motion on the axis of the connected SC coordinates acquire a simple form

$$
K_x=I_x\omega_x;\quad K_y=I_y\omega_y;\quad K_z=I_z\omega_z, \tag{4}
$$

where Ix, Iy, Iz axial moments of inertia; $\omega_x$, $\omega_y$, $\omega_z$ projections of the vector of the angular velocity of rotation of the aircraft on the axis of the connected SC.

Considering (4), the moment equations in (3) will have the following form:

$$
\begin{aligned}
& I_x\dot{\omega}_x+(I_z-I_y)\omega_z\omega_y=M_x; \\
& I_y\dot{\omega}_y+(I_x-I_z)\omega_x\omega_z=M_y; \\
& I_z\dot{\omega}_z+(I_y-I_x)\omega_y\omega_x=M_z.
\end{aligned} \tag{5}
$$

But it is more expedient to write the force equations in the normal coordinate system OXgYgZg, which does not rotate. In a normal SC, the OYg axis is directed upward along the local vertical, and the direction of the OXg and OZg OZg axes is chosen according to the tasks. In the absence of rotation, the force equations in (3) take the form:

$$
\begin{aligned}
& m\dot{V}_{x_g}=F_{x_g}; \\
& m\dot{V}_{y_g}=F_{y_g}; \\
& m\dot{V}_{z_g}=F_{z_g}.
\end{aligned}
$$

Let's supplement this system with ratios describing changes in rotation speeds $\Omega_{1\text{-}4}$ and, accordingly, the thrusts T1-4 of the four supporting screws:

$$J_\omega \dot{\Omega}_i = M_{\text{tor}_i}; \qquad i = 1...4$$
$$T_i = c_T \Omega_i^2;$$

where $J_\omega$ – moments of inertia (same for all screws); $\left(M_{\text{tor}_i} = M_{\text{mot}_i} - M_{\text{sh}_i}\right)$– moments on the shafts of the supporting screws; $\left[M_{\text{mot}_i}(u_i)\right]$ – control moments $u_i$, created by propeller engines; $\left[M_{\text{sh}_i}(\Omega_i, V_{y_g})\right]$– moments of load on the shafts of the supporting screws; $c_T$ – the thrust coefficient of each main propeller, which depends on its geometric characteristics and on the air density ρ, that is, on the flight height H. When the propellers are blown obliquely, the thrust coefficient increases. So $c_T = f(H, V_{x_g})$

Supplementing the obtained equations with kinematic and geometric relations, as well as equations describing the trajectory movement of the center of mass, we will obtain a closed system of equations describing the spatial movement of QC.

Based on the systems of equations (1) and (3), a block diagram of the mathematical model of the linear motion of the CM quadcopter in space is formed, which is shown in Fig. 4.1.

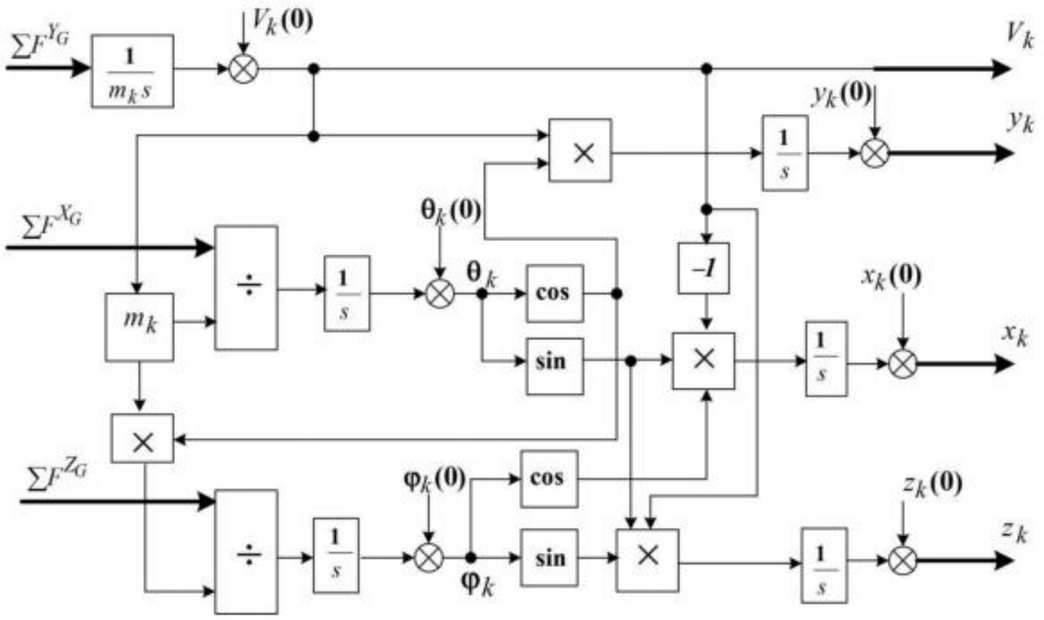


Fig. 4.1

And on the basis of the systems of equations (3) and (5), the block diagram of the mathematical model of the rotational movement of the quadcopter around the CM is shown in Fig. 4.2

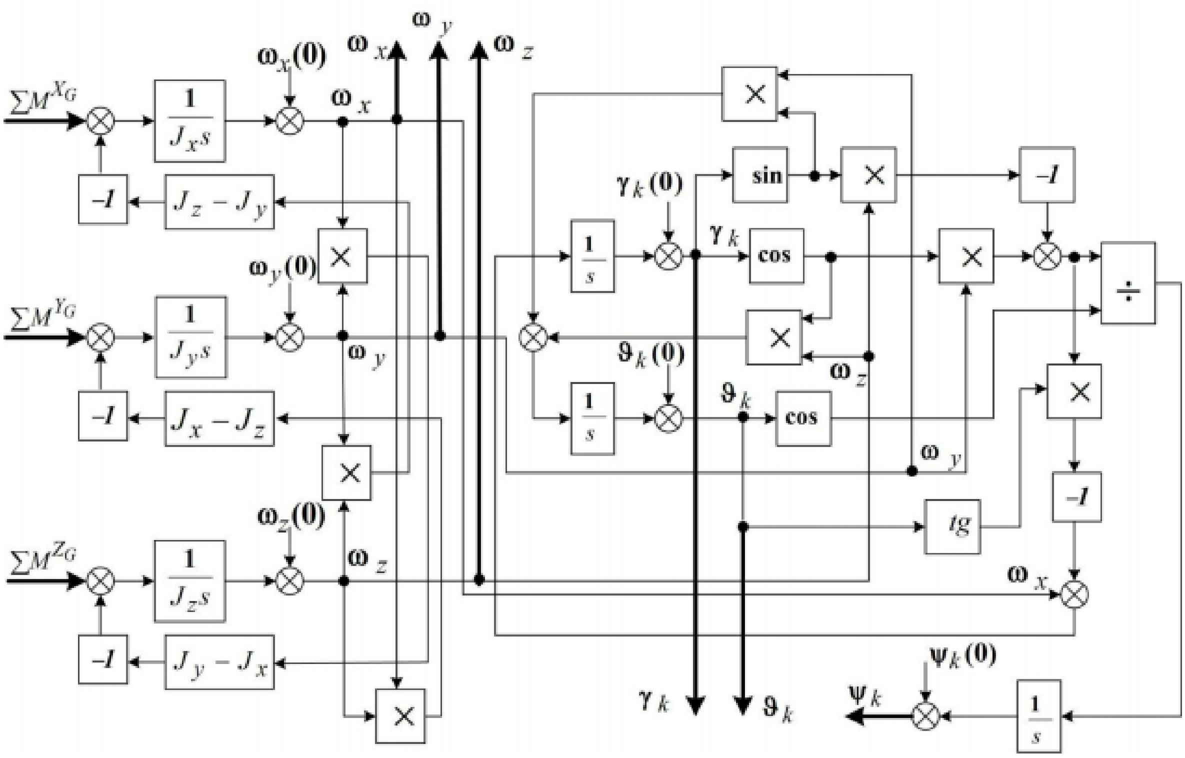

Fig. 4.2

All moments for the formation of the rotational movement of the quadcopter around its CM and forces for the formation of the translational movement of the quadcopter are formed due to the setting of the specified rotation speeds of the rotors of each of the supporting screws, and the magnitude of the force moments - due to the mutual ratios between these traction forces. Setting the specified rotation speeds is implemented with the help of speed stabilization drives (PSSh). The structural diagram of PSSh i based on direct current motors (DC motors) is shown in fig. 1.6,

where: $k_{vz}$, $k_{ui}$, $c_{mi}$, $c_e$ , $R_{ai}$, $L_{ai}$ - air viscosity coefficient, electronic and electromechanical amplification, EMF resistance coefficient, electrical parameters of the DPT winding; $J_{ni}$ - moment of inertia of rotating parts; $T_{ai}$ - electromagnetic time constant of DPS i; M (with subscripts) - DPS moment, moment applied to the propeller and DPS reaction moment; k (with subscripts), – scale factor of the corresponding sensors; $k_{kori}$ $T_{kori}$ – amplification factor and time constant of the correction link.

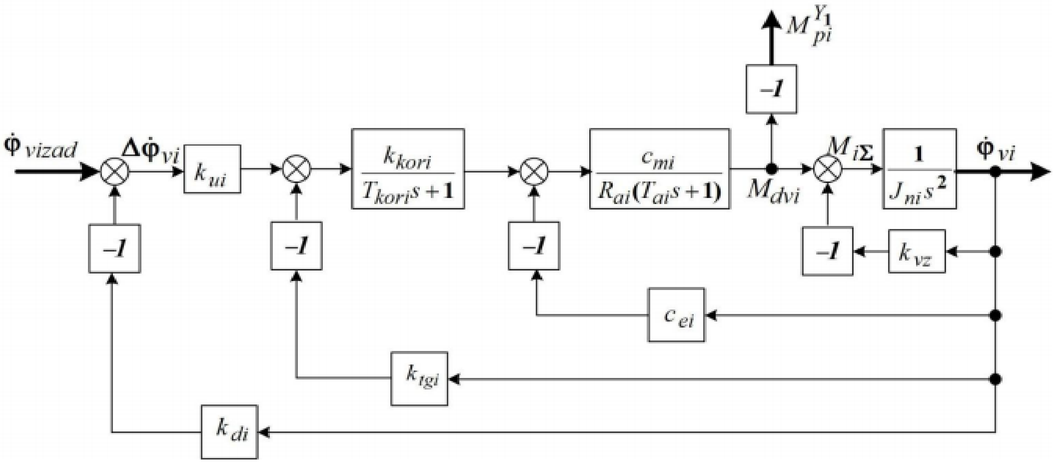


Fig. 4.3

When creating a mathematical model of the quadcopter flight, we will take into account the moments of forces acting on the quadcopter:

- the differential thrust of the supporting screws creates roll and pitch moments;
- the difference in the moments of reaction of the bearing screws creates the moment of yaw and the projection of the traction force vector in the normal coordinate system.

