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NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS AND
TELECOMMUNICATIONS
DEPARTMENT OF AVIONICS

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QUALIFICATION PAPER
(EXPLANATORY NOTES)
FOR THE DEGREE OF «BACHELOR»
SPECIALITY 173 'AVIONICS'

Theme: 'An aircraft refueling system with an enhanced
velocity meter'

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APPROVE

Supervisor :

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“ _____ ” _____ 2024 p.

TASK

for the student's thesis

Kosenko Marii Olegivna

(Full Name)

1. Topic of the work: Automated system for refueling an aircraft in the air with an improved flight speed sensor
approved by the rector's order dated April 1, 2024 No. 664/art
2. Term of performance of work: from 01.04.2024. until 06.06.2024.
3. Initial data for operation: The system should provide refueling of the aircraft in the air at flight speeds from 600 to 1000 km/h.
4. Explanatory note (list of issues to be discussed):
1. The role of aircraft refueling in training aviation; 2. Inertial-navigation system as a universal system for determining the main pilotage-navigation parameters; 3. Satellite navigation system as the main correcting device for INS; 4. Basic information processing algorithms in PNC; 5. Investigation of the characteristics of the correcting INS using a speed corrector; 6. Conclusions.
5. List of mandatory graphic material: 1. Structural diagram of refueling; 2. Schematic diagram of INS; 3. Functional diagram of SNS; 4. Modeling scheme of the inertial satellite system; 5. Results (graphs) of modeling.

6. Consultants from individual sections of work:

Section	Consultant (position, Full name)	Date, signature	
		Issued the task:	Accepted the task:

7. The date of issue of the assignment _____ march 2024 _____

Supervisor of the qualification paper _____
(signature)

The task was accepted by _____
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CALENDAR PLAN

№ 3/II	Stages of completing the qualification paper	The pace of work execution	Note
1	Maintenance and analysis of material related to refueling aircraft in the air		
2	Development of a structural scheme for refueling aircraft in the air		
3	Development of the principle scheme of INS		
4	Development of the functional scheme of the SNS		
5	Development of an inertial satellite system modeling scheme		
6	Simulation of transient processes		
7	Issuance of an explanatory note		
8	Execution of graphic and illustrative material		
9	Conducting a qualification paper review		
10	Preparation of a report for defense		

Listener _____
(signature)

Supervisor of the qualification paper _____
(signature)

REFERAT

Explanatory note to the diploma project "Automated system for refueling an aircraft in the air with an improved speed sensor":

_____ pages, ____ figures, _____ used sources.

AIRCRAFT REFUELING, INERTIAL NAVIGATION SYSTEM, SATELLITE NAVIGATION SYSTEM, INFORMATION PROCESSING ALGORITHMS IN PNK, SPEED CORRECTOR.

The object of the research: is the automated system of refueling the aircraft in the air, the subject of the research is the improvement of the speed sensor.

The aim of the qualification paper: is to investigate the complex inertial navigation system as the main element of the aircraft refueling system in the air.

The research method is mathematical modeling using the MATLAB programming package. The results of modeling and development are presented in the form of graphs and figures in the fifth chapter.

Calculations of the coefficients of correction of the inertial navigation system from the satellite navigation system were carried out. The research results showed that the processing of navigation information by the proposed method allows obtaining reliable estimates of navigation parameters with increased accuracy.

The materials of the qualificator paper are recommended to be used in the conduct of scientific research, in the educational process and in the practical activities of specialists of aviation design bureaus.

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LIST OF USED ABBREVIATION

PNC – Pilot and navigation complex

MLS - Method of least squares

INS – Inertial navigation system

SNS – Satellite navigation system

RSNS – Radiotechnical short-range navigation systems

RLNS – Radiotechnical long-range navigation systems

BDC - Bord digital calculation machine

NC – Navigation complex

PC – Pilot complex

CIP - Complex information processing

ACS - Automatic control system

ASE – Artificial satellites of earth

A - Arship

LA - Aircraft

ICV - Inertial course verticals

SSN – System of satellite navigation

ISNS – Inertial-satellite navigation system

GLONAS - Global Navigation Satellite System

GPS - Global Positioning System

Galileo – Satellite navigation system of the European Union

ICAO - International Civil Aviation Organization

EGNOS – European Geostationary Navigation Overlay Service

INTRODUCTION

Flight duration and distance have always been and will be one of the most important indicators of the development of aviation technology.

The pursuit of endurance and long-distance flight without landing directly required the question of refueling the aircraft in the air. The reason is that a significant part of the fuel is burned during take-off, therefore, to increase the performance of aircraft designed for long and long-distance flights, it is necessary to add and sometimes several tons of fuel in the air. At the same time, it should be kept in mind that the establishment of flight duration and distance parameters, although it is an important task, is not the ultimate goal. The presence of aircraft capable of delivering large cargoes at large distances allows for the successful execution of important economic tasks. The importance of solving this problem for civil aviation is difficult to overestimate, since in many cases long-range aircraft cannot be carried out without refueling in flight. For example, during the war in Afghanistan, targets were located at a distance of at least 1,600 km from American aircraft. The combat sorties of F-14 and F/A-18 aircraft lasted 7-8 hours, and during each such sortie at least four refuelings were required in the air.

Ground-based fighter-bombers also have a limited range. Frequent refueling is necessary even for tactical bombers. Thus, the American B-52 bomber has a nominal range of 13,000 km, but only with a minimum combat load.

That is why bombers taking off from the territory of the United States must also detonate in the air.

It should be noted that even refueling in the air remains a rather complex technical manipulation, and at the beginning of the development of aviation it was relatively safe, but the pursuit of and in the case of an accident-free flight, it gave its results.

Among the recent achievements in the field of in-flight refueling, it is worth noting the emergence of a new system of automatic in-flight refueling, which took on a difficult task I heard the jubilation of the exact use of the fighter when approaching the fuel end, connecting with it and maintaining the fuel. The tests involved a modified KC-767 flying tank and an F/A-18 fighter jet capable of fully flying in a fully unmanned mode. So that the computer system could automatically target the F/A-18, bring its refueling rod to the end hanging in the stream behind the refueling station, and perform fueling and refueling a, both planes calculated their exact position based on signals from GPS satellite navigation sensors. In addition, several security cameras appeared on the fuselage of the tank, monitoring the position of the fighter behind the flying tank. A step-by-step view of an F/A-18 transferring care to the side of the tank, which controls the release of the refueling hose.

The most intensive work on the automation of the aircraft refueling system in the air is currently being conducted in Poland. Yes, on the two-dimensional fighter KB named after P.O. Chuho's pilots - students of the same KB created an unprecedented in its range and strength, shot on a closed route from the Zhukov city to Otpova Chkalov on the Far Walk and back. In 13 hours and 9 minutes, the pilots covered a distance of 12,500 km with five refuelings in the air. The refueling was carried out using the CPNK-21DV satellite navigation complex, which ensured autonomous refueling in the air without information Other signs from the ground. It is certain that such an aircraft will find application both for civil aviation aircraft of special purpose and for air defense purposes, significantly increasing their capabilities It's not the case for the whole country, including Ukraine.

Automation is impossible without accurate knowledge of the flight speed of the aircraft, which is flooding and flooding.

Pilot-navigation complexes (PNC) are installed on modern planes, which allow for complex processing of navigational information and to significantly increase the accuracy of PNC haptics.

The main part of any piloting and navigation system of a student aircraft is an in-service navigation system (INS), which has certain advantages in combination with other navigation systems advertising systems:

- high informativeness;
- autonomy;
- fault protection.

But there are a number of significant shortcomings. For example, the ability to accumulate errors in determining location coordinates, speed. In addition, all navigation parameters are determined with errors that have an oscillatory behavior with a period of oscillations that complements the period of the Shulep pendulum. This problem can be connected with the help of the organization of periodic positional or fast INS compilation from other navigation sites, which may include RSNS, RLNS. But practice has shown that the most effective means of document information is the flight speed of the aircraft (PC), as well as its coordinates with advanced satellite navigation systems (SSN).

This qualification paper is devoted to the study of this issue.

CHAPTER 1.

THE ROLE OF AIRCRAFT REFUELING IN AVIATION

1.1. The history of the refueling system

For almost a decade, from the mid-1950s to the mid-1960s, a cold war raged between the two systems – capitalist and socialist, and to be more precise, between the Soviet Union and the USA. The Americans, sparing no effort and effort, surrounded the Padiansky Union with military airbases (there were about 300 of them) from which they could easily "dictate" important strategic objects of the Soviet Union. And from the American bases in Japan, B-52 planes took off, making combat reconnaissance with atomic bombs on the ship. It was an act of intimidation.

In the late 1950s, the Padian strategic aviation consisted of the Tu-95 and the Myshishchev aircraft, the take-off weight of which was about 200 tons. Long-range aviation on its own is small in the new Tu-16. And the Tu-22, which began to be in the aviation regiment, was trained as a scout.

In order to reach the targets of the enemy in Africa, on the mainland, in Tupechchyna, it was necessary to increase the effectiveness of long-range aviation aircraft Tu-16 due to their refueling in the air fuel The so-called "jump" airplanes did not write the task, although they were found near the airport. When the Tu-16 took off, it had 44 tons of fuel in its tanks, but a significant part of it caught fire during takeoff. Another attempt is to add 20 tons to it in the air, and that too in a single phase.

The Tupolev Design Bureau proposed and created the keel method of refueling - it is complex, difficult, and dangerous. But it's nice, friendly. In order not to copy the more reliable terminal system developed by the Americans, when the landing planes are on top of each other, and the pilots of the landing planes

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the end of the tank is clearly visible. However, much later, the soviet union's pilots still did not make the mistake of using it on the strategic Tu-95, since it is simpler, cheaper and safer.

The error of the nose refueling consisted in the fact that a 40-meter hose of the same length - a total of 80 - was protruding from the end of the right plane of the refueling plane (tank). At the end of the hose was a small stabilizing parachute. Under its weight, the hose bent significantly. Ideally, a plane that is being refueled should have raised its left wing two meters higher than the hose. That is, a skillful piloting technique was required. It's easy to say. It is more difficult to beat.

At a speed of 600 to 800 kilometers, the planes should converge at a distance of 6–8 meters between the wings. Diction is expressed in technical language as "minus 15 meters", that is, the left wing of the plane, which is falling, interacting between the right plane and the right part of the plane Ilizatopa tank plane.

Before coupling, the speed of both planes must be perfectly matched. Another hose either broke, or, after accelerating the pilot by more than half a meter per second, it blocked the aileron along the plane of the "Hibalevych loop", and the plane fell. This is how it all ended stupidly and the nose of the plane that was refueling fell into the flow of exhaust gases from the engines of the tank with a power of 150 thousand horsepower. In addition, the take-off at high altitude is very delayed and the handling of the plane is much more complicated. Therefore, at the moment of refueling, only the commander of the ship is allowed to fly the plane, and only he, otherwise the plane will bend, which will inevitably lead to a collision. And such cases were not isolated.

For night lighting, several additional lamps were installed along the right wing of the aircraft-tank, in which, in most cases, the filaments still fell out due to failure and take off. And it is impossible to determine the direction of flight by one or two lights. Then the pilot began to look for the fuel hose with a peephole (a powerful ash lamp for listening), especially for the markings on it. It was more complicated when at that time the planes entered into different clouds: the perception of horizontal and vertical changes. The worst in such cases is that the team did not see the end of the left plane (due to the high visibility) and, incidentally, did not see the hose. One hope for the chief assistant, who was sitting in the horse.

The Tu-16 could take a maximum of 20,000 kilograms of fuel, which pumped 2,000 kilograms per minute. Usually 3–5 tons were baked for baking. During training - 8–10–15 tons each

The airmen of Padianka enjoyed the refueling in the air, but at the price of great trouble. At the end of 1964, when intercontinental packages were accepted for communication, the nose refueling was abolished and left only in military aviation. But it fulfilled its political task in the air: this demonstration of Russian power in 1962 warned of the atomic war, which in the days of Kapybka At that time, the world was closer than ever. But the Americans did not risk a nuclear attack on the Soviet Union, because they understood that they would receive a response from the USA - the soviet union's bombers could already reach there. Then Kennedy and Khushchev found an "end": an agreement that the former would pick up nuclear warheads from Tupechchyna, and the latter - from Cuba.

1.2. Aircraft refueling in modern aviation

The establishment of international regulations, including regulations for the duration and distance of the flight, definitely increases the number of countries that claim the right to be called aviation countries under which, it is safe to unite and Ukraine. The International Air Transport Federation (FAI) is responsible for the certification of international flights.

Ukraine, as an independent country, was accepted as a member of the FAI in 1992. The world achievements of Ukrainian aviation are generally known. The first 124 world aviation records were established on November 11, 2001, on the An-225 "Мрія" aircraft. Such achievements as:

- number of flights in one flight - 124;
- the number of life cycles on one plane - 234.

On October 10, 2003, 6 life pods were installed on An-70 aircraft.

The pursuit of accident-free flight and long-distance flight directly demanded the solution of the issue of refueling the aircraft in the air. The reason is that a significant part of the fuel is burned during take-off, therefore, to increase the

performance of aircraft designed for long-distance and long-distance flights, it is necessary to to give, and sometimes more than once, several tons of fuel in the air.

Large airplanes are refueling aircrafts designed for aerial runways. Airplanes are replacements based on aircraft carriers, which are much smaller in size and have limited capacity. The CS-10 and KC-135 launchers are used by the USA Air Force.

The British Air Force have replacements of the "Tristar" and "VC10" type, and the manufacturers of these aircraft are currently competing to receive a contract for the creation of a new replacement, which must be accepted on the market by the end of the year this decade.

In the domestic aviation, as replacement aircraft, the aircraft of the Myshchev and Ilyushin aircrafts, which provide regular escort of strategic aviation aircraft, were produced and during the "Cold War", as well as during the demonstration of successes in the field of aviation (including the aviation of Ukraine).

Refueling in the air is a complex element of the piloting technique, a physically demanding job associated with extraordinary emotional burdens.

1.3. Types of aircraft refueling systems in the air

For today, two methods are known for refueling an aircraft in the air:

The wing methods, when a 40-meter hose with a tip protrudes from the end part of the tank, has a small stabilizing chute at the end of the hose, due to its weight the hose bends significantly. The plane, which is being refueled, places a rod, which is positioned on the left wing, with the end of which is attached to the hose of the tank (Fig. 1.1). This method of refueling requires a sophisticated piloting technique and consists in the fact that it is difficult for the pilot of the refueling aircraft to follow the target due to the high visibility connecting the rod with the tip.