The block diagram of the mathematical model of the control forces and moments acting on the quadcopter is shown in Fig. 4.4, and Fig. 4.5 - the general block diagram of the MM of the control object

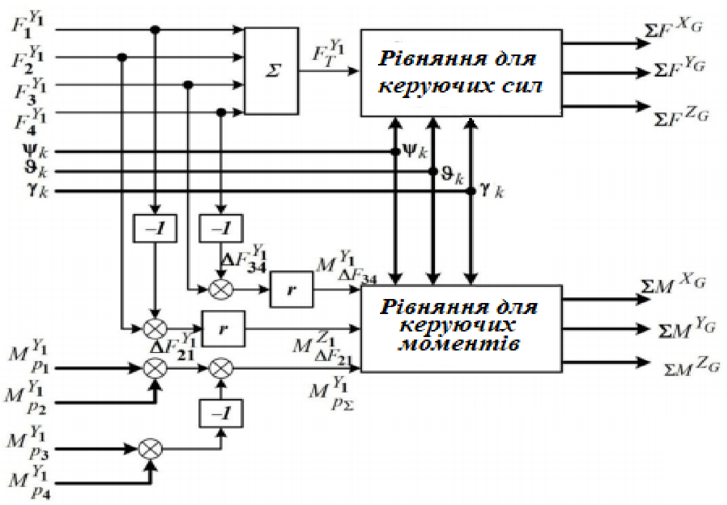


Fig. 4.4

However, some research tasks of the controlled movement of a quadcopter can be carried out using mathematical models of isolated longitudinal or lateral movement.

A closed system of equations describing the longitudinal motion of the quadcopter can be extracted from the full system of equations, provided that the parameters of the lateral movement, as well as the actions controlling roll and yaw, are equal to zero. Then the system of equations describing the isolated longitudinal movement of the quadcopter is reduced to the form:

$$
\begin{aligned}
&m\dot{V}_{x_g} = F_{x_g};\\
&m\dot{V}_{y_g} = F_{y_g};\\
&I_z\dot{\omega}_z = M_z;\\
&\dot{\vartheta} = \omega_z;\\
&\dot{Y}_g = \dot{H} = V\sin\Theta;\\
&\dot{X}_g = V\cos\Theta,\\
&J_{\omega}\dot{\Omega}_i = M_{\text{tor}\,i}; \qquad i = 1...4\\
&T_i = c_T\Omega_i^2;
\end{aligned}
$$

Revealing the right-hand components of the force equations, we note that the flight speed components change $V_{x_g}$ та $V_{y_g}$ occurs under the influence of the components of the traction force $T = \sum_{i=1}^{i=4} T_i$ (control influences), gravity G, as well as the aerodynamic resistance force of the quadcopter fuselage and the captured area of the main rotors.

The resistance of the fuselage in comparison with the aerodynamic resistance force of the captured area of the main rotors is small, it is 3..5% of the thrust, so it can be neglected in the mathematical model. The drag force vector of the captured area of the propellers R is opposite to the air speed vector of the quadcopter. The value R is proportional to the characteristic area S, the air density ρ and the square of the speed V and depends on the angle of attack of the plane of the propellers □, which is the angle between the plane of rotation of the propellers and the projection of the air velocity vector on the plane of symmetry. Since the quadcopter moves in the air in any direction, the angle of attack of the main propellers can vary within ± 180 °.

Thus, the projections of the force vector on the axis of the normal CK have the form:

$$F_{x_g} = T(H, V_{x_g}, V_{y_g})\sin\vartheta - R(H, V, \alpha)\sin\Theta;$$
$$F_{y_g} = T(H, V_{x_g}, V_{y_g})\cos\vartheta - G - R(H, V, \alpha)\cos\Theta,$$

where Θ - angle of inclination of the trajectory.

Airspeed V and angular parameters Θ i α□can be obtained from ratios:

$$V = \sqrt{V_{x_g}^2 + V_{y_g}^2}; \quad \Theta = \mathrm{arctg}\frac{V_{y_g}}{V_{x_g}}; \quad \alpha = \vartheta - \Theta.$$

The components of the moment Mz acting on the quadcopter are:

- the control moment Mz(u), which is created by the difference between the thrusts of the front T1 and rear rotors T2 - $M_z(u) = (T_1 - T_2)l$, (l - distance from the rotor axis of the main rotor to the center of mass of the quadcopter);

- the moment of its own aerodynamic damping $M_z(\omega_z)$.

For further simplification, the quadcopter model can be linearized using the control effects as input data and the center of mass coordinates and angular coordinates as output data. As an undisturbed (programmed) movement, it is advisable to choose a straight horizontal flight with a constant speed, assuming that the pitch angle is equal to the angle of attack.

In contrast to known mathematical models, the obtained models take into account the inertia of the change in the speed of rotation of the propellers, which is a feature of heavy quadcopters.

In the work, linearized mathematical models of the longitudinal movement of the quadcopter, taking into account the inertia of the change in the speed of rotation of the propellers, and mathematical models that do not take into account this inertia, were obtained for the purpose of comparative research.

These mathematical models are presented in the section "Research of automatic control circuits".

When researching the controlled movement of a quadcopter, in addition to the mathematical model of the control object, it is necessary to have a model of the automatic control system. The general block diagram of the mathematical model of the controlled spatial flight of the quadcopter is shown in Fig. 4.5

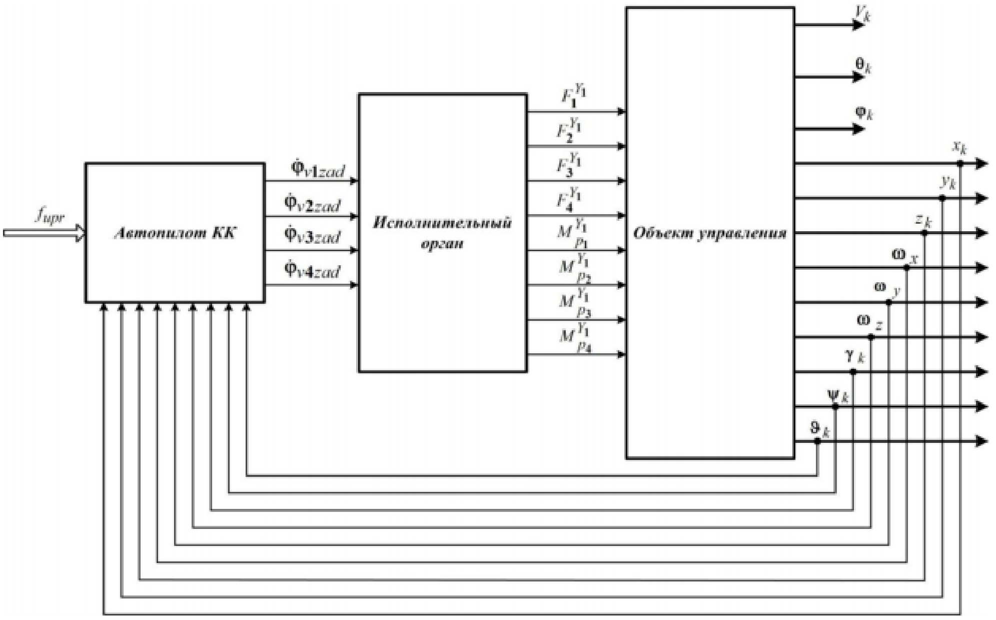


Fig. 4.5

# CHAPTER 5.

# SYNTHESIS OF CIRCUITS OF AUTOMATIC QUADROCOPTER MOVEMENT CONTROL.

The quadcopter has a symmetrical structure with four engines located on the beams along the axes of the connected coordinate system at a distance $l$ from the center of mass. The inertia matrix has the following form:

$$I_A = \begin{bmatrix} I_x & 0 & 0 \\ 0 & I_z & 0 \\ 0 & 0 & I_y \end{bmatrix},$$

where $Ix$, $Iy$, $Iz$ are moments of inertia during rotation along the respective axes, $Ix = Iz$.

A quadcopter can be represented in the form of a ball with four balls attached to the ends of the rays, which represent engines. The model also takes into account the inertia of the screws, represented as rods, fixed in the middle on the axis of the screws perpendicular to them. In fig. 5.1 shows this view of the quadcopter.

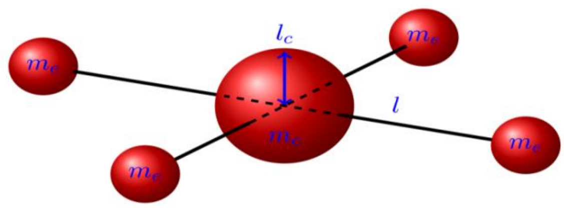


Fig.5.1

Inertia is calculated as follows:

where $mc$ is the mass of the center of the quadcopter; $lc$ - the radius of the center of the sphere, which describes the center of the quadcopter; $me$ - engine mass. It is also necessary to take into account the inertia of the motor rotor $Ir$:

$$I_r = \frac{1}{3} m_p R^2,$$

$$I_x = I_z = \frac{1}{2} m_c l_c^2 + 2 m_e l^2, \quad I_y = \frac{1}{2} m_c l_c^2 + 4 m_e l^2,$$

where $mp$ is the mass of the main screw, and $R$ is its radius. The total mass is calculated as the sum of all elements:

$$m = m_c + 4m_e + 4m_p.$$

The rotation of the motor rotor is described by the $\dot{\omega}_i = I_r(\tilde{\omega}_i - \omega_i)$, expression where $\tilde{\omega}_i$ - the desired speed determined by the speed controller on the quadcopter platform.