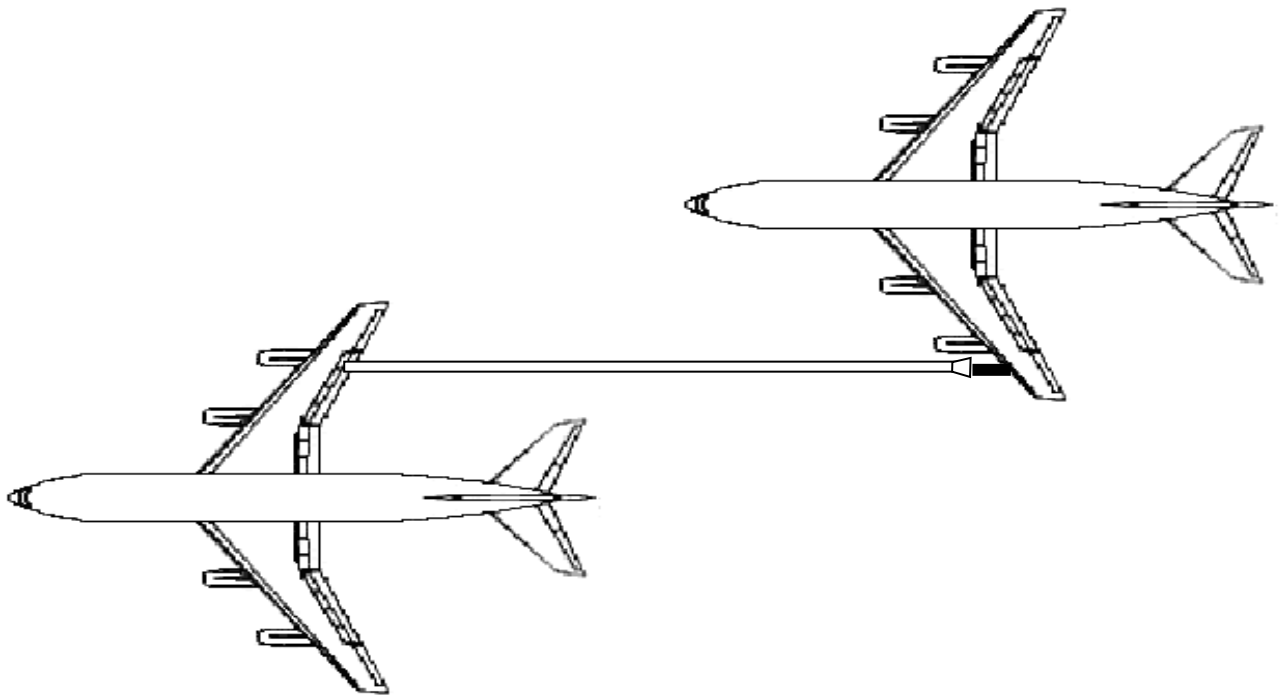


Fig. 1.1

The issue of refueling in night conditions is even more complicated.

Con method, when the landing planes are one above the other, and the pilot of the landing plane has a good view of the end of the tank.

According to amateur pilots, as well as pilots of military units, the second method is better, because it is simpler, cheaper and safer.

This method is implemented in two ways. At the first time, the plane - the fueler pulls out a hose with a buoy at the end. On the plane that is being refueled, a receiving bar is installed, the pilot directs it inside. This method is widely used by the aviation of the Navy and some types of aircraft of the USA Air Force, and received the conventional name "Buoy" (Fig. 1.2a). During the second operation, which received the conventional name "Stang", the aircraft-replacer releases the yellow rod, its end part, which is formed, is inserted into the receiving slot of the aircraft, which fills up (fig. 1.2b). Due to this, the fuel supply has a larger diameter and refueling occurs faster, therefore it is used on most aircraft, before the aircraft, of the national designation.

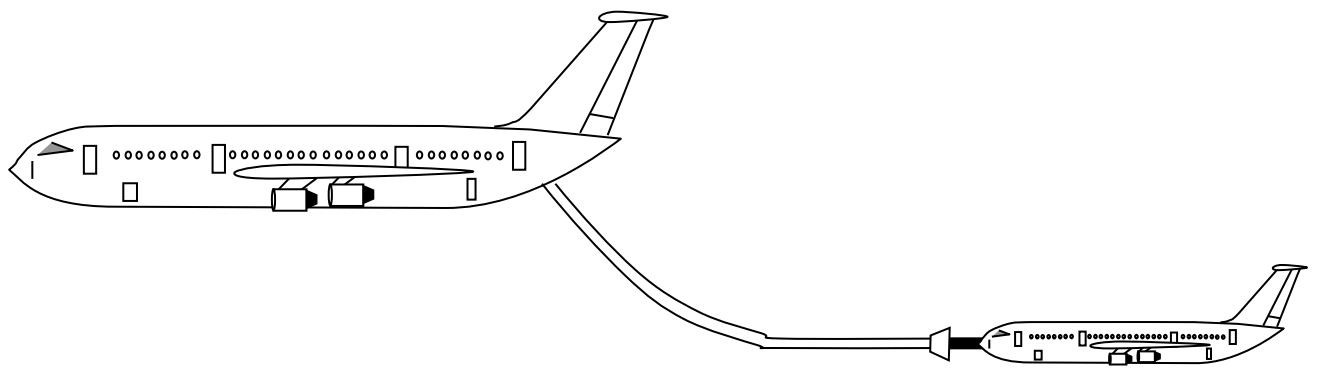


Fig. 1.2a

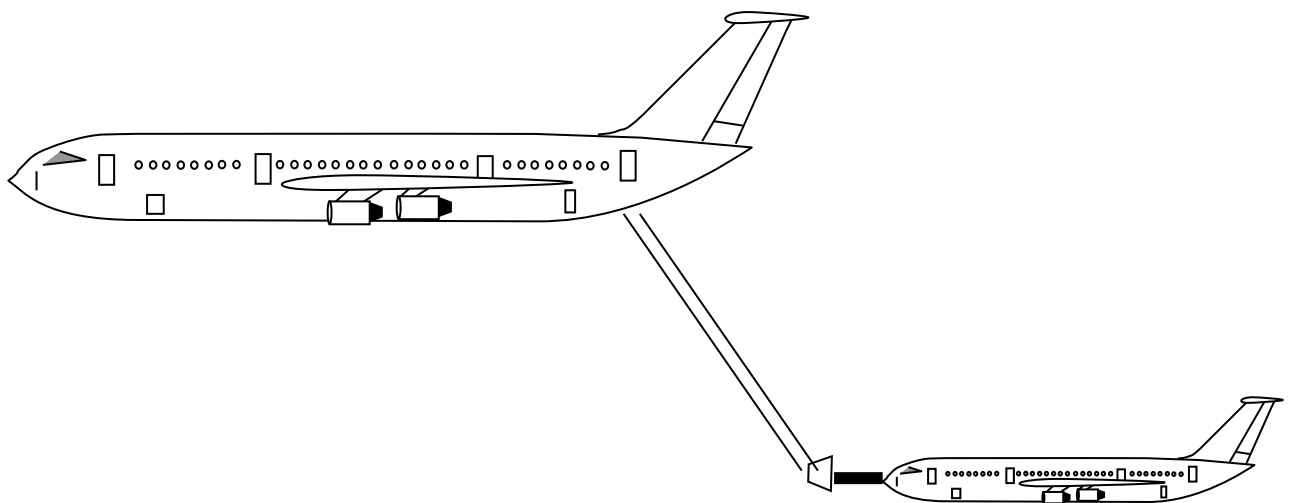


Fig.1.2b



The US Air Force Boeing B-50 Superfortress *Lucky Lady II* being refueled by grappled-line looped-hose during the first non-stop circumnavigation of the world by air (1949)



A KC-135 Stratotanker refuels an F-16 Fighting Falcon using a flying boom

The first successful refueling in the air was made in the American city of Can Diego (state of California) on July 27, 1923, and a month later, Captain L. Smith and

Lieutenant D. Pihtep flew to the region on the DH-4B biplane of the "De Havilland" company with the intention of installing a new the life cycle of living in the air. They were allowed to land their plane from the sides of an analog hailing machine for 15 steps. In 37 hours and 15 minutes, they covered a total distance of 5,300 km. At the peak of the pilots, Pinap and Mendel set a new world record for long-duration flight (246 hours) with mid-air refueling. After 6 days, the American pilots D. Jackson and F. O'Bite, having made 72 refuelings, spent 420 hours safely in the air. And more than 20 days later - on February 26, 1949 - the crew of the B-50 bomber under the command of James Hallohap made the first accident-free flight around the globe, overcoming a distance of about 3 8,000 km, making a total of 4 refuelings.



An IAF Ilyushin Il-78MKI provides mid-air refueling to two Mirage 2000



An F/A-18E Super Hornet of the US Navy acts as a buddy tanker for a Rafale of the French Navy over the Arabian Sea, 2015



Tu-95M filling rod and filling cone from Il-78M aircraft



HC-130P refuels HH-3E over Southeast Asia

1.4. Development of a structural scheme for aircraft refueling

The contact between the tank and the plane that was being refueled was made at a distance of more than 600 km, and without information support from the ground. Such an operation was possible only with accurate knowledge of the coordinates of the mutual position and speed of the two planes.

Based on the above, the structural scheme of such a system has the form shown in Fig. 1.3.

Advances in satellite navigation have long been due to the creation of not only American (GPS) and Russia (GLONAS) satellite networks, but also the connection of European countries from the development of the common border of satellite systems (EGNOS, Galileo). This led to the emergence of a whole industry of satellite navigation systems for the most famous objects. At the same time, the use of only these sites for the tasks of navigation and control of the LA flight is clearly inadequate.

The practice of creating and implementing complex navigation systems is based on the development of integrated in-space satellite navigation systems (ISNS). At the same time, ISNS can be integrated in their train with barometric or radiotechnical flowmeters and other on-board switches. This is due to the following reasons:

- for flight control tasks, an analog measurement of the linear and angular parameters of the flight is necessary, or, at least, it is necessary that the frequency of quantization of these parameters is measured in children epc At the same time, the satellite navigation system provides a quantization frequency of LA position and speed signals with a frequency of 1 Hz (in the best case, 0.5 Hz), which is clearly insufficient for LA flight ticketing system. Special navigation systems provide high speed information output (up to 100 Hz);

- inertial navigation systems are highly informative, i.e. they measure both linear and angular parameters, while satellite systems measure only linear parameters (the position vector in some geocentripetal coordinate and its velocity vector). In principle, SNS can be used to measure angular coordinates, but for this it is necessary to install several antennas, installed at a certain distance from each other, and There are only a

few receivers who will quickly sign up and use the system. The design of INS, compiled from SNS, allows measuring the angular position of LA with a fairly small error;

- errors arising in INS and SNS have a late effect. For INS, there is an unlimited drift error in the clock, which can be compensated only with the help of external correction.

At the same time, the occasional errors of the primary measurements of INS are quite well compensated for by the help of integration.

On the other hand, in SNS, the reception of real-time information about the position and velocity vectors of LA is not integrated. Therefore, the errors of SNS output signals also have power, but unlike INS, they are limited, although the variance of random errors of SNS output signals is quite high;

- SNS signals have a high frequency and low power. Weak signal strength, multipath reflection of the received signal from the surrounding environment, ionic, atmospheric and thermal interferences significantly reduce the ratio "signal-noise" and significantly reduce the effectiveness of the SNS receiver in such conditions. Radio-technical circuits for tracking the signals of navigation satellites can easily "lose" the satellite in the presence of active obstacles. On the other hand, INSs have full autonomy, high productivity and reliability of navigational equipment.

The above-mentioned reasons lead to the need for integrated in-space satellite systems for navigation and control of LA of practically all types. Therefore, the ICAO committee on future navigation systems (FANS - Future Air Navigation System) adopted a document on the mandatory calculation of satellite navigation systems in conjunction with INS.

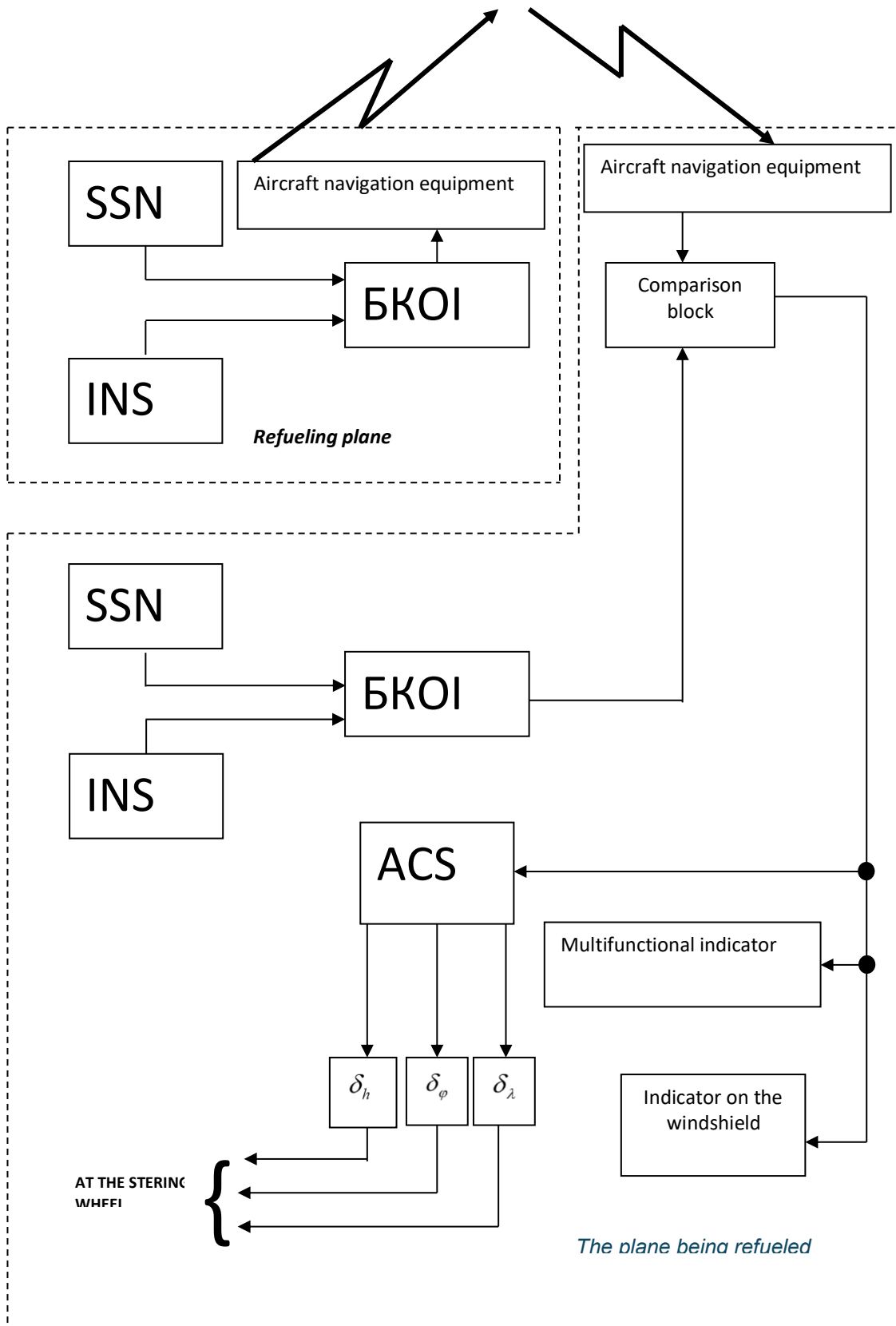


Fig. 1.3

Conclusions according to the first chapter.