Two screws rotate clockwise, two counterclockwise, and their speeds are limited as $0 < \omega_{min} < \omega i < \omega_{max}$. In flight, the propeller cannot move in reverse, has rotational limits and cannot be stopped. In view of the relative smallness of the moment of inertia of the motor rotor $Ir$, the inertia of the motor is not taken into account.

Together, the forces of the four rotors create thrust $\tau_y$ in the direction of the vertical axis. Torque $\tau$ consists of moments $\tau_\gamma$, $\tau_\vartheta$ i $\tau_\psi$ in the direction corresponding to the rotation angle of the quadcopter reference system.

Let's introduce the formulas of the forces produced along the corresponding axes and angles of rotation:

$$\tau_y = k_l\,(\omega_1 + \omega_2 + \omega_3 + \omega_4),$$

where $a_r$ - table of rotational motion.

In addition, the quadcopter model must take into account the total speed $\omega R$, which is calculated as follows:

$$\omega_R = \omega_1 - \omega_2 + \omega_3 - \omega_4.$$

Recalculation of velocities, based on the specified influences, occurs according to the following formula:

$$\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_3\\ \omega_4\end{bmatrix} = \begin{bmatrix}\frac{1}{4} & 0 & -\frac{1}{2l} & -\frac{1}{4a_r}\\ \frac{1}{4} & -\frac{1}{2l} & 0 & \frac{1}{4a_r}\\ \frac{1}{4} & 0 & \frac{1}{2l} & -\frac{1}{4a_r}\\ \frac{1}{4} & \frac{1}{2l} & 0 & \frac{1}{4a_r}\end{bmatrix} \begin{bmatrix}\tau_y\\ \tau_\gamma\\ \tau_\vartheta\\ \tau_\psi\end{bmatrix}.$$

In the real system, there are various aerodynamic effects, for example: the dependence of the thrust on the angle of attack, the interaction of the propeller blades and the air flow. A model that takes these factors into account is highly complex and contains a large number of parameters that are difficult to calculate. Therefore, at the stage of synthesis of control algorithms, these factors will be neglected, their significance for the behavior of the system will be determined as a result of experimental studies.

Based on the materials of the previous section, we will form a set of equations that fully describe the dynamics of the quadcopter. The system looks as follows:

$$
\begin{aligned}
&m\dot{V}_x = \tau_y(C_\psi S_\vartheta C_\gamma + S_\psi S_\gamma) - V_x A_x,\\
&m\dot{V}_y = -mg + \tau_y(C_\vartheta C_\gamma) - V_y A_y,\\
&m\dot{V}_z = \tau_y(S_\psi S_\vartheta C_\gamma - C_\psi S_\gamma) - V_z A_z,\\
&\dot{\gamma} = \omega_x + S_\gamma T_\vartheta \omega_z + C_\gamma T_\vartheta \omega_y,\\
&\dot{\vartheta} = C_\gamma \omega_z - S_\gamma \omega_y,\\
&\dot{\psi} = \frac{S_\gamma}{C_\vartheta}\omega_z + \frac{C_\gamma}{C_\vartheta}\omega_y,\\
&I_x\dot{\omega}_x = (I_y - I_z)\omega_y\omega_z - I_r\omega_z\omega_r + \tau_\gamma,\\
&I_y\dot{\omega}_y = (I_z - I_x)\omega_x\omega_z + \tau_\psi,\\
&I_z\dot{\omega}_z = (I_x - I_y)\omega_x\omega_y + I_r\omega_x\omega_r + \tau_\vartheta,
\end{aligned}
$$

where $Vx$, $Vy$, $Vz$ - linear speeds along the corresponding axes; $\omega x$, $\omega y$, $\omega z$ - angular velocities of rotation of the quadcopter around the respective axes; $Ax$, $Ay$, $Az$ - aerodynamic coefficients along the corresponding axes; $S_\alpha$ = sin(α), $C_\alpha$ = cos(α),

$T_\alpha$ = tg(α); $g$ - free fall acceleration.

The parameters of the mathematical model of the quadcopter are given in Table 5.1

*Таблиця* 5.1

| Parametr | Size | Parametr | Size | Dimensionality |
|---|---|---|---|---|
| Waight (kg) | | Coefficients | | |
| $m_c$ | 1 | $g$ | 9,81 | м/с$^2$ |
| $m_e$ | 0,1 | $k_l$ | $3{\cdot}10^{-6}$ | кг·м |
| $m_p$ | 0,01 | $a_r$ | 0,033 | кг·м |
| $m$ | 1,44 | $A_x$ | 0,25 | кг/с |
| Moments of inertia, (kg ·м$^2$) | | $A_y$ | 0,25 | кг/с |
| $I_x$ | 0,0151 | $A_z$ | 0,25 | кг/с |
| $I_y$ | 0,0253 | $l$ | 0,225 | м |
| $I_z$ | 0,0151 | $l_c$ | 0,1 | м |
| $I_r$ | $5{,}38{\cdot}10^{-5}$ | $R$ | 0,127 | м |

Let's linearize the quadcopter model using control influences as inputs, and height (coordinate $y$) and angles as outputs. We will linearize the system at the zero point, assuming that the angles γ, θ, ψ - small, the corresponding sines are close to zero and the cosines are close to unity. We also believe that all are reciprocal products of angular velocities $\omega_x$, $\omega_y$, $\omega_z$ are close to zero, as are the products $I_r\omega_x$, $I_r\omega_z$, because of smallness $I_r$. Finally, we will get a system of linearized equations describing the dynamics of the quadcopter movement.

$$m\ddot{y} = -mg + \tau_y - \dot{y}A_y,$$
$$\dot{\gamma} = \omega_x,$$
$$\dot{\vartheta} = \omega_z,$$
$$\dot{\psi} = \omega_y,$$
$$I_x\ddot{\gamma} = \tau_\gamma,$$
$$I_y\ddot{\vartheta} = \tau_\vartheta,$$
$$I_z\ddot{\psi} = \tau_\psi,$$

from where we get the following transfer functions from the inputs $\tau_y$, $\tau_\gamma$, $\tau_\vartheta$, $\tau_\psi$ to the exits $y$, γ, ϑ, ψ in accordance

$$W_y(s) = \frac{m^{-1}}{s(s + A_y m^{-1})},\ W_\gamma(s) = \frac{I_x^{-1}}{s^2},$$
$$W_\vartheta(s) = \frac{I_z^{-1}}{s^2},\ W_\psi(s) = \frac{I_y^{-1}}{s^2},$$

which describe the movement along the $OY$ axis and through the corners γ, θ, ψ ψ in accordance.

To control the movement of the quadcopter, we will use PD-regulators, since the P-regulator will make the angle control system oscillating, when using the PI-regulator, there will also be two complex roots in the angle control system, and with the PID-regulator, the order of the system increases to the third. To select coefficients, we will use the method of standard transient functions, based on the desired time of transient processes.

## 5.1 Synthesis using the method of modal control

For the synthesis of regulators, we use the modal control method. Since over-regulation during flight must be excluded, we set the desired characteristic polynomial of the closed system in the form of Newton's binomial $D(s) = s^2 + 2\omega_0 s + \omega_0^2$, де $\omega_0$ - parameter that determines the speed.

First, we will calculate the coefficients for vertical movement along the $OY$ axis, the process will be similar for other movements. Let it be necessary that the time of the transient process is 1 s, then the desired frequency $\omega_0$ = 4,8. Turning to the desired polynomial and solving the resulting equations, we find the proportional and differential coefficients of the regulator:

$K_p^y = 33{,}18$ и $K_d^y = 13{,}58$ in accordance. Coefficients for angles γ, θ, ψ are calculated similarly. The obtained data are summarized in Table 2.

| | ПД-регулятор | |
|---|---|---|
| | $K_p$ | $K_d$ |
| $z$ | 33,18 | 13,58 |
| $\psi$ | 0,58 | 0,24 |
| $\gamma$ | 0,35 | 0,14 |
| $\vartheta$ | 0,35 | 0,14 |

*Table* 2

### 5.2 Synthesis using the "backstepping" method»

Another method of regulator synthesis is the backstepping method. The essence of the "backstepping" method is to present a complex system in the form of a chain of nested subsystems, for each of which auxiliary signals are formed and Lyapunov functions dependent on these signals are formed. The fulfillment of Lyapunov stability criteria with the sequential selection of these signals for each subsystem ensures the stability of the system as a whole. The procedure has the character of a step-by-step bypass of integrators with feedback, hence the name "integrator backstepping", or for short - backstepping (English Backstepping). In certain private cases, the procedure becomes regular and quite simple. For the angular movement of the aircraft, such a case is possible at small angles of pitch and roll, when the derivatives of the angles γ, ψ and υ can be considered equal to the corresponding angular velocities. Then the equations of angular motion can be roughly represented in the form of three subsystems

$$\begin{cases} S_1 = \begin{cases} \dot{\gamma} = w_x \\ \dot{w}_x = \dfrac{(I_y - I_z)}{I_x} w_y w_z + \dfrac{M_{R_x}}{I_x} \end{cases} \\ S_2 = \begin{cases} \dot{\psi} = w_y \\ \dot{w}_y = \dfrac{(I_z - I_x)}{I_y} w_x w_z + \dfrac{M_{R_y}}{I_y} \end{cases} \\ S_3 = \begin{cases} \dot{\vartheta} = w_z \\ \dot{w}_z = \dfrac{(I_x - I_y)}{I_z} w_x w_y + \dfrac{M_{R_z}}{I_z} \end{cases} \end{cases}$$

Following the instructions given in the algorithm, we introduce an auxiliary control signal for subsystem $S_1$ $z_1 = \gamma_d - \gamma$ and the corresponding Lyapunov function $V_1(z_1) = z_1^2/2$ derivative of which $V_1(z_1) = z_1\dot{z}_1 = z_1(\dot{\gamma}_d - w_x)$.

The second auxiliary control signal will be formed in the form $z_2 = w_x - \dot{\gamma}_d - k_1 z_1$ with the corresponding Lyapunov function $V_2(z_1 z_2) = (z_1^2 z_2^2)/2$, $\dot{V}_2(z_1, z_2) = z_1\dot{z}_1 + z_2\dot{z}_2 = z_1(\dot{\gamma}_d - w_x) + z_2(\dot{w}_x - \ddot{\gamma}_d - k_1\dot{z}_1)$. derivative of which Taking for the stabilization system $\dot{\gamma}_d = 0\,; \ddot{\gamma}_d = 0$, we get

$$\dot{V}_2(z_1, z_2) = z_2\dot{w}_x + (k_1^2 - 1) z_1 z_2 - k_1 z_1^2 + k_1 z_2^2.$$

In order for the subsystem to be stable, that is $\dot{V}_2(z_1, z_2) \le 0$, Besides $\dot{V}_2(z_1, z_2) = 0$ only when $z_1 = 0, z_2 = 0$ let's accept, $\dot{V}_2(z_1, z_2) = -k_1 z_1^2 - k_2 z_2^2, k_1 > 0, k_2 > 0$

Then the control signal will have the form:

$$U_2 = -I_x\left[\frac{I_y - I_x}{I_x} w_y w_z - \dot{w}_x\right] = -I_x\left[\frac{I_y - I_x}{I_x} w_y w_z + (k_1^2 - 1) z_1 + (k_1 + k_2) z_2\right]$$
$$= -I_x \cdot \left[\frac{I_y - I_x}{I_x} w_y \cdot w_z + (k_1 \cdot k_2 - 1)\cdot \gamma_d + (k_1 \cdot k_2 + 1)\cdot \gamma + (k_1 + k_2)\cdot w_x\right]$$

Lyapunov function , $V_3(z_1) = V_2(z_1, z_2) = \left[z_1^2 + (w_x - \dot{\gamma}_d - k_1 z_1)^2\right]/2 \ge 0$ and its derivative

$\dot{V}_3(z_1) = \dot{V}_2(z_1, z_2) = -k_1 z_1^2 - k_2 z_2^2 = -k_1 z_1^2 - k_2 (w_x - \dot{\gamma}_d - k_1 z_1)^2 \le 0$, that is, a closed subsystem is stable.

Other control signals can be obtained in a similar way:

$$U_3 = -I_y \cdot \left[ \frac{I_x - I_y}{I_x} w_y \cdot w_z + (k_3 \cdot k_4 - 1) \cdot \psi_d + (k_3 \cdot k_4 + 1) \cdot \psi + (k_3 + k_4) \cdot w_y \right]$$

$$U_4 = -I_z \cdot \left[ \frac{I_y - I_x}{I_x} w_y \cdot w_z + (k_5 \cdot k_6 - 1) \cdot \vartheta_d + (k_5 \cdot k_6 + 1) \cdot \vartheta + (k_5 + k_6) \cdot w_z \right]$$

where $k_3 > 0, k_4 > 0, k_5 > 0, k_6 > 0$.

By choosing values $k_1 - k_6$ it is possible to achieve the desired quality of transient processes. The values of these coefficients are given in table 5.2

Table 5.2

| $k_1$ | $k_2$ | $k_3$ | $k_4$ | $k_5$ | $k_6$ |
|---|---|---|---|---|---|
| 20 | 3 | 21 | 2,5 | 35 | 25 |

# CHAPTER 6 STUDY OF CONTROL CIRCUITS

We will investigate the synthesized control loops by means of mathematical modeling using the matlab simulink application program package, the structural diagram of the model is presented in Fig. 6.1, and Fig. 6.2 and 6.3 present the model of the automatic control system and the model of the quadcopter, respectively.

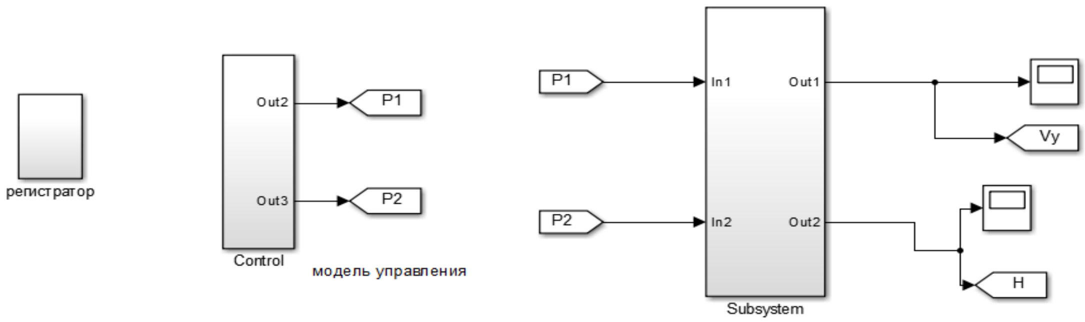


Fig. 6.1 is a structural diagram for the study of quadcopter control circuits

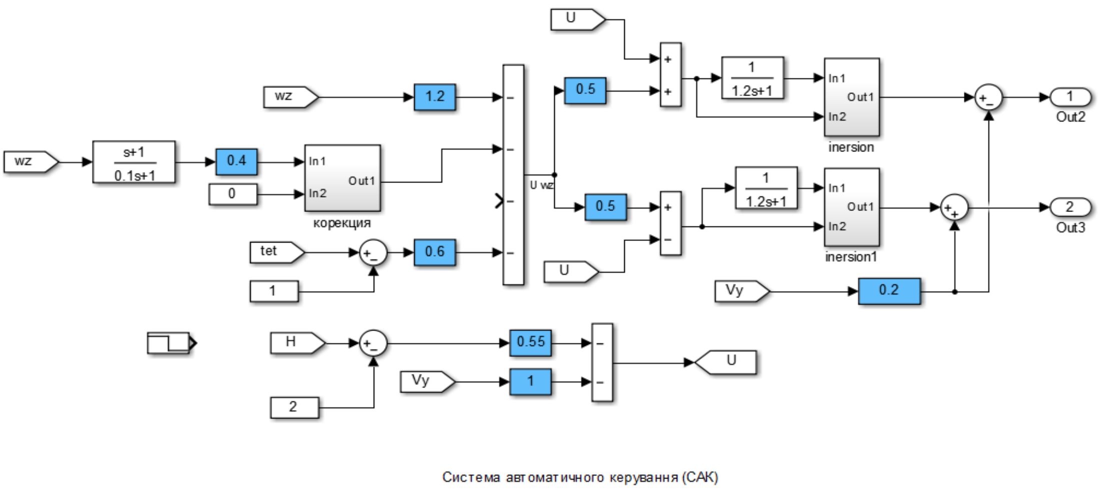


Fig. 6.2 automatic control system

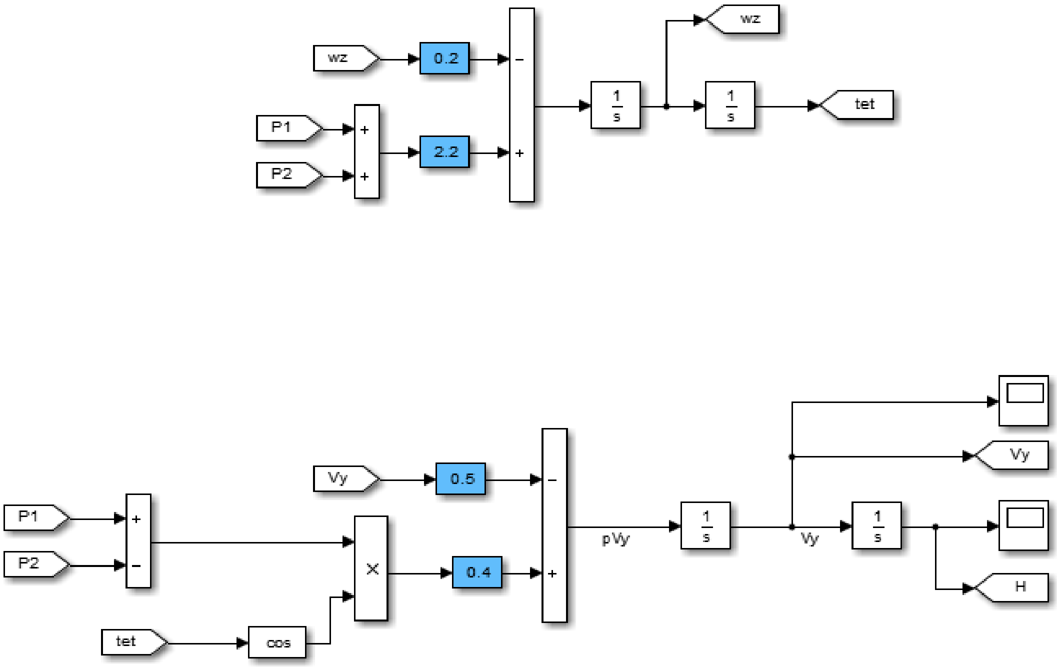


Fig. 6.3 diagram of the quadcopter model

We will conduct a study of the synthesized control circuit using a simplified mathematical model, without the influence of inertia, the results of this system are presented in Fig. 6.4

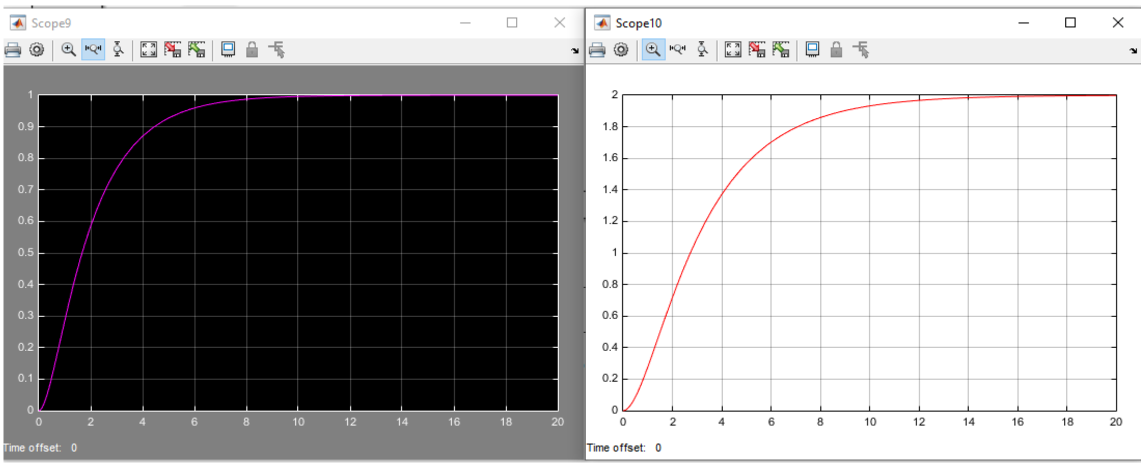


Fig. 6.4 results of the study of the control circuit without the influence of inertia

We will conduct a study of QC, a complicated model that takes into account the inertia of the change in the speed of rotation of the supporting screws (Fig. 6.5, 6.6).