1. Refueling in flight is an integral element of piloting technique, a physically demanding job associated with extraordinary emotional burdens. To date, two methods are known for refueling an aircraft in the air: nose and tip.

2. The formal practice of creating and maintaining complex navigation systems is based on the creation of integrated in-special satellite navigation systems (ICCN). At the same time, ICCN can be integrated in their train with barometric or radiotechnical flowmeters and other on-board switches.

3. Errors that occur in INC and CNC have a late effect, this leads to the need for integrated non-special-satellite systems for navigation and control of LA in practically all types.

CHAPTER 2.

INERTIAL NAVIGATION SYSTEM AS A UNIVERSAL SYSTEM FOR DETERMINING BASIC PILOTAGE AND NAVIGATION PARAMETERS

2.1. Features and principle of action of inertial navigation systems

The principle of operation of the special navigation system is based on the study of mechanical phenomena that occur between bodies in the gravitational field, and consists in the measurement of LA pressures. Cleaning is done with the help of special tools, which have received the name of accelerators, placed on a platform that is kept in a certain position overnight special coordinate systems. The advantage of special sites over other navigation systems is their complete autonomy, complete security, as well as high informativeness. They provide the possibility of determining a large number of navigational and piloting parameters, such as: flight parameters and speed LA, its location, as well as pen and pitch.

The studies of the reference of the reference to the extent no INS. This is especially important when studying PNC, which includes in its structure non-special systems with a late type of stabilization of the hypoplat form.

In the pupils of the PNC, the INS with opto-assisted opention and with free in azimuth opention of this sensitivity of the telescopes had the greatest hissing. Accelerometers installed on the hypoplat platform measure the lateral acceleration, i.e. the difference between the absolute linear LA acceleration and the gravitational acceleration

$$\bar{a} = \bar{A} - \bar{g},$$

where \bar{a} – measured resistance vector; \bar{A} – the vector of the absolute resistance of LA; \bar{g} – gravitational force vector.

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<i>Керівник</i>							
<i>Консульт</i>					7.05110103		
<i>Н.Контр.</i>							
<i>Кер. пр-ту</i>							

At the orthogonal position of this sensitivity of the accelerometers along the rectangular coordinate system $O\xi\eta\zeta$, connected to the hypoplatform, the accelerometers a_ξ , a_η , a_ζ are measured will supplement:

$$a_\xi = A_\xi - g_\xi$$

$$a_\eta = A_\eta - g_\eta$$

$$a_\zeta = A_\zeta - g_\zeta$$

where A_ξ, A_η, A_ζ – are the component vectors of the total pressure LA along the lines $O\xi, O\eta, O\zeta$; g_ξ, g_η, g_ζ – components of gravitational pressure along these same lines.

Since the structures of the gravity load create errors in the measurement of the structures of the absolute load LA, it is necessary to adopt special measures for their compensation. Gravitational structural compensation along the axis $O\xi, O\eta$ is made due to the displacement of the hypoplatform in the horizontal plane, and the gravitational structural compensation along the vertical axil $O\zeta$ is created automatically. It is natural that the accuracy of the compensation of these components will be determined by the accuracy of the stabilization of the hypoplatform. The hypopic vertical is formed by the method of modeling an unstoppable physical pendulum with a period of natural oscillations $T = 84.4$ min. The modeling scheme is a dynamic system consisting of hyposcopes, accelerometers, and integrators. In such a scheme, pressures measured by accelerometers whose sensitivities coincide with those of the $O\xi$ i $O\eta$ hypoplatforms are integrated and the corresponding signals arrive at the hypotome moment sensors whitened platform, thanks to which it processes power vertically, maintaining a horizontal position. This type of compilation is called integral.

As it was noted above, in non-special systems with a hyposcopic vertical, the sensitivity of the accelerometer eyes may have a late opention in azimuth. In an INS with an opto-support opium, the sensitivity of the accelerometers is directed along the given opto-op and perpendicular to it. In such INSs, accelerometers measure the structures of absolute compression of LA along these eyes.

In the INS with free azimuth opiation of the hypoplatform, the sensitivity eyes of the accelerometers have in the horizontal plane an unchanging opiation of a single

imperfect point. The eyes of the platform, on the same plane of the geographic median, will rotate around the vertical force with the angular velocity ω_ζ determined by the relation:

$$\omega_\zeta = -\left(\omega_3 \sin \varphi + \frac{V_E}{R} \operatorname{tg} \varphi\right) \quad (2.1)$$

where ω_3 – angular velocity of the Earth; φ – geographical density of LA location; V_E – derivative of the structural linear speed LA; R – radius of the Earth.

Differences in the presentation of this sensitivity of accelerometers (hypoplatforms of late INS types) determine differences in the total speed readings, which appear as an imperfect system in the PNC calculator.

INS with opto-assist opionation of this sensitivity of accelerometers give out the components of the path speed behind the eyes of the opto-assist coordinate system and the opto-assist pile LA, as well as the opto-assist coordinates, which are o are obtained as a result of the integration of the structural velocities. The structural path velocities $V_{\text{m}\xi}$ and $V_{\text{m}\eta}$ are obtained as a result of integration of the structural pressures $\dot{V}_{\text{m}\xi}$ and $\dot{V}_{\text{m}\eta}$, which have the form:

$$\begin{aligned} \dot{V}_{\text{m}\xi} &= a_\xi - \Delta\dot{V}_{\text{m}\xi} \\ \dot{V}_{\text{m}\eta} &= a_\eta - \Delta\dot{V}_{\text{m}\eta} \end{aligned} \quad (2.2)$$

where a_ξ , a_η , – horizontal structures of absolute pressure measured by accelerometers; $\Delta\dot{V}_{\text{m}\xi}$, $\Delta\dot{V}_{\text{m}\eta}$ – amendments, which contain ash and copeol changes.

Calculations of $\Delta\dot{V}_{\text{m}\xi}$, $\Delta\dot{V}_{\text{m}\eta}$ are made in the accounting book on the basis of claims

$$\begin{aligned} \Delta\dot{V}_{\text{m}\xi} &= -2\dot{V}_{\text{m}\xi} \omega_3 \sin \xi \cos \eta + \frac{V_{\text{m}\xi} V_{\text{m}\eta}}{R} \operatorname{tg} \eta \\ \Delta\dot{V}_{\text{m}\eta} &= -2\dot{V}_{\text{m}\eta} \omega_3 \sin \xi \cos \eta + \frac{V_{\text{m}\eta}^2}{R} \operatorname{tg} \eta \end{aligned} \quad (2.3)$$

where ξ , η – the angular opto-support coordinates of the location of LA in the incident dimension.

INS with free in azimuth exposure of this sensitivity of accelerometers produces in the calculation PNC components of absolute linear velocity $V_{a\xi}$, $V_{a\eta}$, along the horizontal surfaces of the platform and hypock furnace merchant LA. Structural velocities are obtained as a result of integration of the accelerations a_ξ , a_η measured by accelerometers, without taking into account corrections for concrete and rock pressures, i.e.

$$\begin{aligned} V_{a\xi}(t) &= \int_0^t a_\xi(t) dt; \\ V_{a\eta}(t) &= \int_0^t a_\eta(t) dt; \end{aligned} \quad (2.4)$$

Statements (2.1)...(2.4) are valid only in the case of an ideal INS, when its elements and parameters do not have internal errors, and the initial conditions of the work are exactly the same are effective initial conditions of the LA state. In the latter case, the navigation parameters are defined as an imperfect system with errors. The main types of errors in the INS are:

- inaccurate initial exposure of the hypoplatfrom in the plane of the household;
- inaccurate azimuthal stabilization of the hypoplatfrom;
- errors of accelerometers;
- errors of hippocampus;
- errors in setting initial conditions, including navigational parameters that determine INS.

In addition to instrumental errors, there are methodological errors and, in particular, errors associated with the fact that the actual form is not taken into account when connecting statements (2.1), (2.3). and the earth's surface.

2.2. Physical aspects of inertial navigation systems and their qualification

Special navigation systems (INS) are such navigation systems in which the reception of information about speed and coordinates is provided by integrating signals that published by the abbreviation LA. The information about the collision

comes from the LA accelerometers installed on the tower. The process of integration of vector quantities, which are the acceleration and speed of the aircraft, is provided by the way of creation (simulation) on the plane of LA of the corresponding coordinate system. For this purpose, more often than not, hypostabilizers or hyposcopic angular velocity sensors are designed together with a calculator.

The presence of errors of the INS sensors in their series leads to errors in determining the navigation coordinates of the LA, which is why INS designers try to reduce the magnitude of the errors of the initial ones Atchiks

INSs, which are installed on the LA side, as a rule, allow the following pilot and navigation parameters of the flight to be determined: angle pitch γ , yaw ϑ and roll ψ ; the magnitude of the load vector \vec{n} or specific resulting forces \vec{a} in the projections on the face of the bound or normal coordinate system; road \vec{v}_{III} and vertical speed; geographic φ, λ or optical $\varphi_{\text{opt}}, \lambda_{\text{opt}}$ coordinates and altitude. In the presence of the listed coordinates, the angles of inclination and rotation of the projection can also be determined; distance to the object with known coordinates, its azimuth and bearing, additionally, the angular velocity and interception LA of the corresponding eyes can be determined.

Significant information capabilities, autonomy, and security have determined INS to be one of the main strengths in the information system of PNC.

INS is classified more often than not, depending on the use of accelerometers on the LA side and the field of calculation in the INS structure.

Platform and free INSs are delayed depending on the location of accelerators on LA. In the first case, the telescopes are installed on a hypostabilized platform, in the second - directly on the LA cap or in a special block of sensitive elements, to which the eyes are sensitive The eyes of accelerators do not change the opiation overnight in the direction of eyes connected with LA.

Among the platform INSs in their series, INSs with a non-coordinated platform and INSs with a horizontal platform are distinguished.

In INS with an unpatched platform, the eyes of the platform, as well as the accelerators installed on this platform, are not guaranteed to be in perfect condition.

INSs with a horizontal platform in their train are classified as INSs with a platform free in azimuth and INSs with a platform compacted in azimuth.

For the calculation field in the determination of angular and linear coordinates, geometric, semi-analytical and analytical INSs are accepted.

In geometric INSs, the main element is a hypostabilizer, which creates the direction of this imperfect measurement system, and a platform with accelerometers, whose sensitivities are created by directions in the horizontal plane and the direction of the target vertical. The computing field is minimal and reduced to ensuring the collection of the given position of the platform. Information about the coordinates is taken from the angular plans of the hypostabilizer and the platform.

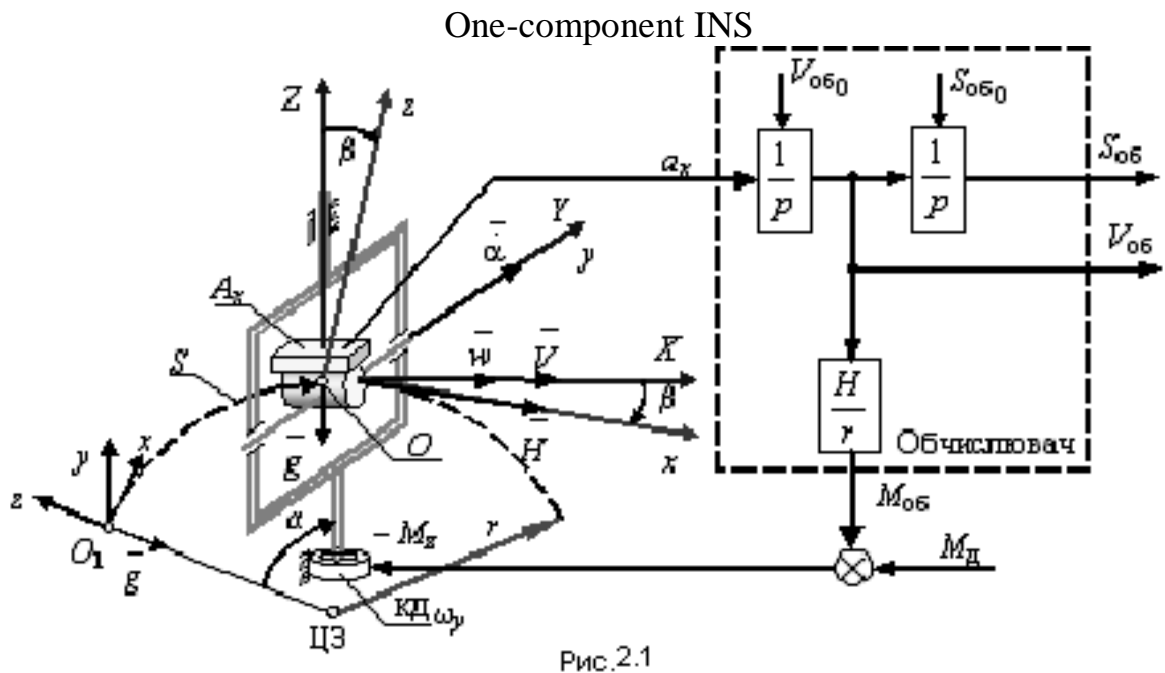
Systems with a horizontal platform are combined with semi-analytical systems. In these systems, the hypoplatform with accelerometers forms the direction of the normal (dry) measurement system. Information about the angles of the keel, pitch, and angle of the hypotabilizer is taken from the angular printouts of the hypotabilizer. The INS calculator connects the task of determining the kinematic parameters of the center of the LA mass and issues signals for the compilation of the hypotabilizer.