In fig. 6.5 and fig. 6.6 it can be seen that the inertia of the rotation of the propellers especially affects the control of the angular movement of the quadcopter in the form of high-frequency oscillations, the inertia has almost no effect on the movement of the center of mass.

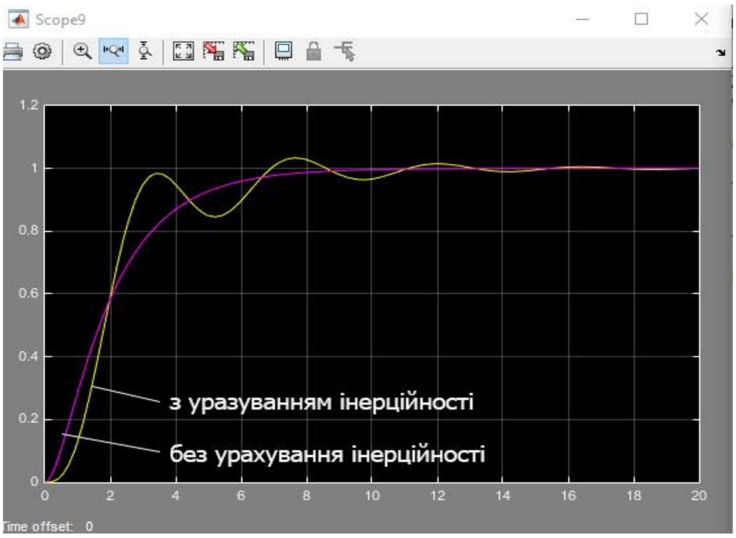


Fig. 6.5 the influence of inertia on the angular movement of a quadcopter

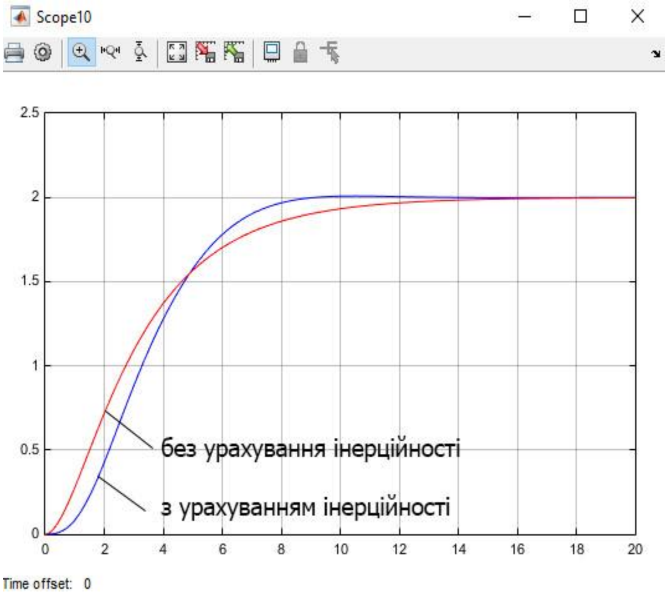


Fig. 6.6 Effect of inertia on the center of mass of the quadcopter

We introduce a correction to the law of controlling the angular movement of the quadcopter by introducing a forced component into the signal chain of the angular velocity sensor

$$u_{\vartheta} = K_{\vartheta}(\vartheta - \vartheta_{set}) + K_{\omega z}\omega_z + K_{p\omega z}(p+1)/(0{,}1p+1)$$

As a result of such correction of the control law, it can be seen (Fig. 6.7, 6.8) that the transient processes are aperiodic, thus it is possible, due to the correction of the control law, to ensure a satisfactory quality of the transient processes of the dynamics of the quadcopter movement

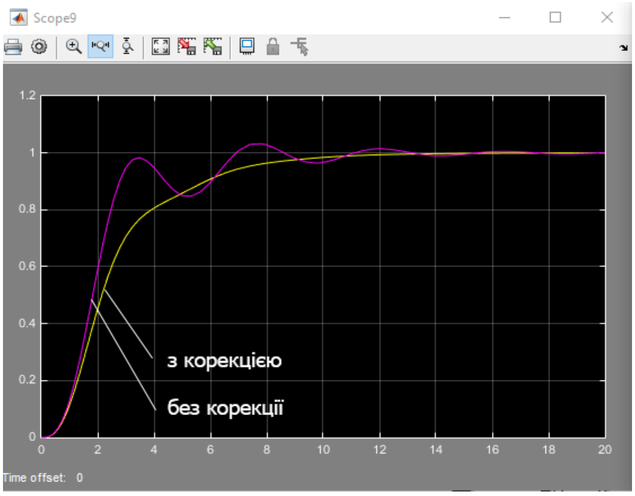


Fig. 6.7 The influence of inertia on angular motion control with correction

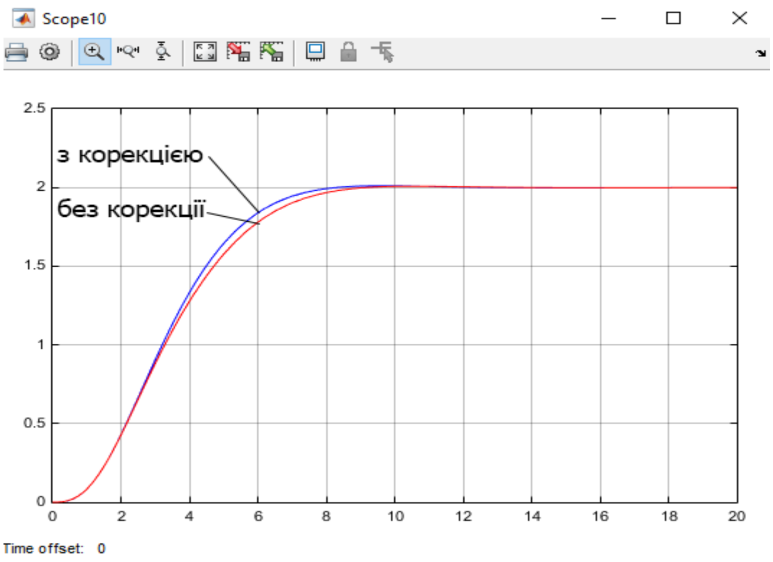


Fig. 6.6 Effect of inertia on the center of mass of the quadcopter with correction

# CHAPTER 7 OQCUPATIONAL HEALTH

## 7.1. Basic provisions for the prevention of injuries when working with aircraft

To avoid injuries, violations of the correctness of work, emergency situations, oQCupational diseases and equipment failure, the person involved in setting up, integrating and repairing must follow clear instructions.

Individuals at least 18 years of age who have passed a medical examination and have no medical contraindications, who have undergone special training, certification and have a relevant certificate, who have undergone introductory training on labor protection, training at the workplace and training on fire safety, are allowed to independently service electrical installations. Employees who maintain electrical installations are required to have an appropriate electrical safety group. Know and be able to apply safety rules in practice to the extent necessary for the work being performed.

When setting up, testing and debugging electrical equipment, it is necessary to strictly follow the rules of operation of electrical equipment, safety precautions during operation of consumer electrical equipment and technological processes.

There are many dangerous and harmful things when working with electrical equipment

- factors for the personnel who serve it. Some of them:
- electric shock;
- falling during work at height;
- increased air mobility;
- increased level of static voltage;
- burns during power cable repair work (heating of the cable mass);
- injury by rotating parts of electric drives, parts of machines and mechanisms;

- electric arc burns during short circuits;
- the electric field strength is more than 5 kV/m;
- step and applied voltage;
- increase or decrease in ambient temperature;
- traffic in the working area, during the location of substations and substations next to roads and other transport highways;
- insufficient lighting of the working area;
- action of chemicals (acetone);
- insufficient lighting of the working area.

Parts of tools that are isolated and used for servicing electrical equipment must be made of conductive materials.

When working in an explosive zone, the use of materials or tools that can cause sparks is prohibited.

For work in the dark period, for local lighting of the area where work is being carried out, battery lights with a voltage of up to 12 V in explosion-proof form are used in areas with an increased risk of explosion.

When using absolutely any electrical equipment, it is very important to observe safety rules. Any malfunctions detected in electrical equipment should not be neglected, such a careless attitude, first of all to oneself, leads to injuries of varying degrees of severity, and sometimes to death.

Work safety is greatly influenced by the environment in which electrical installations are operated. Aggressive gases and vapors destroy the insulation of electrical installations, reduce its resistance, and create a threat of voltage transfer to metal structures. This is facilitated by high temperature and air humidity, conductive dust.

In turn, premises in which electrical equipment is operated

divided into three main categories:

- premises with increased danger;
- particularly dangerous premises;

- premises without increased danger.

Premises with an increased risk of electrocution are characterized by the presence of one of the following conditions:

- humidity (a room in which the relative humidity of the air is more than 60%, but does not exceed 75%);

- conductive dust (technological or other dust settles on wires, can penetrate inside the machine and devices);

- conductive floors (metal, earth, reinforced concrete, brick);

- elevated air temperature (long-term above +35°C, short-term +40°C);

-possibility of human contact with the metal housings of electrical equipment on the one hand and with the earth-connected metal structures of buildings, technological equipment, and mechanisms on the other.

Particularly dangerous rooms are characterized by the presence of one of the conditions that create a special danger: very high relative humidity (about 100%), chemically active environment; or the simultaneous presence of two or more conditions that create an increased risk. Premises without increased danger are characterized by the absence of conditions that create increased or special danger (dry administrative premises, etc.).

During the analysis of electrotraumatism, four main causes of electric injuries are distinguished, namely: organizational, technical, sanitary, hygienic and psychophysiological.

The main causes of electrocution in Ukraine are organizational and technical.

The main organizational reasons are:

- ineffective supervision - departmental and public control over compliance with safety requirements;
- absence or low-quality training on labor protection issues;
- absence or lateness of medical control of the health of electrical

personnel;

- violation of the requirements of standards, norms regarding the operation of electrical installations;
- non-implementation of labor protection measures;
- violation of technological regulations;
- violation of regulatory, planned and repair work;
- insufficient technical supervision of dangerous works

Technical reasons include:

- discrepancies with general security requirements;
- malfunction of the electrical installation;
- structural defects of the equipment;
- lack of personal protective equipment;
- lack of signaling devices.

Sanitary and hygienic reasons include:

- increased content of harmful substances;
- insufficient or irrational lighting;
- increased noise level;
- unsatisfactory microclimatic conditions;
- the presence of radiation.

Psychophysical reasons include:

- wrong actions of employees due to fatigue;
- inconsistency of the employee's psychophysiological or anthropometric data with the work performed.

An analysis of industrial injuries shows that a dangerous factor for personnel servicing electrical equipment is electric shock. And the main causes of electrocution are the appearance of voltage in those places where it should not be. The reason for this is a violation of the insulation of cables, wires and windings.

The possibility of touching non-insulated parts that conduct current. This happens when the terminals and busbars are placed at an incorrect height. The formation of an electric arc between a conductive part and a person.

Every year in Ukraine, approximately 1,500 people die from electric current. The largest number of cases of electrocution, including those with fatal consequences, oQCurs during the operation of electrical installations with a voltage of up to 1000 V, which is due to their distribution and relative availability for almost everyone who works in production. Cases of electrocution during the operation of electrical installations with a voltage of more than 1000 V are infrequent, which is due to the small distribution of such electrical installations and their maintenance by highly qualified personnel.

Analysis of aQCidents related to the action of electric current allows dividing the main causes into groups:

- aQCidental contact with current-carrying parts;
- voltage on metal parts of the equipment;
- mistakenly connecting the equipment under voltage during maintenance and preventive work on it;
- oQCurrence of step voltage on the surface of the earth, on which a person is located.
- Each of the presented groups includes specific dangerous factors, namely:
- violation of the rules of installation, technical operation and safety of electrical installations;
- lack of reliable means of protection;
- imperfection of electrical installation design;
- performing electrical installation and repair works under voltage;
- malfunction of insulation of current-conducting parts of the system;
- mistakenly connecting the equipment under voltage during regular maintenance work;
- low-skilled training by workers who use manual electric machines;

- using of cables and wires that do not meet production conditions.

### 7.2. Technological measures to reduce the impact of harmful production factors

The development of measures to reduce dangerous factors means the organization of labor protection management. This allows you to reduce the risks of injuries, aQCidents and deaths, oQCupational diseases and emergency situations. Ensuring safety is achieved thanks to the development and implementation of production processes, which are developed in aQCordance with the requirements of the Order of the Ministry of Social Policy of Ukraine dated 28.12.2017 No. 2072 "Safety and health protection requirements during the use of production equipment by employees", as well as the requirements of state and industry standards of labor safety by types of technological processes and works, norms and rules of state supervision bodies. The principles of ensuring the safety of activities can be characterized by

groups of activities that are performed:

Technical measures — technical means that allow you to ensure safe and harmless conditions for the performance of the assigned work, the introduction of new equipment, devices and appliances. Technical measures can be divided into 2 large groups:

- tools during work with voltage removal on operating electrical installations;
- tools during work on conductive parts.

The means of the first group include:

- turning off the installation or part from the power source;
- mechanical blocking of drives that perform shutdown, removal of fuses, disconnection of the ends of the power supply line;
- installation of grounding (turning on grounding knives or installation of portable grounding devices).

The means of the second group include:

- execution of work by order of at least two workers using electrical protective equipment, under constant supervision, ensuring the safe location of workers.

Regulatory and methodical measures include:

- development of manuals and recommendations;
- development of the regulatory framework;
- development of educational methods;
- development of labor protection sections in job instructions.

Organizational activities include:

- control over the technical condition of the equipment;
- control over compliance with the requirements of regulatory documents on labor protection;
- provision of appropriate safety signs;
- providing employees with means of individual and collective protection

Sanitary and hygienic measures include:

- provision of sanitary and household conditions in aQCordance with current regulations;
- control over the influence of production factors on the health of employees;
- planning measures to improve sanitary and hygienic conditions;
- certification of the sanitary and technical state of working conditions.

Socio-economic measures include:

- social insurance of employees by the employer;
- funding of labor protection measures;
- compensation by the employer to the employee in case of mutilation.

Treatment and preventive measures include:

- observance of labor protection of women, minors and disabled persons;
- control over the health of employees during their work;
- provision of medical assistance to victims of industrial aQCidents;
- conducting medical examinations of employees (preliminary and periodic).

Scientific events include:

- aQCident localization and liquidation plans;
- evaluation of the effectiveness of labor protection management;
- simulation of emergency situations and development of measures to prevent them.

The main regulatory documents regarding electrical safety in Ukraine are:

Rules of construction the electrical installations. The effect of these rules applies to electrical installations constructed with a voltage of up to 500 kV. They establish general requirements for the structure of electrical installations, for sewerage (transmission) of electricity, for protection and automation, for distribution devices and substations, for electric power installations, for electric lighting and for electrical equipment of special installations.

Rules of construction the electrical installations.

Electrical equipment of special installations (DNAOP 0.00-1.32–01). This document was approved by the Ministry of Labor of Ukraine and includes some issues of electrical lighting and equipment of special installations with changes and additions in aQCordance with the current Ukrainian and international regulatory acts, namely:

- "Rules for the technical operation of electrical stations and networks" is a sectoral (energy) regulatory document, the effect of which applies to electrical installations with a voltage of up to 500 kV, establishing requirements for condition control and maintenance of electrical installations in the energy industry.

- "Rules for the technical operation of consumer electrical appliances"

- an inter-branch regulatory act, the effect of which applies to electrical installations with a voltage of up to 220 kV, establishes requirements for monitoring the condition and technical maintenance of electrical installations, keeping relevant documentation.

- DNAOP 1.1.10-1.01-97. Rules for the safe operation of electrical installations—industry normative document (power industry). Its effect extends to electrical installations of the power industry with a voltage of up to 500 kV. It establishes requirements for the safe operation of electrical installations.

- DNAOP 0.00-1.21-98. The rules for the safe operation of electrical installations of consumers is an interdisciplinary NA that defines the requirements for the safe operation of electrical installations, its effect is extended to electrical installations with a voltage of up to 220 kV.

- DNAOP 1.1.10-1.07-01. Rules for the operation of electrical protective equipment - NA, which establishes requirements for the necessary list of electrical protective equipment depending on specific conditions, for storage, testing, checking the condition and use of electrical protective equipment.

-sectoral normative acts on electrical safety. Inter-branch normative acts on electrical safety do not object to the development of branch NAs if this is appropriate. At the same time, sectoral NAs should not interfere with inter-sectoral ones and reduce the level of security.

-normative acts of enterprises on electrical safety issues. Basically, these are instructions for the safe maintenance of electrical installations and the performance of work in electrical installations, developed and approved in aQCordance with current requirements. AQCording to the state standards on electrical safety and the Rules for the arrangement of electrical installations, the nomenclature of types of protection against electric shock includes the following means and methods.

Three systems of means and measures to ensure electrical safety can be distinguished:

- system of technical measures and means;
- system of electrical protective devices;
- a system of organizational and technical measures and means.

The main technical means and measures to ensure electrical safety:

- insulation of conductive parts;
- protective separation of electrical networks;
- equalization of potentials;
- compensation of capacitive earth fault currents;
- unavailability of conductive parts.

Insulation of conductive parts. Ensures the technical efficiency of electrical installations reduces the probability of a person falling under voltage, short circuits to the ground and the body of electrical installations, reduces the current through a person when touching non-insulated conductive parts in electrical installations powered by an isolated from the ground network, provided there are no phases with damaged insulation.

DSTU B V.2.5-82:2016 "Electrical safety in buildings and structures. In the requirements for protective measures against electric shock" insulation is distinguished:

- working - ensures normal operation of electrical installations and protection against electric shock;
- additional — provides protection against electric shock in case of

damage to the working insulation;

- double - consists of working and additional;
- reinforced - improved working insulation, which provides the same level of protection as double.

Protective separation of electrical networks. The total resistance of the insulation of the wires of the electrical network relative to the ground and the capacitive component of the ground fault current depend on the length of the network and its branching.

As the disorder of the network increases, the capacitance increases and the resistance decreases. Separation of such an extended network into separate, electrically disconnected, parts using transformers with a transformation factor equal to unity helps to increase the insulation resistance and decrease the capacity and, as a result, leads to an increase in the level of safety.

Ensuring the inaQCessibility of conductive parts. Statistical data on electrocution indicate that the majority of electrocutions are associated with contact with conductive parts of electrical installations (about 56%). If in installations up to 1000, the main measures to ensure the inaQCessibility of conductive parts are the use of protective fences, closed switching devices (package switches, complete starting devices, remote electromagnetic devices for controlling electricity consumers, etc.), placing non-insulated conductive parts out of reach for unintentionally touching them with a tool, various height adjustments, restricting the aQCess of outsiders to electrical premises, etc.

*System of electrical protective equipment:*

DNAOP 1.1.10-1.07-01 "Rules for the use of electrical protective devices" (hereinafter the Rules) is a valid regulatory document, which lists the protective devices, requirements for their design, scope and standards of tests, the procedure for use and storage, equipping with protective devices for electrical installations and production crews. The means of protection used in electrical installations must meet the requirements of current state standards, technical conditions for their design, etc.

Electrical protection means are divided into insulating (insulating rods, clamps, pads, dielectric gloves, etc.), protective (fences, shields, screens, posters) and protective (goggles, helmets, safety belts, gloves for hand protection).

*System of organizational and technical measures and means:*

The main organizational and technical measures and means for the prevention of electrical injuries are regulated by DNAOP 0.00-1.21-98 "Rules for the safe operation of consumer electrical installations", aQCording to which the owner is responsible for the organization of safe operation of electrical installations.

- the main organizational and technical measures and means for the prevention of electrical injuries are regulated by DNAOP 0.00-1.21-98 "Rules for the safe operation of electrical installations of consumers", by which responsibility for the organization of safe operation of electrical installations rests with the owner.;
- create and staff an electrical service aQCording to needs;
- to create such conditions at the enterprise so that the employees who are responsible for the maintenance of electrical installations, in aQCordance with the current requirements, carry out their inspection and testing in a timely manner;
- to develop and approve job instructions for electrical service workers and instructions for safe performance of work in electrical installations, taking into aQCount their characteristics.