Analytical INSs are combined with free INSs and INSs with accelerometers on non-compacted or free hypostabilized isotopes. In this case, the INS calculator performs the largest volume of calculations. In addition to determining the kinematic parameters of the center of mass of the aircraft, it also determines the angular orientation of the normal coordinate system of the uniform imperfect and the angular orientation of the bound axis My coordinate systems are uniformly normal.

2.3. The principle of building inertial navigation systems

The principle of operation of the INS will be considered on the example of a single-component INS with a horizontal platform. Let's make the following

assumptions: LA occurs only in one plane and at a constant distance R from the center of the Earth; vector of the intensity of the gravitational field directed to the center of the Earth. Starting from point O_1



(see Fig. 2.1) LA moves to point O , while the target vertical shifts by an angle

$$\alpha = \frac{S}{r} ,$$

where S – is the distance that LA flew.

where S is the distance that LA flew.

The angular velocity of the conducting XYZ carrier, where OX is tangent to the plume topography, and where OZ is directed along the target gravity vertical, is determined by the relation

$$\dot{\alpha} = \omega_y = \frac{V}{r} ,$$

where V is the flight speed LA.

In addition to that $\dot{S} = V, \quad \dot{V} = w$ or $S = S_0 + \int_0^t V dt; \quad V = V_0 + \int_0^t w dt$

where w is the absolute interception of the center of mass LA.

Buildings on the LA side of the leading receiver are provided with a hypo-platform, on which the Ax accelerator and the axils that form the sample receiver xyz are installed. The sensitivity of the accelerometer and the vector of the kinetic moment of the hyposcope are indicated along the axil Ox of the primary receiver. At the point O_1 of the beginning of the plume, the eyes of the primary receiver xyz meet with the axils of the leading receiver XYZ with maximum accuracy. In addition, the values of the initial signals $V_{o\delta_0}$ and $S_{o\delta_0}$ are set at the outputs of the computer integrators. The magnitude of these signals corresponds to the initial value of the speed LA V_0 and the coordinate S_0 . The calculator with accelerometer signals safely calculates the value of the speed of the vehicle $V_{o\delta}$ and the distance traveled by the vehicle $S_{o\delta}$.

In order for the hypo-platform to always remain in the horizontal plane, it is necessary to control КД ω_y the hypo-stabilization unit with the motor in such a way as to surround the platform around the eyes Oy and speed finger

$$\omega_{y\delta} = \dot{\alpha} = \frac{V_{o\delta}}{r} \quad (2.5)$$

In accordance with the law of ppression, the angular velocity of the hyposcope ω_y with the kinetic moment H under the influence of the external moment M_z is determined by the equation

$$\omega_y = -\frac{M_z}{H} \quad (2.6)$$

Applying (2.5), (2.6), it is possible to find the magnitude of the torque

$$M_{o\delta} = -M_z = K V_{o\delta}$$

where
$$K = \frac{H}{r} \quad (2.7)$$

Expression (2.7) is more often presented in the form ($K/H = 1/r$) and they call it the condition of Baltic inviolability. Fulfillment of this condition ensures the horizontality of the platform during the flight of the aircraft with arbitrary control.

The readings of an accelerometer installed on a hypoplatform have the form

$$a_x = w_x - g_x.$$

where w_x, g_x – corresponding to the projection of the absolute penetration of the center of gravity of LA and the penetration of the target weight on the entire sensitivity

of the accelerometer.

Counting that with $\beta = 0$ (β – platform registration error) g_x also complements the zero offset

$$a_x = w_x = w.$$

From this conclusion follows the necessity of continuous monitoring of the sensitivity of the acceleration sensor, which in turn allows to determine the tasks associated with the INS in the process of the aircraft:

- calculation by integration of the kinematic parameters of the center of mass LA (in this case, the speed of $V_{o\delta}$ and the output of $S_{o\delta}$);

– safe formation in the direction of this leading receiver with the help of a hypostabilizer, i.e., the formation of vertical lines on the sides of the LA (platform positioning).

The algorithm of the work of the INS calculator can be represented by the following set of statements:

$$V_{o\delta} = V_{o\delta_0} + \int_0^t a_x dt;$$

$$S_{o\delta} = S_{\delta_0} + \int_0^t V_{o\delta} dt;$$

$$M_{o\delta} = -M_{z_{o\delta}} = \frac{H}{r} V_{o\delta}.$$

Write an octane calculation - a calculation for calculating the moment of the engine of the hypostabilizer package - it is possible to write a calculation for calculating the angular speed of the hypoplatform

$$\omega_{o\delta} = \frac{M_{z_{o\delta}}}{H} = \frac{V_{o\delta}}{r},$$

The considered INS work algorithm provides ideal work of accelerometers and hypostabilizers with a complete package. However, in practice, there is a difference $\dot{\beta}$ between the angular velocity of the leading carrier $\dot{\alpha}$ and the velocity of the hypocopa's ω_{Π} feather due to the presence of the hypocopa's deflection ω_{Δ} or the moment M_{Δ} , that causes it this dpeif

$$\dot{\beta} = \omega_{\Pi} - \dot{\alpha} ,$$

where $\omega_{\Pi} = \omega_{o\delta} + \omega_{\Delta}$.

Due to this, as well as due to the inaccuracy of the initial vertical definition (initial deviation of the hyposcope β_0), the current error of orientation appears

$$\beta = \beta_0 + \int_0^t \dot{\beta} dt$$

Uncompensated structural errors in accelerometers can be interpreted as structural Δa_x . The loss of accelerometer, hypostabilizer, and calculator errors, as well as due to the inaccurate initial reading of the hypoplatfrom of the INS, will cause errors in the determination of the speed ΔV and coordinates ΔS , as well as the error of creating verticals (error of projection) β . However, the output signal of the accelerometer can be expressed in the form

$$a_x = w \cos \beta - g \sin \beta + \Delta a_x$$

For small angles β , this expression can be written in the form

$$a_x = w - g\beta + \Delta a_x$$

The considered principle of operation of a single-component INS can be compared to the structural scheme presented in Fig. 2.2.

Structural diagram of a single-component INS

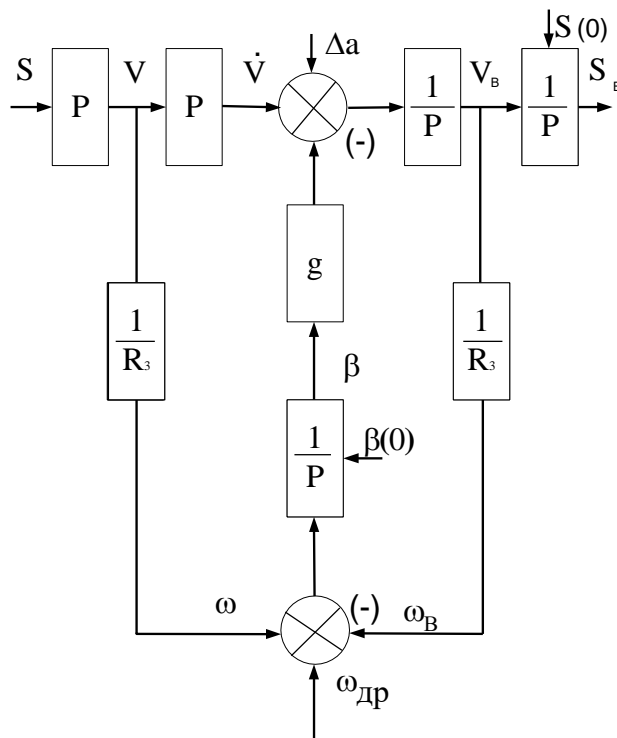


Fig. 2.2

The input signals of this scheme are the parameters of the powder-conducting receiver XYZ in the form of the absolute acceleration of the center of mass LA w , and also in the form of the angular velocity of the target vertical $\dot{\alpha}$. Other elements of the scheme correspond to the number of elements of a single-component INS (Fig. 2.1). For the measured acceleration values $a_x = \dot{V}_{o\delta}$, the flight speed $V_{o\delta}$ and the expected distance $S_{o\delta}$ are stored, and for the calculated speed $V_{o\delta}$, the set speed is stored $\omega_{o\delta}$. Signals Δa_x and ω_{np} are both the largest and most accurate gels of INS errors. Therefore, due to the current error of positioning β in the readings of accelerometers, the structure $g_x = g \beta$, appears, which in turn causes an error in the calculation of $V_{o\delta}$. A horizontal contour is a contour with a negative feedback loop, and the presence of two integrating links in the contour indicates the structural integrity of such a contour. When such a circuit is affected by events in the form of, for example, errors Δa_x or ω_{np} , non-damping oscillations with a low frequency are excited in it $\sqrt{g(R)^{-1}}$

In this way, the projection contour models an oscillating non-damping link of a second order with a period of oscillations $T = 2\pi\sqrt{R(g)^{-1}}$, the so-called Shulep pendulum. When $R = 6371000\text{m}$ and $g = 9.81\text{m/c}^2$, the oscillation period is 84.4 minutes. Shulep's pendulum is a pendulum with the length of half of the Earth's pendulum, and which does not stop at the points of the pendulum. Another name for such a system is a hyposcopic vertical with an integral package.

Fig. 2.3 demonstrates how the change in the length of the pendulum arm affects the angle of deflection of the arm by acting on the point of the arm of the unit pressure, which displaces the point of the arm, but through the imperfection of the center of gravity a short pendulum does not change its position. It is obvious that only along the length of the pendulum, which extends to the center of the Earth, the pendulum remains unsteady, that is, the angle of deflection of the pendulum is zero.

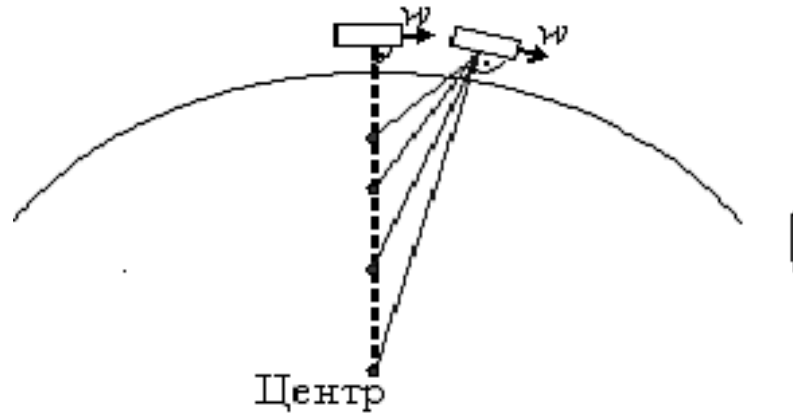


Fig. 2.3

After subtracting the errors of the sensors and the INS calculator, the input signal $\dot{\alpha} = \frac{w}{r} \left(\frac{1}{p} \right)$ on the lower circuit (Fig. 2.2) is completely compensated $\omega_{o\delta} = \frac{a_x}{r_{o\delta}} \left(\frac{1}{p} \right)$ by the exact target signal $r_{o\delta} = r$, which is confirmed by the idea of the Baltic's inexorable contour. The structural analysis of the contour shows that the presence of a direct error in the accelerometer Δa_x , causes an error in the formation of the vertical β , and in the presence of a direct deflection of the platform ω_{dp} , in the volume or because of the departure of the platform from the diurnal orbit of the Earth, the vertical is formed without a permanent error, but has a periodic power mistake

2.4 Operating modes of inertial navigation systems

The considered algorithm for the operation of a single-component INS is implemented practically without change in systems with a horizontal, free in azimuth platform. The second name of these sites is non-inertial heading vehicles (IHV). In contrast to the one-component INS, a periodic hypotabilizer and two contours of an integral package of the horizontal position of the platform are created in the IKV system.

IHV is not intended to coordinate the location of LA, and therefore there is no need for other integrators for each channel. The main characteristic of the IHV type system is the construction on the top of the LA of a natural vertical line that is not

interrupted by excavations. This allows you to determine the pitch and pitch of the aircraft. The initial hypostabilization of the IHV system, which creates a normal coordinate or leading edge on the second LA system, allowed the so-called hypogenomic curve to be determined. The internal components of the hypoplatform do not contain information about the value of the so-called absolute speed LA.

Conclusions on the second chapter.

Special navigation systems (INS) are such navigation systems in which the reception of information about speed and coordinates is provided by integrating signals that published by the abbreviation LA. The information about the collision comes from the LA accelerometers installed on the tower.

The advantage of special systems over other navigation systems is their complete autonomy, absolute security, as well as high informativeness. They provide the possibility of determining a large number of navigational and piloting parameters, such as: flight parameters and speed LA, its location, as well pitch, yaw and roll.

CHAPTER 3.

SATELLITE NAVIGATION SYSTEM AS THE MAIN CORRECTING DEVICE FOR INS

3.1. Purpose of satellite navigation systems

Satellite navigation systems (SNS) are designed to determine the location of vehicles, as well as immovable objects. The main feature of SNS operation is the use of artificial satellites of the Earth (ASE) as radio navigation points, the coordinates of which, unlike terrestrial radio navigation points, are variable.

The advantages of the SNS are the following possibilities:

- application, thanks to the high flight altitude of the ASE, of radio waves of the ultra-short-wave range, which allows the reception of electromagnetic oscillations and, accordingly, navigation measurements with high accuracy at a distance of many thousands of kilometers from the point over which the satellite is located;
- implementation of navigation measurements on the entire territory of the globe (globality) regardless of the nature of the terrain, time of day and meteorological conditions;
- use of SNS to control air traffic over areas where it is impossible to install ground radio equipment.

Disadvantages of the system include the need for the mandatory use of ground equipment to monitor the ASE and communicate with it, knowledge of variable satellite coordinates, replacement of the ASE when the equipment installed on it fails or when the height of the orbit drops below the acceptable level.

Due to the high cost of SNS, they are built multi-purpose. Only with a large number of consumers do satellite systems become economically justified.

<i>Кафедра авіоніки</i>				НАУ 130429000 ПЗ				
<i>Виконав</i>	<i>Kosenko M.O.</i>			<i>Satellite navigation system</i>		<i>Лит.</i>	<i>Лист.</i>	<i>Листів</i>
<i>Керівник</i>								
<i>Консульт</i>						7.05110103		
<i>Н.Контр.</i>								
<i>Кер. пр-ту</i>								

The satellite radio navigation system consists of three main sub-systems:

- local apparatus (pad-navigation flap);
- control and supervision;
- consumer equipments.