## 7.3. Safety instructions during operation electrical equipment

1. The instruction applies to all units of the enterprise.

2. AQCording to this manual, personnel must undergo training before starting work (initial training) and then every 3 months (re-training).

3. The owner must insure the staff against aQCidents and oQCupational diseases.

4. For failure to comply with this instruction, the staff bears disciplinary,

material, administrative and criminal responsibility.

5. Individuals at least 18 years of age who have passed a medical examination and have no medical contraindications, who have undergone special training, certification and have a relevant certificate, who have undergone introductory training on labor protection, training at the workplace and training on fire safety, are allowed to independently service electrical installations. .

6. Employees servicing electrical installations are required to have an appropriate group on electrical safety.

7. The certificate of verification of the employee's knowledge is a document that certifies the right to work independently in electrical installations in the specified position by profession.

8. During the performance of official duties, the employee must carry a knowledge test certificate with him. In the absence of a certificate or in the presence of a certificate with expired terms of knowledge verification, the employee is not allowed to work.

9. The knowledge test certificate is subject to replacement in the event of a change of position or in the absence of space for records.

*Safety requirements before performing work:*

1. Check and put on personal protective equipment (special clothing, special shoes, etc.). The overalls of the electrician must be well-fitted and fastened, as the hems and sleeves can be caught by moving parts of mechanisms and machines. A headdress must be worn on the head.

2. Inspect the workplace and check for the proper operation of ventilation systems, the absence of malfunctions in the operation of electrical equipment that is subject to maintenance, the availability and serviceability of fire extinguishing means, means of collective protection, and the availability of tools necessary for work.

3. Remove outsiders from the work area, clear the workplace of unnecessary items and materials, fence off the work area and install safety signs.

4. Before carrying out work with increased risk, which is carried out aQCording to the order or approval order, make sure that the documentation is properly drawn up, undergo a targeted briefing and carry out the measures provided for by the approval order, order, requirements of the rules for the safe operation of electrical installations of consumers.

*Safety requirements during work:*

1. It is forbidden to independently open electrical cabinets, equipment, carry out any repair of electrical equipment, open (remove) blocking and protective devices.

2. When necessary, if the instructions require it, use electrical protective equipment. Protective equipment must be tested and have a special stamp on the conduct of the test.

3. Electrical personnel who perform work near live parts under voltage must be positioned so that these live parts are in front of them only on one side. It is forbidden to carry out work if live parts under voltage are located behind or on both sides of the worker.

4. Approved lists of work with and without voltage removal, which are performed by electrical personnel at a fixed site during one shift in the order of current operation and aQCording to orders on electrical equipment up to 1000 V, as well as approved lists of works that are performed aQCording to the order.

5. During work in the circuits of measuring devices and relay protection devices, all secondary windings of current and voltage measuring transformers must be permanently grounded.

6. It is not allowed to remove the guard of those parts of electric motors that rotate during the operation of the electric motor.

*Safety requirements after work:*

1. Turn off electrical equipment and devices that were used during work.

2. Collect parts, materials, tools, devices, put them in proper condition (clean, wipe), remove tools and devices in the designated place.

3. Clean the place of work, collect waste in a garbage box and take it out of

the room to a designated place.

4. Remove and put away in the designated place the work clothes and other means of personal protection used during the work

**Conclusions**:

1. The main legislative acts on labor protection are the Laws of Ukraine: "On labor protection", "On health protection", "On fire safety", "On ensuring the sanitary and epidemic welfare of the population, the Code of Labor Laws (KZpP) and state inter-branch and sectoral normative acts, which are mandatory for all state and non-state institutions throughout the territory of Ukraine.

2. AQCording to a large amount of collected statistical information, one of the main causes of electrocution is electric shock, so it is an important aspect to pay sufficient attention to the establishment and observance of oQCupational safety rules when working with electricity. Attention was paid to the calculation of contour grounding for the area where the electrical equipment is located.

3. Considered main groups of preventive measures to avoid injuries. Means and measures of protection against electric shock, injuries and aQCidents are highlighted. The main technical and organizational measures to avoid fire were considered. The structure of the fire extinguisher as a primary means of fire extinguishing is considered.

4. The basic instructions for working with various types of electrical equipment are described, the peculiarities of the preparation of the regulatory framework are taken into aQCount.

# CHAPTER 8 PROTECTION OF THE ENVIRONMENT

Environmental protections, rational use of natural resources, ensuring human environmental safety are an integral part of the economic and social development of our country.

Relations in the field of environmental protection in Ukraine are regulated by the Law of Ukraine "On Protection of the Natural Environment", as well as land, water, forest legislation, legislation on the subsoil, on the protection of atmospheric air, on the protection and use of flora and fauna developed in aQCordance with it and other special legislation (Article 2 of the Law).

Basic principles of environmental protection aQCording to Article 3 of the Law "On Environmental Protection":

- guarantee of ecologically safe environment for people's life and health;
- the priority of environmental safety requirements, the obligation to comply with environmental standards, regulations and limits on the use of natural resources when carrying out economic, managerial and other activities;
- greening of material production based on the complexity of solutions in matters of environmental protection, use and reproduction of renewable natural resources, wide implementation of the latest technologies;
- the preventive nature of the measures for the protection of the natural environment;
- mandatory environmental examination;
- openness and democracy in decision-making, the implementation of which affects the state of the natural environment, the formation of the population's ecological outlook;
- scientifically based regulation of the impact of economic and other activities on the natural environment;

- compensation for damage caused by violation of environmental protection legislation;

- establishment of environmental tax, fee for special use of water, fee for special use of forest resources, fee for use of subsoil in aQCordance with the Tax Code of Ukraine.

Various environmental regulations are established by legislation.

For example, the standard of use of natural resources. Environmental regulations establish the maximum permissible emissions and discharges into the surrounding natural environment of polluting chemical substances, the levels of permissible harmful effects of physical and biological factors on it

Norms of maximum allowable concentrations of pollutants in the surrounding natural environment and levels of harmful physical and biological effects on it are uniform for the entire territory of Ukraine.

All enterprises and organizations whose activities are associated with certain impacts on the environment, regardless of the time of their commissioning, must be equipped with structures, equipment and devices for cleaning emissions and discharges or their neutralization. They must be equipped with devices for controlling the amount and composition of pollutants.

## 8.1. Impact of noise, vibration, electromagnetic radiation on environment

Because the warehouses still have operators who monitor the work of manipulator robots. But some processes are performed by operators, so the task of reducing noise at the facility where the actions are performed becomes necessary.

Noise is considered to be sounds that have a negative effect on the human body and interfere with his work and rest. Therefore, noise is often called an unfavorable sound.

Usually, noise is created during the chaotic alternation of sounds of different frequencies and intensities. Sound is a physical phenomenon that propagates as a wave in an elastic medium. Sound, and therefore noise, is characterized by: speed of sound s, m/s; frequency, Hz; sound pressure p, Pa; intensity, W/m2.

Noise is a random combination of sounds of different intensity and frequency. As a rule, two main sources of noise are distinguished:

- noises of natural origin;
- noises of technogenic origin.

Noise in the urban environment and residential buildings is created by vehicles, industrial equipment, sanitary and technical installations. On city highways and in areas adjacent to them, sound levels can reach 70...80 dBA, and in some cases 90 dBA and more. In the area of airports, the sound levels are even higher.

It is necessary to pay special attention to noises of man-made origin, because they have a particularly negative effect on the body. The degree of harmful effects of noise depends on its intensity, spectral composition, time of exposure, location of a person, the nature of the work performed by him and individual characteristics of a person.

Often man-made noise is a mixture of random sounds and vibrations. Sources of man-made noise include all the mechanisms, equipment and transport used in modern technology, which create significant noise pollution of the environment.

Depending on the environment in which noise spreads, two main groups can be distinguished:

- structural noises;
- air noises.

Structural noise oQCurs when the oscillating body is in direct contact with parts of machines, their body, pipelines, foundations, building structures, etc. The oscillating energy that oQCurs in this case spreads in the form of longitudinal and transverse waves.

The harmful and dangerous effects of noise on the human body have now been established with complete certainty. The degree of impact depends mainly on many characteristics, such as: level, duration of noise and no less on the individual characteristics of a person. Numerous studies have confirmed the fact that noise is a physiological stimulus that, under certain circumstances, can affect most organs and systems of the human body, as well as cause negative consequences for the environment, buildings, man-made rocks due to its waves. So, aQCording to medical experts, noise can cause a large number of health problems (nervous problems; cardiovascular problems; peptic ulcers; metabolic disorders; hearing disorders).

Adaptation of the body to noise is practically impossible, therefore regulation and limitation of noise pollution of the environment is an important and mandatory measure.

The corresponding sound landscape has always existed on Earth, and man has always used the properties of the environment as a conductor, carrier of sounds. The noise of the surrounding natural environment is 30 - 60 decibels. Under modern conditions, production and transport noises are added to the natural background, the level of which often exceeds 100 decibels. Sources of noise are all types of transport, industrial facilities, as well as loudspeakers, elevators, televisions, radios, musical instruments, crowds of people, etc.

The human body cannot adapt to noise. Adapting to noise, a person spends a lot of energy, as a result of which fatigue, nervous and mental disorders oQCur. Noise is harmful not only for people, but also for animals and plants.

Modern noise control methods are a difficult and rather expensive task.

It is important to destroy sources of noise, to create silent or low-noise machines and technological processes, transport and industrial equipment.

Noise levels are set as aQCeptable norms, the effect of which for a long time does not cause a decrease in hearing acuity and ensures satisfactory intelligibility of speech at a distance of 1.5 m from the interlocutor. The pain threshold is determined by sound power equal to 140 dB. With a noise background of 70 dB and above, disorders of the human endocrine system oQCur, and the number of neuroses and psychoses increases significantly. With long-term exposure to noise of 90 dB, problems with auditory mechanisms are possible, and long-term exposure to background noise above 120 dB causes physical pain and becomes unbearable. Disorders of the central nervous system, cardiovascular diseases, hypertension, mental depression, etc. also oQCur.

However, sound waves with a frequency of up to 16 Hz are perceived by the human body as vibrations. Many manufacturing processes involve vibration.

Vibration is the shaking of the whole or a part of the body as a result of certain actions.

The main sources of vibrations are mechanical, pneumatic, electric impact or rotary tools. Also, equipment without sufficient damping and vibration isolation. Manipulator robots are also capable of exerting a vibrational effect on the surrounding environment. Vibrating sensations appear when a person touches objects that oscillate under the action of corresponding forces.