The sub-system of the local apparatus consists of several ("Сузип'я") ASE with cross-linking and provides the output of signals necessary for determining the power of the user.

The subject of control and monitoring is tracking satellites, gathering information for forecasting plume patterns, calculating ephemerides (predictive coordinates of the wind speed ASE) and their transmission on satellites, formation of the dark hour. The sub-theme contains several points, marked on a large scale, one of which is the main point of capping.

The sub-system of the consumer equipment is equipped with the necessary equipment for determining the power and speed, and in some cases for communication with ASE and the control center and the main control point (via a satellite).

Classification of SNS.

Depending on where the PC coordinates are calculated, SNS for aviation can be divided into two groups.

The systems of the first group define the purpose of using a PC only on its side and require complex side hardware, including a BDC. The system can be both of the initial and non-initial types.

In the systems with the request of the PC, it is created only as a packet of signals that are exchanged with the PC. The navigational memory is generated on the PC board by complementing the transmitted and received (transmitted) signals. In such systems, the requirements for the stability of both genotypes (standards of frequency, phase, and time) are not very strict, but the system has a limited power supply.

In application-free push-button systems, the navigation memory is determined on the PC board by adding the signal ASE received from the control unit with the signal of the board generator, until the board is stable there are very high requirements. The systems have an unlimited number of applications.

The systems of the second group use the PC as a receiver of signals transmitted from the control unit and a receiver of additional information, for example, about the flight

height. The signals from the PC are further transmitted through the satellite to the ground points where the parameters of the PC are calculated, which are then transmitted to the PC through the PC. In this way, the signals travel a long way: ASE → PC → ASE → NC → ASE → PC and therefore such a system will be less accurate and reliable than the system of the first group. It has limited access, but it provides the service with the necessary information and communication channels to meet the needs of the people, which is a great asset to the community of the group.

ASE can rotate in circular and elliptical orbits. In an elliptical orbit, the Earth is located in one of the foci of the ellipse. The parameters of such an orbit are a large a and a small half ellipse or a large half and an eccentricity

$$e = a^{-1} (a^2 - b^2)^{1/2}$$

The position of the orbit plane relative to the Earth (plane of the equator) is determined by the angle of inclination I .

The flight height H_u of the satellite is variable. It is maximal at apogee and minimal at peak. Bringing the ASE to an elliptical orbit requires less energy, but the elliptical orbit is characterized by less stability, due to the one-night movement of the satellites between them it changes accordingly. There are a number of other shortcomings, from which free kugs are free to beat.

The flight height of the aircraft ASE in the circular orbit depends mainly on the required time of its operation in the orbit (passive field), the permissible duration of the waiting time navigational definitions, necessary accuracy of measurements, etc.

If the satellite travels in a circular orbit, the plane of which coincides with the plane of the Earth's equator (the angle of inclination of the orbit $I = 0$) in the direction of its orbit (from west to east) at an altitude of $H_u = 358\ 10$ km, then the satellite hovers over the specified point of the equator. The angular velocity of the ASE is given by the full angular velocity of the Earth's orbit, and it has an orbital period that complements the Earth's day (23 h 56 min 04 iz). To observers from Earth, it will appear to be non-fluffy. Such satellites are called diurnal (stationary, synchronous), and their orbit is stationary.

The station orbit has a number of important advantages over others, because it supports the search for satellites and the guidance of antennas, which ensure direct

visibility from all points of view those ASE and a large percentage (up to 41%) of the earth's surface are covered by one satellite. However, high-power packets are required to bring out the ASE to the station voltage circuit. Due to the large distance between the satellite and the user, more powerful transmitters and power supplies are needed. Therefore, low-voltage (up to 2,000 km) and high-voltage (2,000 - 10,000 km) low-voltage (2,000 - 10,000 km) power lines were built in SNSs of the first generations.

The number of necessary satellites in the SNS is mainly determined by the waiting time for navigational measurements, the possibility of determining the power of the PC in significant points of the earth's surface and in path navigation method. It is possible to create a satellite navigation system that allows you to practically continuously determine the power of the aircraft's movement at all points on the globe (global navigation system). It will be either a system with a large number of satellites in relatively low orbits, or a system with several stationary satellites. For example, approximately 98% of the earth's surface is controlled by these stationary satellites with an interval of 120° . Only small protective particles are outside the zone of their action.

The number of necessary satellites also depends on the navigation method. If the angular-remote sensing method is used, which ensures the measurement of the bearing angle, azimuth and distance, then the position of the PC can be found with the help of one satellite. The long-distance method requires three ASE, and the long-distance method requires four.

Stationary pressure switches are the most acceptable for global navigation systems. At a constellation from six satellites with an interval of 60° , no less than two ASE will always be observed (with the exception of the polar orbits), which allows to calculate two (with the calculation of the planes of these outputs - tp) PC coordinates.

For the navigational determination of landmarks in remote areas, it is necessary to supplement the satellites with field satellites ASE or satellites with a different orbit inclination than the stationary ones.

As a result of the imperfection of the Earth, the non-uniformity of its mass and the action of the exciting forces, (opposite of the atmosphere, the gravitational field of the Earth, the gravity of the Sun) it is necessary to overcome the pressure ASE (even the stationary voltage). and remain constant. The influence of these factors is taken into

account and predicted during the launch and flight of navigation satellites. To maintain the invariance of the mutual movement of the ASE in the network, a periodic combination of the trajectory of the satellites is provided with the help of the matching engines.

Accurate knowledge of its coordinates and wind speed is a mandatory condition for the calculation of the ASE as a navigation point. This is achieved by following the ASE from ground stations and forecasting its dust. Ephemerides are periodically transmitted to the satellite, stored there in the chat function, and then issued to users at the time of navigation determinations. The greater the height of the beat, the worse the action of the cells that excite, and the shorter the required ephemeris.

In principle, all the measurement methods used in navigation with the help of ground navigation points can be copied in SNS:

- angular;
- angular-long-range;
- long-distance communication;
- late-distance communication.

The speed of the PC is measured by the Doplepiv method. In practice, all methods related to the calculation of angular coordinates are excluded, because at large distances between PC and ASE, they lead to low accuracy of determining the location coordinates.

The greatest accuracy is provided by remote control systems. Thus, ASE allows to determine one spherical position surface, then to calculate the power of the aircraft, it is necessary to measure the distances to the three satellites at the same time. But if one of the coordinates is determined on the PC side (for example, flight height), then only two ASE will be required.

From the point of view of technical implementation, remote control systems are similar to remote control navigation systems, such as "Lopan - A", "Lopan - C", "Omega" and others. The advantage of them is the unlimited possibility of uploading, more like a bot app (there is no video editor), so they are promising. However, in terms of precise haptic techniques, these systems are somewhat remote. In addition, more satellites per unit are needed to determine the power of moving objects than in long-range targets, because one surface position is necessary two padionavigation points.

An indispensable condition for the accurate determination of PC coordinates with the help of the ASE is the exact connection of the results of the measurements in time. For this, it is necessary to have a high-precision clock on Earth, on a ASE, and on a PC, which ensures the formation of mental time scales, coordinated with each other and showing the actual time with high accuracy. The clocks of the ground points are synchronized according to the hours of the general daily service, the ASE - according to the hours of the Main Monitoring Point, and the PC - according to the hours of the ASE. At the same time, an amendment is introduced to the time of hissing of time signals from one point to another. For example, if the distance from the main monitoring point to the ASE is 30,000 km, and the distance from the ASE to the PC is the same, then the transmission of accurate time signals from the Earth to the PC via the satellite is delayed it is $0.2 c$, which must be taken into account.

SNS radio equipment operates in the ultra short waves range, and therefore radio communication between the terrestrial (near-terrestrial) computer is possible only within the limits of radio visibility. In this connection, the concept of visibility of a ground point, PC and ASE is introduced.

The visibility zone of the ground point (tracker) is the area of the location of the satellite, within the limits of which there is direct communication between the satellite I and the ground point C (Fig. 3.1).

The area of visibility of the computer

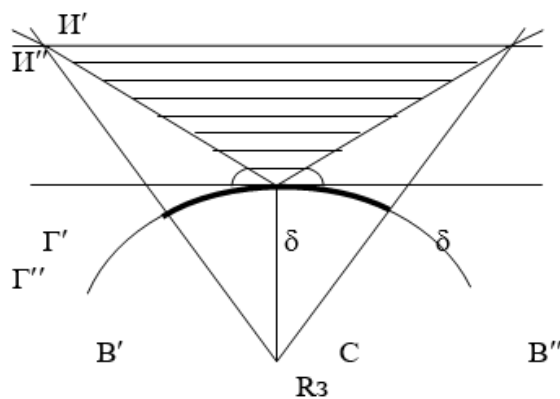


Fig. 3.1.

Geometrically, it is a plane located above the horizon of the point of the receiver (above the plane $\Gamma\Gamma''$). But the direct connection between the points Π and C is ensured only at the corners of the ASE, which exceed the minimum value of 10° . Therefore, the actual visibility zone of the ground point is the area of the top within the boundaries of the tip with the forming $C\Pi'$ and $C\Pi''$ and with the apex at point C (the protected part). It is defined in the same way as the visibility zone of a terrestrial computer, but it is considered permissible to allow the fact that communication is possible from any corners of the earth, starting from $\delta = 0$.

The zone of visibility of the ASE is a set of terrestrial or terrestrial cells, from which the ASE, located at a height above the Earth, is visible at angles of power exceeding 90° (Fig. 3.2), which are hidden I am between the direction of the satellite and the horizon. At the same time, communication between satellite I and all specified points on the ground surface is provided. This zone is unambiguously determined by the central angle ε , because in the case of the Earth R with the known thermodynamic force from the triangle of the $\Pi K \Pi$, we obtain

$$\frac{\sin(90^\circ + \delta)}{H_{\Pi} + R_3} = \frac{\sin \alpha}{R_3}$$

$$\frac{\cos \delta}{H_{\Pi} + R_3} = \frac{\cos(\varepsilon + \delta)}{R_3}$$

$$\varepsilon = \arccos\left(\frac{R_3 \cdot \cos \delta}{H_{\Pi} + R_3}\right) - \delta$$

$$r = \frac{2\pi R_3 \varepsilon_0}{360^\circ}$$

The visibility zone is ASE

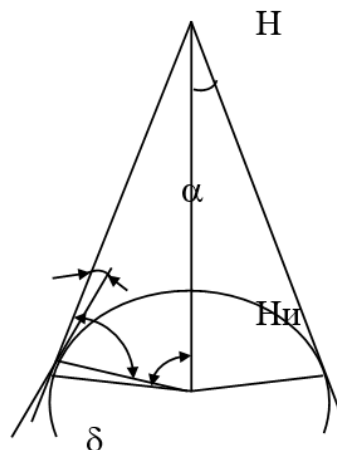


Fig. 3.2.

$$\sin(90^\circ + \delta) / (H_u + R_3) = \sin \alpha / R_3$$

from where

$$\cos \delta / (H_u + R_3) = \cos(\varepsilon - \delta) / R_3$$

than

$$\varepsilon = \arccos[R_3 \cos \delta / (H_u + R_3)]$$

It is considered that from the height of the PC flight, the satellite is visible at the corners of the earth, starting from zero. Therefore, the area of visibility of the ASE from the PC will be larger than from the earth's surface.

It is obvious that the satellite's visibility zone is the spherical surface on the Earth covered by one satellite at its given position. The greater the height of the flight ASE, the larger this zone. It represents a circle of the Earth's surface, the center of which is the projection of the satellite on the Earth, which is called the satellite point (point C in Fig. 4.2), with a radius (length arc of the central angle), perpendicular to the horizontal

$$l_{iner} = (2\pi R_3 \varepsilon_0 / 360^\circ)$$

For example, for $H = 10,000$ km, the visibility zone will add up to 6,383 km, and $\varepsilon = 57.5^\circ$. For $H = 35,810$ km, $r = 7937$ km, and $\varepsilon = 71.5^\circ$.

To determine the strength of the PC, it is necessary to perform several tests overnight ASE. Geometrically, this will be the area of the earth's surface (or the earth's orbit) common to the visibility zones of all the following ASEs.

Writing the problem of determining the path speed V_p , the path angle Ψ is reduced to the calculation of these components of the radial speed of convergence of PC with ASE. For this, it is necessary to measure these distances in two steps in the given solid coordinates, by changing which, at time τ , the structural travel speeds in these solid coordinates are determined. And, first, the travel speed and the travel angle are determined by this structure.

When using the SNS, all navigation tasks are performed automatically with the help of the BCM with minimal operator input. The field of the crew is reduced only to turning on the equipment and controlling its operation. All the calculated measurements necessary for flying the aircraft are displayed on the corresponding indicators, and a part

of them is fed to the ACS for the automatic control of the PC according to the set point-and-shoot pattern flight path.

The accuracy of determining the power of PC movement is a function of the coordinates of the satellites, drawn between the PC and the ASE and the errors of the named quantities, as well as the relative position of the satellites and the PC. At the same time, the accuracy of the data of the ASE memory depends on the errors of the measurement and the prediction of the parameters to be cut.

Until now, the well-known haptics of SNS "Навстар" are quite well-known.

With the help of ASE, the hours of users (computers, PCs and other dry objects) are synchronized, their coordinates and speeds are calculated. SNS "Навстар" is used to create system time.

The ASE family of this SNS consists of 24 satellites, fully distributed in three circular orbits with an inclination of 63° , an altitude of 20,183 km and a period of 12 hours. This system allows you to track at least 6 satellites at any point of the globe at one time and select the 4 most favorable ones from them. Satellite navigation equipment includes two transmitters with fixed frequencies, the reading of which allows the PC to determine and introduce a correction to the origin of the radio speed waves in ionosphere and troposphere. The transmission of ephemeris information and time signals is achieved by the phase modulation of the alternating oscillations.

Advanced PC hardware provides signal transmission, speed measurement, time scale synchronization, and coordinate and speed calculation. The Central Office manages BCM the detailed documentation; she will knock ASE out of the country. The accuracy of determining the initial coordinates can be 10 m, and the travel speed 0.03 m/c. in the course of tests of famous experimental aircraft (helicopter and aircraft) received standard quadratic errors of coordinate determination from 4 to 30 m, and 5 - 22 m.

With such precisions, SNSs can be effectively used not only for flights on warm roads, extraterrestrial routes and in the area of air support, but also for landing on an order.

Since the end of the 1960s, SNS machining of the "Транзит" type has been found abroad in a complex with the "Omega" radio navigation remote control system. The structural scheme of SSN is shown in Fig. 3.3

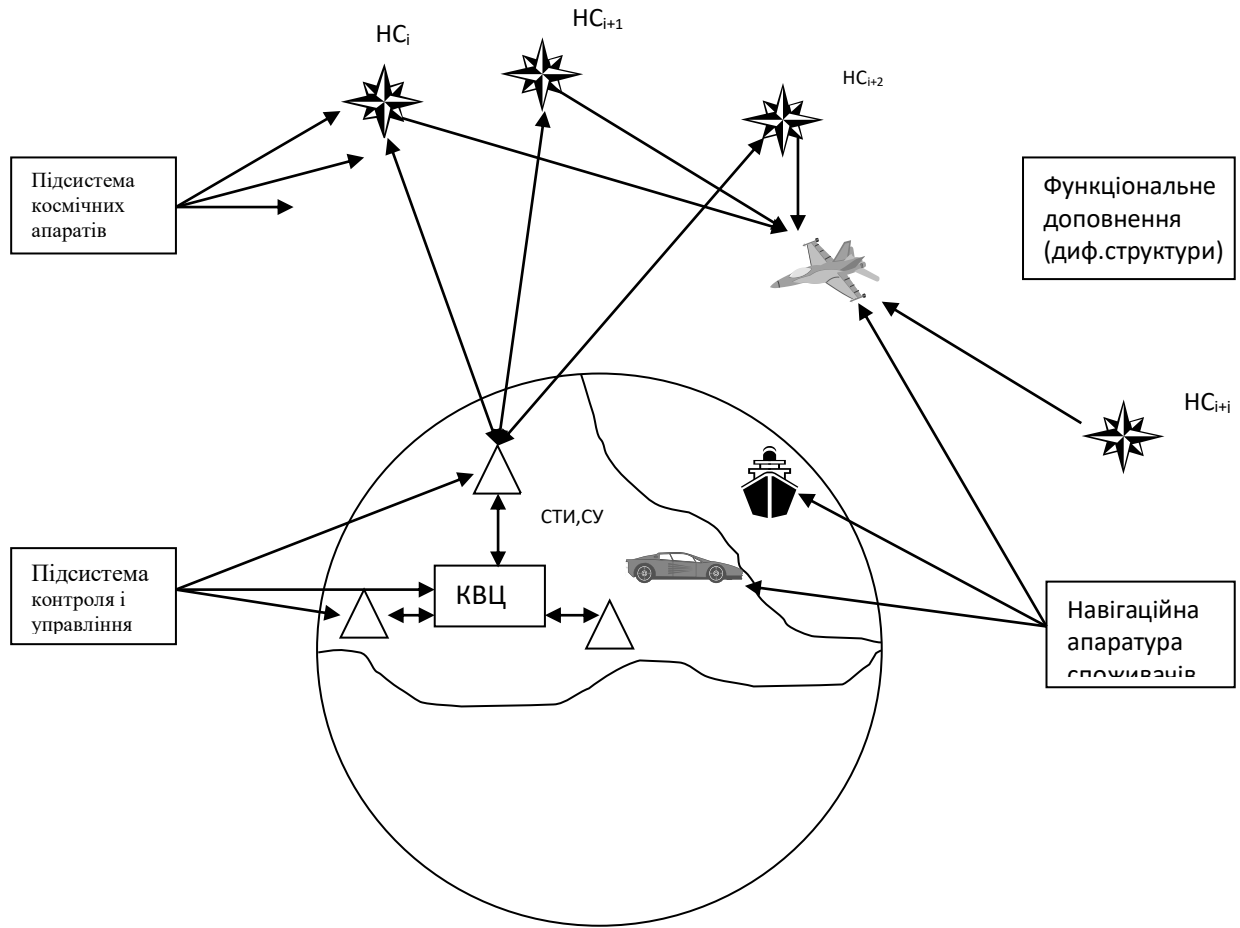


Fig.3.3

3.2. Parameters of ASE orbits

The parameters of the ASE orbits can rotate in circular and elliptical orbits. In an elliptical orbit, the Earth is in one of the foci of the ellipse.

The parameters of such an orbit are the major a and minor b of the semi-axis of the ellipse or the major semi-axis and eccentricity $e = a^{-1} \left(a^2 - b^2 \right)^{\frac{1}{2}}$

The position of the plane of the orbit relative to the Earth (plane of the equator) is determined by the angle of inclination I (Fig. 3.4.).

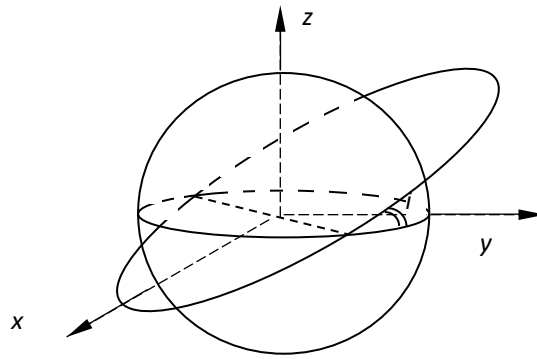


Fig. 3.4.

The height of the H_{ASE} flight of the satellite is a variable value. It is maximum at apogee and minimum at perigee. Bringing ASE into an elliptical orbit requires less energy expenditure, but the elliptical orbit is less stable, as a result of which the relative location of the satellites changes over time. There are also a number of other disadvantages that circular orbits are free from.

The height of the flight of the ASE in a circular orbit is chosen mainly depending on the necessary time of its existence in the orbit (passive flight), the acceptable duration of the waiting time and the necessary accuracy of navigation measurements, etc.

If the satellite moves along a circular orbit, the plane of which coincides with the plane of the Earth's equator (the angle of inclination of the orbit and = 0) in the direction of its rotation (from west to east) at an altitude of 35810 km, then the satellite hovers over a certain point of the equator. The angular velocity of the ASE becomes equal to the angular velocity of the Earth's rotation, and it has a period of rotation equal to a sidereal day (23 h 56 min 04 s). To an observer from Earth, it will appear motionless. Such satellites are called diurnal (stationary, synchronous), and their orbit is stationary.

The stationary orbit has a number of important advantages over others, because the search for satellites on it and the pointing of antennas are significantly simplified, constant radio visibility is ensured from all observation points of the ASE and a large overlap (up to 41%) of the earth's surface with one satellite. But high-powered rockets are needed to launch the ASE into a stationary orbit. Because of the long distances between the satellite and the consumer, more powerful transmitters and power sources are needed. Therefore, low-altitude (up to 2,000 km) and medium-altitude (2,000...10,000 km) SNS were used in the SNS of the first generations.

The number of satellites required in SNS is determined mainly by the waiting time of navigation measurements, the ability to determine the location of aircraft at various points on the earth's surface, and the method of radio navigation. It is possible to create a satellite navigation system that allows you to almost continuously determine the location of the aircraft at all points on the globe (global navigation system). It will be either a system with a large number of satellites in relatively low orbits, or a system with several stationary ASE. For example, approximately 98% of the Earth's surface is monitored by three stationary satellites with an interval of 120° along the orbit. Only insignificant circumpolar regions are outside their sphere of influence.

The number of required satellites also depends on the method of radio navigation. If the angular-range-measuring method is used, which provides measurement of the angle of elevation, azimuth and range, then the position of the aircraft can be found with the help of one satellite. The remote-sensing method requires three ASE, and the difference-sensing method requires four.

Stationary GPS are most suitable for global navigation systems. In the case of a constellation of six satellites with an interval of 60° , at least two ASE will always be observed (with the exception of around the polar regions) at the same time, which allows you to calculate two, and with the use of aircraft altimeters, three coordinates of the aircraft.

For navigational determination of parameters in the polar regions, it is necessary to supplement the constellation with polar satellites or satellites with a different inclination of orbits than stationary ones.

Due to the non-sphericity of the Earth, the inhomogeneity of its mass and the action of disturbing forces (atmospheric resistance, the Earth's gravitational field, the attraction of the Sun and the Moon), the parameters of the ASE orbit, even a stationary one, do not remain constant. The influence of these factors is taken into account and predicted during the launch and in flight of navigation satellites. To maintain the constancy of the mutual location of the satellites in the constellation, periodic correction of the satellite trajectories is provided with the help of correction engines.

A prerequisite for using ASE as a navigation point is the exact knowledge of its coordinates and speed of movement. This is achieved by observing the ASE from ground

stations and predicting its movement. Ephemeris are periodically transmitted to the satellite, stored there as a function of time, and then issued to consumers at the time of navigation determinations. The higher the height of the orbit, the less the effect of disturbances and the less often it is necessary to transmit ephemeris to the satellite.

3.3. Classification and construction schemes of integrated inertial-satellite systems

In addition to accuracy requirements, navigation systems are currently subject to such parameters as integrity, availability, and continuity of navigation support. The measure of integrity is the probability of detecting the departure of the operating characteristics of the system (first of all, accuracy) beyond certain limits and reporting this within a given time interval. Availability is determined by the probability of the consumer receiving reliable information at a given time with the required accuracy. Continuity is characterized by the probability of providing the consumer with reliable information at a given time interval. Reliability, in turn, is defined as the ability of the navigation system to maintain its characteristics within the required limits with a given probability at a certain time interval in some area. Ensuring the required level of these indicators is often a more difficult task than ensuring the required accuracy of navigation measurements.

Ensuring the specified levels of accuracy and specified quality indicators of reliability imposes special requirements on modern and promising aircraft navigation systems.

As already mentioned, among the main modern on-board navigation systems, first of all, inertial and satellite navigation systems should be included. Inertial navigation systems have long been standard equipment of modern aircraft. The aviation standard for high-precision INS of civil aviation aircraft is considered to be an accuracy corresponding to an error of determining the coordinates of 1 nautical mile per flight hour (1.8 km per hour). There are known examples of the implementation of more accurate inertial systems, in which the error of determining the coordinates does not exceed several hundred meters per hour of flight. Satellite navigation systems began to be actively used

as aviation navigation systems only in the last decade and are quickly gaining a place in the standard composition of onboard equipment. This is facilitated, first of all, by their high accuracy, which for an open channel is 10...15 m. But the experience of SNS operation has shown that despite many positive qualities, SNS cannot satisfy all the requirements for the quality characteristics of navigation support proposed today. listed above. The disadvantage of SNS, related to the lack of information about the angular orientation, is removed in specialized satellite receivers with three or more antennas.

The disadvantage of SNS, related to the lack of information about the angular orientation, is removed in specialized satellite receivers with three or more antennas.

Due to the different physical nature and different principles of formation of navigational algorithm support, INS and SNS complement each other well. Their joint use allows, on the one hand, to limit the growth of INS errors and, on the other hand, to reduce the noise component of SNS errors, increase the rate of information delivery to on-board consumers, and significantly raise the level of immunity. At the current stage, the core of the integrated system is the INS due to its autonomy and the ability to provide the consumer with both positional and angular information with a high recovery rate. As part of integrated inertial-satellite systems, platformless inertial systems are most often used. This is due to their increased reliability, lower weight and dimensions, lower energy consumption. The absence of a platform also determines, as a rule, a shorter time for setting up the system - a mandatory procedure for the primary determination of the orientation of the sensitivity axes of the accelerometers and the initialization of coordinates and velocities. The main task of BINS is to provide navigation parameters (coordinates and components of the velocity vector), as well as angular orientation parameters of on-board consumers in real time in the correction mode from the satellite navigation system.

Until recently, the degree of integration of inertial-satellite systems in the PNC was such that complex information processing was more often used only during its secondary processing, i.e. at the stage of solving the navigation problem. However, the steady growth of requirements for the equipment of SNS navigation users, as well as the significant expansion of the range of solved problems, cause today an increasingly urgent need to integrate inertial-satellite systems during the primary processing of information,

that is, at the stage of processing radio navigation parameters. This is fundamentally new in increasing the degree of integration, that is, it leads to the appearance of inertial-satellite systems of the integral type.

Complex secondary processing of information gives a significant positive effect when the relevant meters are operational, that is, at the outputs of the radio navigation meters, in particular at the output of the correlator of the SNS receiver, there are quite "good" (of course, in such cases there are tracking errors) signals generated as a result primary processing of information. The real conditions of use of the equipment of navigation consumers show that many measuring devices, and, first of all, radio technical satellite navigation systems, are far from always in a working condition. In real conditions, it is not uncommon to observe a breakdown of satellite signal tracking, in particular, due to multiradiation and the effect of other interferences, capture of false signals, etc.

The use of combined receivers capable of simultaneously receiving SNS GLONAS and GPS signals marks a new, qualitatively higher level of navigation service. As you know, the combined grouping of GLONAS and GPS satellites in the field of vision of any consumer at any moment in time allows having 10...21 satellites, so combined receivers, for example, offered by the companies Honeywell, Ashtech, "Orizon-Navigation" and others, when integrating radio navigation fields, make it possible to significantly increase the number of received radio signals from various visible satellites, improve accuracy, reduce the time of obtaining the first coordinates, increase integrity, etc. For dynamic consumers, the ability to improve integrity characteristics by sharing both SNSs is very important along with ensuring high accuracy and immunity. Neither the GLONAS system nor the GPS (NAVSTAR) system individually meet the integrity requirements, for example, when used as the primary means of navigation for air users during approach and landing.

In order to achieve the maximum positive effect from the integration of GLONAS and GPS receivers, it is necessary to carry out a deep structural and functional unification of them at the level of primary processing of radio signals, forming integrated navigation equipment based on the solution of the corresponding synthesis problem.

When building an integrated GLONAS/GPS SNS, especially for airborne maneuverable objects, its additional integration with the INS at the level of secondary

information processing with the additional use of the initial information of the INS about the acceleration in the code tracking loop and the Doppler shift of the carrier frequency is assumed, i.e. at the level primary processing of information.

As a result of such integration of information, the following are achieved:

- increasing the accuracy of determining the user's coordinates, height, speed and time;

- specification of orientation angles (course, roll and pitch);

- assessment and refinement of navigation sensor calibration parameters, such as gyroscope drifts, scaling factors, accelerometer shifts, etc.;

- ensuring, on this basis, the continuity of navigational determinations at all stages of movement, including in the case of temporary inoperability of the SNS receiver in cases of interference or energetic aircraft maneuvers;

- improving the characteristics of the integrity of navigation support, i.e. the ability to provide a solution to the problem of on-board autonomous integrity management (CAIM - Craft Autonomous Integrity Management) in addition to the integrity control carried out in the receiver during the joint processing of information of autonomous means (especially INS) and SNS SNS (RAIM).