The force of impact and the nature of vibrations depends on the amount of absorbed energy.

During vibration, wave action oQCurs with alternating compression or stretching of human tissue or body parts. Vibrating processes cause a reaction in the body similar to multiple concussions, therefore they are the cause of functional disorders of various organs.

A person can tolerate horizontal rather than vertical oscillations along the axis of the body better. AQCording to the ways of transmission to the human body, vibration can be:

- general;
- local

The general vibration is transmitted through the support surfaces to the human body.

Local vibration is transmitted through the hands. In production conditions, there are often cases of combined influence of general and local vibration.

When vibration affects human organs, such a phenomenon as resonance of internal organs may oQCur, they begin to behave like pendulums.

This is due to the fact that all organs of the human body work with a certain frequency of oscillation. For most internal organs, their own frequencies lie in the range of 6-9 Hz, and within the range of frequencies of 25-30 Hz - the resonance of the head relative to the shoulders.

If the frequency of vibrational noise is synchronized with the frequency of operation of a certain organ, vibrational disease may appear. Features of vibration action are determined by frequency spectra and maximum levels of vibration energy. General vibration causes the highest specific gravity among oQCupational diseases.

General vibration can be classified into three main groups:

- transport;
- transport and technological;
- technological.

Transport vibration oQCurs as a result of traffic on roads.

Transport and technological vibration oQCurs during the operation of machines that are in a stationary position or move on specially prepared parts of production premises. Manipulator robots are capable of spreading this type of vibration.

The main causes of vibrations during the operation of the equipment are:

- imbalance and imbalance of parts of mechanisms;
- displacement of the center of gravity of the body and the axis of rotation;
- deformation of parts due to heating;
- wear of parts due to unsatisfactory maintenance of mechanisms;
- structural defects;
- non-uniformity of pressure in the working bodies of machines

Technological vibration is a vibration that spreads to operators of stationary machines or is transferred to a workplace that does not have a direct source of vibration.

Any airport, terminal, or even a modern enterprise or residential building, the streets of modern cities, cannot be imagined without various electronic or electrical devices. The intensive development of modern technologies has caused significant pollution of the environment by electromagnetic radiation.

The main sources of radiation are:

- radio and radar stations;
- television stations;
- high-voltage lines;
- electrical appliances and electric transport.

The electromagnetic field propagates in the form of an electromagnetic wave, which carries the energy locked in the electric and magnetic fields. Electric and magnetic fields change simultaneously, the parameters of which are:

- speed of wave propagation;
- wavelength;
- frequency of oscillations.

All these characteristics are related to each other. The spectrum of electromagnetic oscillations is conventionally divided into ranges by oscillation frequency and wavelength:

1. Ranges aQCording to the frequency of oscillations (low; medium; high; very high; ultrahigh; ultrahigh; extremely high).

2. Wavelength ranges (kilometer, hectometer, decameter, meter, decimeter).

Sources of electromagnetic pollution in the production room can be unshielded working elements of high-frequency installations (inductors, capacitors, HF transformers, feeder lines, capacitor batteries, coils of oscillating circuits, etc.).

Every year, various countries increase their energy capacity, as a result of which the electromagnetic field (EMF) of anthropogenic origin has become a significant environmental factor with high biological activity. In 1995

The World Health Organization even coined the term "global electromagnetic pollution." EMFs of anthropogenic origin have different characteristics than the geomagnetic field and lead to desynchronization of intercellular interactions in the biological system, which is tuned in unison with the natural electromagnetic background. The activity of cells, individual organs and the course of biochemical reactions are significantly affected by EMF of both ultra-high-frequency and low-frequency ranges. The measure of electromagnetic pollution is defined as field strength (V/m).

Organisms that come under the influence of such fields are damaged, first of all, of the nervous system. For example, a field strength of 1000 V/m causes a person a severe headache, fatigue, contributes to the development of neuroses, insomnia and serious diseases.

Electromagnetic fields have a very negative effect on human health from or near the radiation source. In the range of industrial frequencies, the electric component of the field has a more negative effect on the biological object.

Various neurodynamic processes are sensitive to electromagnetic radiation, which, in turn, switch the body to a pathological or stressful mode of functioning.

It is necessary to take into aQCount the functional and resistance characteristics of the human body to the influence of various factors. As a rule, the effect on the body of radiation in the range from 30 kHz to 300 MHz is:

- general weakness;
- fatigue;
- sleep disturbance;
- headache;
- pain in areas of the heart.

There is also a certain number of symptoms that indicate a malfunction of the organs. Various natural reflexes, such as sexual and food, activity of the cardiovascular system deteriorate, and changes in protein and carbohydrate metabolism indicators are recorded. The composition of the blood changes. With prolonged and intense radiation, oQCupational diseases oQCur.

## 8.2. Measures to protect against noise, vibrations and electromagnetic radiation

When normalizing noise, different types of it are taken into aQCount.

Sanitary and hygienic regulation of noise is usually carried out by two methods:

- method of limit spectra;
- sound level method.

The method of limit spectra is used to normalize constant noise, it involves limiting sound pressure levels in octave bands with geometric mean frequencies. The set of these marginal octave levels is called the marginal spectrum.

The method of sound levels is used for approximate hygienic assessment of permanent noise and determination of non-permanent noise. For example, the external noise of robotic manipulators, vehicles. The measured level makes it possible to characterize the amount of noise with one indicator. In this case, the noise level is measured with a special device, a noise meter. Where sensitivity to low- and high-frequency noises is reduced with the help of certain filtering.

Measures to reduce the noise level are divided into collective and individual.

Collective protection means include:

- reduction of noise at the source itself;
- reduction of noise in the path of its propagation;
- medical measures;
- organizational and technical measures.

The method of reducing noise at the source is considered the most radical of all. It is implemented with the help of equipment and is achieved with the help of certain measures and means:

- carrying out static and dynamic balancing and balancing;
- production of parts from non-metallic materials (plastic, textolite, rubber);
- alternation of metal and non-metal parts;
- increasing the aQCuracy of manufacturing parts and the quality of

assembly of assemblies and equipment;

- reduction of gaps in connections by reducing allowances;
- application of lubrication of rubbing parts, etc.

Means that reduce noise in the path of its arrival, as a rule, are divided into architectural and planning and acoustic. Individual protection methods can include headphones, anti-noise tabs and helmets.

Normalization and protection against vibration fluctuations is also an important aspect.

A distinction is made between hygienic and technical regulation of vibration. Hygienic regulation regulates the appropriate conditions for protection against vibrations of a person, technical regulation regulates the conditions for protection against vibrations of equipment. Hygienic regulation of vibration makes it possible to ensure vibration safety of working conditions.

Hygienic and technical means of protection against vibrations include:

- creation of new designs of machines, equipment and tools, the vibration of which does not exceed safe limits, and the pressing force does not exceed 15-20 kg;
- elimination of imbalance of rotating masses by balancing them;
- elimination of direct human contact with vibrating equipment through the introduction of remote control, industrial robots, automation and changes in technological operations;
- balancing of working parts of the machine;
- elimination of defects of loosening of parts;
- use of dynamic vibration dampers, which represent an oscillating system with a resonance frequency that coincides with the vibration frequency of the structure;
- vibration damping — using the shock energy absorption method.

Methodological and preventive methods include:

- special mode of work and rest;
- medical examinations;
- courses.

Normation and protection against electromagnetic radiation: norming of electromagnetic radiation in the radio frequency range is carried out in aQCordance with GOST 12.1.006-84 "Electromagnetic fields of radio frequencies. Permissible levels at workplaces and requirements for the implementation of control", DSN 239-96 "State sanitary norms and rules for the protection of the population from the influence of electromagnetic radiation" and DSanPiN 3.3.6.096-2002 "State sanitary norms and rules when working with sources of electromagnetic fields".

AQCording to these documents, the standardization of electromagnetic radiation is carried out in the frequency range of 50 kHz - 300 GHz.

The main methods of protection against electromagnetic radiation are:

- time protection;
- distance protection;
- shielding of radiation sources;
- shielding of workplaces;
- organizational methods of protection;
- personal protective equipment.

Protection is sometimes used in cases where it is not possible to reduce the radiation intensity by other methods.

The distance protection method takes into aQCount the distances at which the maximum permissible level of radiation will meet the standards. This method is used in cases when other methods cannot be used.

Shielding of sources oQCurs by creating metal sheets or grids in the form of cameras. The process of shielding oQCurs when a field of the opposite direction begins to appear in the thickness of the screen.

Screening of workstations is performed only when it is not possible to screen devices. It is implemented by arranging workplaces covered with absorbent materials.

**Conclusions**:

In the modern world, various man-made factors that pollute the environment have increased by an incredible amount. The use of airport robot-manipulators allows to improve factors of speed, productivity, quality of baggage service. This increase, in turn, leads to an increase in the effect index, which directly depends on the efficiency and quality of the impact of the work process on the environment. All this, in modern conditions of use, allows to minimize the pollution of the surrounding environment.

Also, in connection with the dynamic development and wide spread of replacing the human factor with flying machines, the most negative factors are the problems of noise, vibrations and electromagnetic radiation.

In this section, the problems and harmful factors that these negative factors carry are considered. Any of these factors has a negative impact on the health of living organisms. Therefore, the problem of eliminating or reducing negative factors is at the heart of the planning of the modern aviation industry.

Methods of noise, vibration and radiation level normalization were considered. Methods, measures and means of reducing the impact of negative influences are also considered.

# Conclusions

1. The structure of the automatic control system of the cargo quadcopter as part of the information and control complex was proposed in the paper.
2. For the tasks of synthesis and analysis of automatic control circuits, a modernized and verified mathematical model of the cargo quadcopter as a control object is taken into account, which takes into account the inertia of the change in the rotation speed of the rotors and the influence of flight parameters on the aerodynamic characteristics of the rotors.
3. Variants of the synthesis of control algorithms are presented, which allow stabilizing the height and angular position of the quadcopter and tracking the given trajectory.
4. As a result of the simulation, corrective changes were made to the synthesized control laws, which improve the dynamics of the angular movement of the cargo quadcopter.
5. The obtained control circuits show their efficiency and the possibility of implementation in existing systems of automatic control of cargo quadcopters.

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