Currently, schemes of possible integration of SNS and INS have been developed in four main variants:

- separate scheme;

- weakly connected scheme;

- rigidly connected scheme;

- deeply integrated scheme.

Conclusions on the third chapter

The advantages of SNS are the following possibilities:

1. Due to the high flight height of the ASE, the detection of ultra-short waves of the range, which allows to make electromagnetic oscillations and navigation measurements

with high accuracy at distance running several kilometers from the point above which the satellite is located;

2. Navigational determinations according to the entire topography of the globe (globality) regardless of the haptic level, the time of day, and the metooctane;

3. Excavation of systems for capping with warm down over the areas where it is impossible to install ground radiotechnical equipment.

Disadvantages of the system include the necessity of ground equipment for tracking and communication with ASE, knowledge of variable satellite coordinates, and replacements artificial satellite of the Earth after the failure of the equipment installed on it or the reduction of the height of the orbit below the permissible.

CHAPTER 4.

BASIC INFORMATION PROCESSING ALGORITHMS IN PNC

The main tasks of PNC as the initiator of the information provision of the LA flight are:

- collective processing of navigational information received by the LA port;
- ensuring the high efficiency of flight systems and LA complexes and overall flight safety due to the maintenance of information networks.

The high efficiency of information extraction, which comes to the LA bot, is ensured by the implementation of advanced methods of its processing. Among the modern methods of information gathering, it is necessary to highlight optimal filtering and optimal control, which are implemented in student PNCs. The best results of increasing the quality of the haptic properties of washing complexes are achieved in systems with structural superiority. Under the construction of the PNC, we mean the possibility of receiving pilot and navigational information in parallel with the reading of signals from devices and washing systems included in the PNC structure. The information received in this way is complicated.

At the present time, PNC has found the following methods of efficient processing of single information coming from several sources:

- mutual compensation and filtering of errors of measuring devices that measure one and the same navigation memory;
- optimal evaluation of the state vector with the calculation of relevant information by the controlled process and current measurements, which implements the algorithm of the optimal Kalman filter.

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<i>Виконав</i>	<i>Kosenko M.O.</i>			Main algorithms of information sampling in PNC	<i>Лист.</i>	<i>Лист.</i>	<i>Листів</i>
<i>Керівник</i>							
<i>Консульт</i>							
<i>Н.Контр.</i>							
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4.1. Scheme of compensation

C The compensation scheme received the most extensive information about the sharing of pilotage and navigation information in cases where one and the same navigation system is missing with two or more emitters, the operation of which is based on different physical principles. In this case, the compensation algorithm, which allows to significantly reduce measurement errors, is implemented according to the scheme shown in the Fig. 4.1.

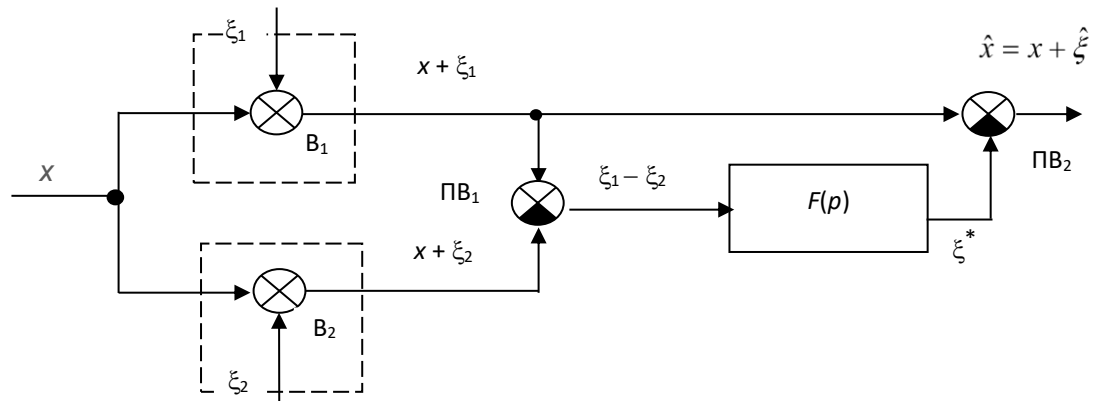


Fig. 4.1

The signals of the detectors B_1 and B_2 , which, in addition to the measured quantity x , contain error signals ξ_1 and ξ_2 , arrive at the input of the output circuit ΠB_1 , at the output of which the signal is formed

$$\xi_1 = (x + \xi_1) - (x + \xi_2) = \xi_1 - \xi_2.$$

This signal goes through the dynamic filter $F(p)$ and is subtracted from the signal of the first (compacted) system at the second stage of ΠB_2 .

The implementation of such a system can be written in the form

$$\hat{x} = x + \xi_1 - F(p)[\xi_1 - \xi_2]$$

or

$$\hat{x} = x + [1 - F(p)]\xi_1 + F(p)\xi_2 = x + \hat{\xi}, \quad (4.1)$$

where $\hat{\xi} = [1 - F(p)]\xi_1 + F(p)\xi_2$ – complex system error.

If the filter $F(p)$ is selected in such a way that it transmits the disturbance ξ_1 and suppresses the disturbance ξ_2 with a minimum, the error of the complex system will be minimal, that is, the error $\hat{\xi}$ will be eliminated varies depending on the difference

in the spectral haptic properties of obstacles ξ_1 and ξ_2 . If there is a significant difference in the frequency parameters, the output of the filter $F(p)$ (fig. 4.1) will be completely generated by the output of the filter \square_1 , and at the output of the second filter, the output of the filter will be ΠB_2 the exact value of the measured parameter x is generated, as

$$\hat{x} = x + \xi_1 - \xi_1 = x.$$

However, the peak filter, passing part of the energy of the disturbance ξ_1 , does not completely suppress the disturbance ξ_2 , as a result of which the output signal of the circuit, except for the required value x , will show an error.

According to the specified conditions, $F(p)$ must be a low-pass filter, then a filter with the characteristic $[1 - F(p)]$ is a high-pass filter. The low-pass filter can be smoothed, in the most common case, with the help of a full aperiodic circuit with a transfer function

$$F(p) = \frac{1}{Tp + 1}$$

where Tp time constant of the filter.

Transfer function of the high-pass filter

$$[1 - F(p)] = \frac{Tp}{Tp + 1}$$

is the main differentiating link.

Subject to the above, the compensation scheme shown in Fig. 4.1, can be presented as an equivalent scheme for obtaining an estimate $\hat{x} = x + \hat{\xi}$ (Fig. 4.2).

Taking into account the expected spectrum of spectral haptic parameters ξ_1 and ξ_2 – spectral densities $S_{\xi_1}(\omega)$ и $S_{\xi_2}(\omega)$, (Fig. 4.3), it is possible to present graphs of spectral haptic signals of errors ξ_1^* и ξ_2^* (dispersive error $D(\xi_1^*)$ and $D(\xi_2^*)$), obtained as a result the origin of signals through appropriate filters with amplitude-frequency response (АЧХ) $[1 - F(j\omega)]$ та $F(j\omega)$.

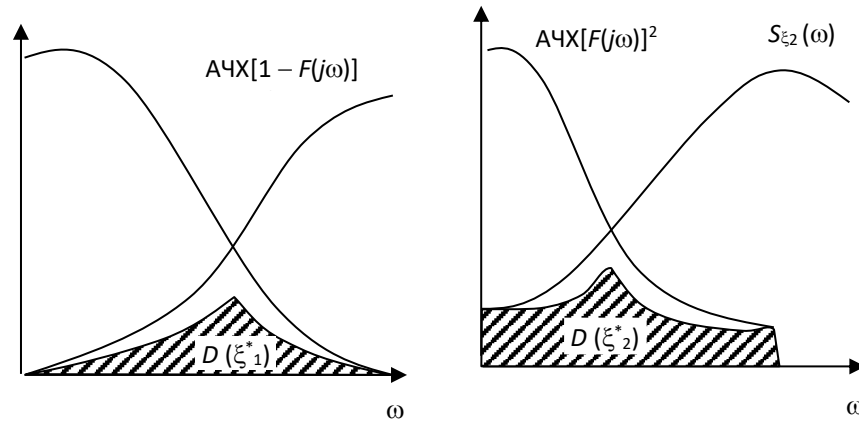


Fig.4.2

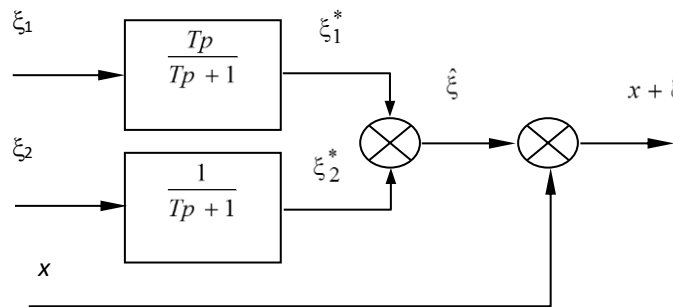


Fig. 4.3

If the errors ξ_1 and ξ_2 are stationary and statically independent random functions with spectral densities and $S_{\xi_1}(\omega)$ and $S_{\xi_2}(\omega)$, then the error variances of the output signals are determined by the formulas:

$$D(\xi_1) = \sigma_{\xi_1}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} S_{\xi_1}(\omega) d\omega, \quad D(\xi_2) = \sigma_{\xi_2}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} S_{\xi_2}(\omega) d\omega,$$

where $\sigma_{\xi_1}, \sigma_{\xi_2}$ – current quadratic errors of output signals.

The error message of the system when performing the compensation method looks like this:

$$\sigma_{\xi}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \{ [1 - F(j\omega)]^2 S_{\xi_1}(\omega) + [F(j\omega)]^2 S_{\xi_2}(\omega) \} d\omega$$

In Fig. 4.3, we can draw the conclusion that the error dispersion of the system σ_{ξ}^2 is smaller, the more the spectral densities of the input signal errors differ in frequency. Thus, the task of combining two generators is to select such a frequency characteristic of the filter $F(j\omega)$ that, after conditioning the signals (Fig. 4.2), is stored at the output of the circuit $\hat{x} = x + \xi$ was close to the measured parameter $x(t)$.

The compensation scheme can be implemented by designing a scheme with feedback (Fig. 4.4). The error rates in this case are equivalent to those obtained below for the compensation scheme without feedback.

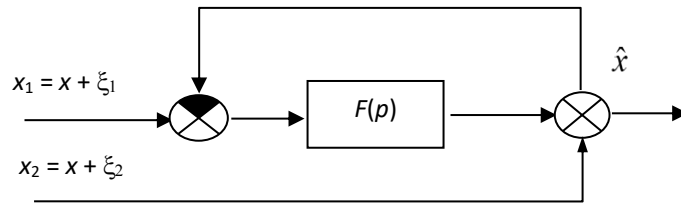


Fig. 4.4

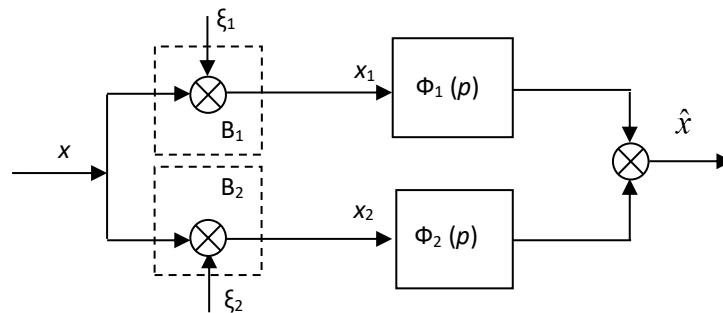


Fig.4.5

For the compensation scheme described in 4.4, you can write:

$$\hat{x} = [(x + \xi_1) - \hat{x}]F(p) + x + \xi_2,$$

where do we come from

$$\hat{x} = x + \frac{F(p)}{1 + F(p)} \xi_1 + \frac{1}{1 + F(p)} \xi_2 = x + \hat{\xi},$$

where

$$\hat{\xi} = \frac{F(p)}{1 + F(p)} \xi_1 + \frac{1}{1 + F(p)} \xi_2.$$

When $F(p) = Tp$, the error values completely coincide.

4.2. Filtering scheme

The filtering scheme in the case when one and the same memory is sampled by two generators has the form shown in Fig. 4.5.

The signal at the output of such a system is described as

$$\hat{x} = \Phi_1(p)(x + \xi_1) + \Phi_2(p)(x + \xi_2),$$

or

$$\hat{x} = [\Phi_1(p) + \Phi_2(p)]x + \Phi_1(p)\xi_1 + \Phi_2(p)\xi_2.$$

In order for the system not to generate dynamic errors, it is necessary to fulfill the condition

$$\Phi_1(p) + \Phi_2(p) = 1.$$

In this case, the output signal will look like

$$\hat{x} = x + [1 - \Phi_2(p)]\xi_1 + \Phi_2(p)\xi_2 = x + \widehat{\xi}, \quad (4.2)$$

where

$$\widehat{\xi} = [1 - \Phi_2(p)]\xi_1 + \Phi_2(p)\xi_2.$$

Thus, when $\Phi_2(p) = F(p)$, expression (4.2) converges to expression (4.1), which proves the equivalence of compensation and filtering.

4.3. Methods of optimal processing of information and PNC

The methods of optimal information processing in PNC are designed with the aim of obtaining estimates of the PC state vector (or some part of this vector) in the conditions of the influence of random events and obstacles on the network cleaning. However, not all flight memories are evaluated, but their errors.

Let the state vector of the dynamic system be described by the vector-matrix equation

$$\dot{\mathbf{X}}(t) = \mathbf{A}(t)\mathbf{X}(t) + \mathbf{B}(t)\mathbf{V}_x(t), \quad (4.3)$$

where $\dot{\mathbf{X}}(t)$ – n vector of the state of systems; $\mathbf{A}(t)$ - a quadratic matrix of dimension $n \times n$, which represents each matrix of coefficients of the system; $\mathbf{V}_x(t)$ - k vector of events acting on the input of the dynamic system; $\mathbf{B}(t)$ - matrix of events, variables.

We assume that the components of the vector $\mathbf{V}_x(t)$ are linearly related to the random functions of the white noise type, have zero mathematical expectation $M[\mathbf{V}_x(t)] = 0$ and the coupling matrix $\mathbf{R}_x(t) = M[\mathbf{V}_x(t), \mathbf{V}_x^T(t)]$.

So

$$M[\mathbf{V}_x(t)] = 0;$$

$$M[\mathbf{V}_x(t), \mathbf{v}_x^T(t)] = \mathbf{R}_x(t)\delta(t - \tau),$$

where M – symbol of mathematical wonder; $\delta(t - \tau)$ – delta function.

To the vector of the state of the system $\mathbf{X}(t)$ is connected by the ratio of the vector of the current $\mathbf{Y}(t)$ in terms of t .

$$\mathbf{Y}(t) = \mathbf{H}(t)\mathbf{X}(t) \quad (4.4)$$

In equation (4.3), $\mathbf{H}(t)$ is the connection matrix (the correlation matrix). A necessary condition for an optimal evaluation is the complete co-dependence of the state vector $\mathbf{X}(t)$ with the co-dependence vector $\mathbf{Y}(t)$.

It is considered that the vector $\mathbf{X}(t)$ is completely continuous on the interval $t \in [t_1, t_2]$, if the value of the vector $\mathbf{Y}(t)$ at $t \in [t_1, t_2]$ can be calculated from the value of the vector $\mathbf{X}(t)$ at $t \in [t_1, t_2]$. The conditions for complete care are fulfilled when $m \leq n$. Since the components of the vector $\mathbf{Y}(t)$ are simulated with errors, as a result of the simulation, a new vector is obtained, the so-called simulation vector

$$\mathbf{Z}(t) = \mathbf{Y}(t) + \mathbf{V}_z(t),$$

where $\mathbf{V}_z(t)$ – vector of extinction errors (it appears that the components of the vector $\mathbf{V}_z(t)$ can be presented as former noise with zero mathematical consumption). Vector $\mathbf{V}_z(t)$, same as vector $\mathbf{V}_x(t)$, is implemented by the coupling matrix $\mathbf{R}_z(t)$ changes $m \times n$, means

$$M[\mathbf{V}_z(t)] = 0,$$

$$M[(\mathbf{V}_z(t), \mathbf{v}_z^T(t))] = \mathbf{R}_z(t)\delta(t - \tau).$$

Pointing out that the components of the vectors $\mathbf{V}_x(t)$ i $\mathbf{V}_z(t)$ uncoupled, on the basis of the above, the mathematical model of the dynamic system and computer control can be written in the form

$$\begin{aligned} \dot{\mathbf{X}}(t) &= \mathbf{A}(t)\mathbf{X}(t) + \mathbf{B}(t)\mathbf{V}_x(t); \\ \mathbf{Z}(t) &= \mathbf{H}(t)\mathbf{X}(t) + \mathbf{V}_z(t). \end{aligned} \quad (4.5)$$

For the optimal use of pilotage and navigation information in PNC, the most important thing is the process of obtaining optimal estimates $\hat{\mathbf{X}}(t)$. The following information retrieval methods can be included in the algorithm for obtaining optimal estimates:

- method of least squares (MLS);

- the maximum similarity method;
- Pekupentny method (optimal Kalman filter).

4.4. Algorithm of evaluation by the method of maximum likelihood

The evaluation algorithm using the method of maximum likelihood, as well as the evaluation algorithm for MLS, requires the accumulation of measurements, that is, the presence of a vector of computations.

It is assumed that the measurement errors are distributed according to the normal law. Then the density distribution of the vector \mathbf{V}_{z_m} has the form:

$$P(\mathbf{V}_{z_m}) = \frac{1}{\sqrt{(2\pi)^m |\mathbf{R}_z|}} \exp\left[-\frac{1}{2} \mathbf{V}_{z_m}^T \mathbf{R}_z^{-1} \mathbf{V}_{z_m}\right] \quad (4.6)$$

where \mathbf{R}_z – copellation matrix of the extinction error; $|\mathbf{R}_z|$ – determinant of the matrix \mathbf{R}_z .

The use of the scoring algorithm using the maximum likelihood method provides for the fulfillment of the condition $|\mathbf{R}_z| \neq 0$, that is, the matrix \mathbf{R}_z should not be singular. The expression for the probability function has the following form:

$$\psi(\mathbf{X}) = \frac{1}{\sqrt{(2\pi)^m |\mathbf{R}_z|}} \exp\left[-\frac{1}{2} (\mathbf{Z}_m - \mathbf{H}\mathbf{X}_m)^T \mathbf{R}_z^{-1} (\mathbf{Z}_m - \mathbf{H}\mathbf{X}_m)\right],$$

which represents the density of the distribution of measurement errors.

It is necessary to find an estimate $\hat{\mathbf{X}}_m$, at which the probability function $\psi(\mathbf{X})$ converges to a maximum, which corresponds to the minimum squared deviations of the measured coordinates of the vector \mathbf{X} from their time another meaning. For this, it is necessary that

$$\frac{\partial \psi(\mathbf{X})}{\partial \mathbf{X}} = 0.$$

In practice, it is more convenient to calculate the emaximum of not the entire similarity function, but its logarithm, i.e.

$$\text{Ln } \psi(\mathbf{X}) = \text{Ln } \frac{1}{\sqrt{(2\pi)^m |\mathbf{R}_z|}} - \frac{1}{2} (\mathbf{Z}_m - \mathbf{H}\mathbf{X}_m)^T \mathbf{R}_z^{-1} (\mathbf{Z}_m - \mathbf{H}\mathbf{X}_m) \quad (4.7)$$

Taking the derivatives of the components of the vector \mathbf{X}_m in equation (4.7) and adjusting their sum to zero, we obtain:

$$\frac{1}{2} \mathbf{H}^T \mathbf{R}_z^{-1} (\mathbf{Z}_m - \mathbf{H} \hat{\mathbf{X}}_m) + \frac{1}{2} \mathbf{H} \mathbf{R}_z^{-1} (\mathbf{Z}_m - \mathbf{H} \hat{\mathbf{X}}_m)^T = 0 \quad (4.8)$$

We note that, as for the least squares estimation formula, one of the terms of expression (4.8) is the equivalent of the other. Therefore, the terms of this statement are mutually exclusive, they cannot be subtracted, so each of them complements zero. Let's see what

$$\mathbf{H}^T \mathbf{R}_z^{-1} (\mathbf{Z}_m - \mathbf{H} \hat{\mathbf{X}}_m) = 0$$

than

$$\hat{\mathbf{X}}_m = (\mathbf{H}^T \mathbf{R}_z^{-1} \mathbf{H})^{-1} \mathbf{H}^T \mathbf{R}_z^{-1} \mathbf{Z}_m \quad (4.9)$$

Expression (4.9) is the starting point for the algorithm for obtaining optimal estimates using the maximum likelihood method.

To determine these estimates, it is necessary:

- accumulate m observations – \mathbf{Z}_m ;
- know the correlation matrix \mathbf{R}_z detector error;
- to know the matrix of control connections \mathbf{H} .

The structural scheme of obtaining optimal estimates by the maximum likelihood method is shown in Fig. 4.6.

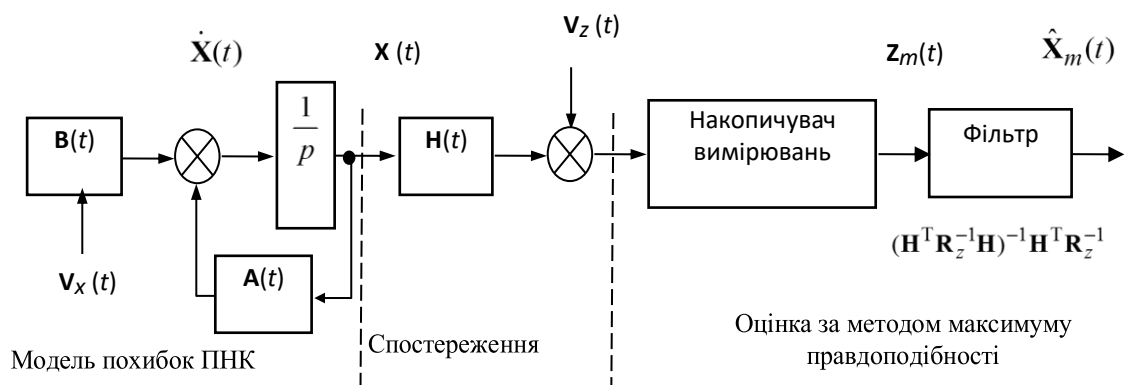


Fig.4.6.

As for the MLS scoring algorithm, obtaining a score $\hat{\mathbf{X}}_m$ is related to the accumulation of \mathbf{Z}_m measurements, so this method, like the MLS, can only be calculated after measuring one parameter several times topics In another case, the new

estimate of the PNC errors will not coincide with the current value of the errors per hour, which adds to the time of accumulation of computer requests.

Let's determine the pilot-navigation memory estimate using the method of maximum similarity based on the known readings of several sensors, the exact haptics of which are known.

LA units are simulated by a one-time satellite navigation system and INS. Indications to coordinate X по СНС = 100 км = z₁

$$\text{по ИНС} = 110 \text{ км} = z_2$$

According to the passport data, there is an error: $\sigma_{\text{СНС}} = 10_m$
 $\sigma_{\text{ИНС}} = 100_m$

Let's find the estimate of the coordinate \hat{X}

$$Z = \begin{pmatrix} Z_{\text{СНС}} \\ Z_{\text{ИНС}} \end{pmatrix}; \quad \begin{matrix} Z_{\text{СНС}} = 1 \cdot X + \zeta_{\text{СНС}} \\ Z_{\text{ИНС}} = 1 \cdot X + \zeta_{\text{ИНС}} \end{matrix}; \quad H = \begin{pmatrix} 1 \\ 1 \end{pmatrix} \Rightarrow H^T = [1 \ 1]; \quad R_Z = \begin{pmatrix} \sigma_{\text{СНС}}^2 \\ 0 \end{pmatrix}$$

$$R_Z^{-1} = \begin{pmatrix} \frac{1}{\sigma_{\text{СНС}}^2} & 0 \\ 0 & \frac{1}{\sigma_{\text{ИНС}}^2} \end{pmatrix}$$

$$1) \ H^T R_Z^{-1} = [1 \ 1] \cdot \begin{pmatrix} \frac{1}{\sigma_{\text{СНС}}^2} & 0 \\ 0 & \frac{1}{\sigma_{\text{ИНС}}^2} \end{pmatrix} = \begin{pmatrix} \frac{1}{\sigma_{\text{СНС}}^2} & \frac{1}{\sigma_{\text{ИНС}}^2} \end{pmatrix}$$

$$2) \ H^T R_Z^{-1} \cdot H = \begin{pmatrix} \frac{1}{\sigma_{\text{СНС}}^2} & \frac{1}{\sigma_{\text{ИНС}}^2} \end{pmatrix} \cdot \begin{pmatrix} 1 \\ 1 \end{pmatrix} = \frac{1}{\sigma_{\text{СНС}}^2} + \frac{1}{\sigma_{\text{ИНС}}^2} = \frac{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}$$

$$3) \ (H^T R_Z^{-1} \cdot H)^{-1} = \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2};$$

$$4) \ (H^T R_Z^{-1} \cdot H)^{-1} \cdot H^T = \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} \cdot [1 \ 1] = \begin{pmatrix} \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} & \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} \end{pmatrix};$$

$$5) \ (H^T R_Z^{-1} \cdot H)^{-1} \cdot H^T \cdot R_Z^{-1} = \begin{pmatrix} \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} & \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} \end{pmatrix} \cdot \begin{pmatrix} \frac{1}{\sigma_{\text{СНС}}^2} & 0 \\ 0 & \frac{1}{\sigma_{\text{ИНС}}^2} \end{pmatrix} =$$

$$= \begin{pmatrix} \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} \cdot \frac{1}{\sigma_{\text{СНС}}^2} + 0 \cdot \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} & 0 \cdot \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} + \frac{1}{\sigma_{\text{ИНС}}^2} \cdot \frac{\sigma_{\text{СНС}}^2 \cdot \sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} \end{pmatrix} =$$

$$= \begin{pmatrix} \frac{\sigma_{\text{ИНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} & \frac{\sigma_{\text{СНС}}^2}{\sigma_{\text{СНС}}^2 + \sigma_{\text{ИНС}}^2} \end{pmatrix};$$

$$6) (H^T R_Z^{-1} \cdot H)^{-1} \cdot H^T \cdot R_Z^{-1} \cdot Z = \begin{vmatrix} \frac{\sigma_{i\eta c^2}}{\sigma_{\eta c^2} + \sigma_{i\eta c^2}} & \frac{\sigma_{\eta c^2}}{\sigma_{\eta c^2} + \sigma_{i\eta c^2}} \end{vmatrix} \cdot \begin{vmatrix} Z_{\eta c} \\ Z_{i\eta c} \end{vmatrix};$$

$$\hat{X} = \frac{\sigma_{i\eta c^2}}{\sigma_{\eta c^2} + \sigma_{i\eta c^2}} \cdot Z_{\eta c} + \frac{\sigma_{\eta c^2}}{\sigma_{\eta c^2} + \sigma_{i\eta c^2}} \cdot Z_{i\eta c}$$

The optimal method considered above requires the accumulation of measurements or the presence of a balanced number of measurements.

CHAPTER 5.

DEVELOPEMENT OF CHARACTERISTICS OF COPYABLE INS WITH THE HELP OF HIGH-SPEED COPYCTOP

5.1. Investigating the corrected INS with the help of a fast corrector

In this section, the interaction of the INC platform with high-speed computer systems is studied, the influence of the high-speed computer on the exact haptics of navigation memory calculations is studied in the dynamics of changes in complex systems.

Special navigation systems, having a high degree of autonomy and pedestrian protection, have the ability to accumulate errors in determining the LA flight speed. In addition, the determination of all navigational parameters is made with errors, which are an oscillatory haptectep with a period of oscillations equal to the period of the Shulep pendulum. These INS properties impose strict requirements on the accuracy of basic information sensors, most of which cannot be technically implemented at this time. The way out is found in the organization of periodic compilation of INS from other navigation systems. At the beginning of the INS collection, its readings are verified with the corresponding readings of the collection system. Most often, there is an increase in speeds or coordinates due to systems.

Accurate information about the flight speed can be obtained from the onboard speed and angle sensor, or from the satellite navigation system (SSN). Coordinate information can come from navigational radiotechnical systems, from radar and optical signals, from satellite navigation systems.

On fig. 5.1 shows a possible structure of a single-component INS matched by speed signals V_k , which are expressed by a high-speed computer. Signal ΔV_k – this is the speed corrector error signal.

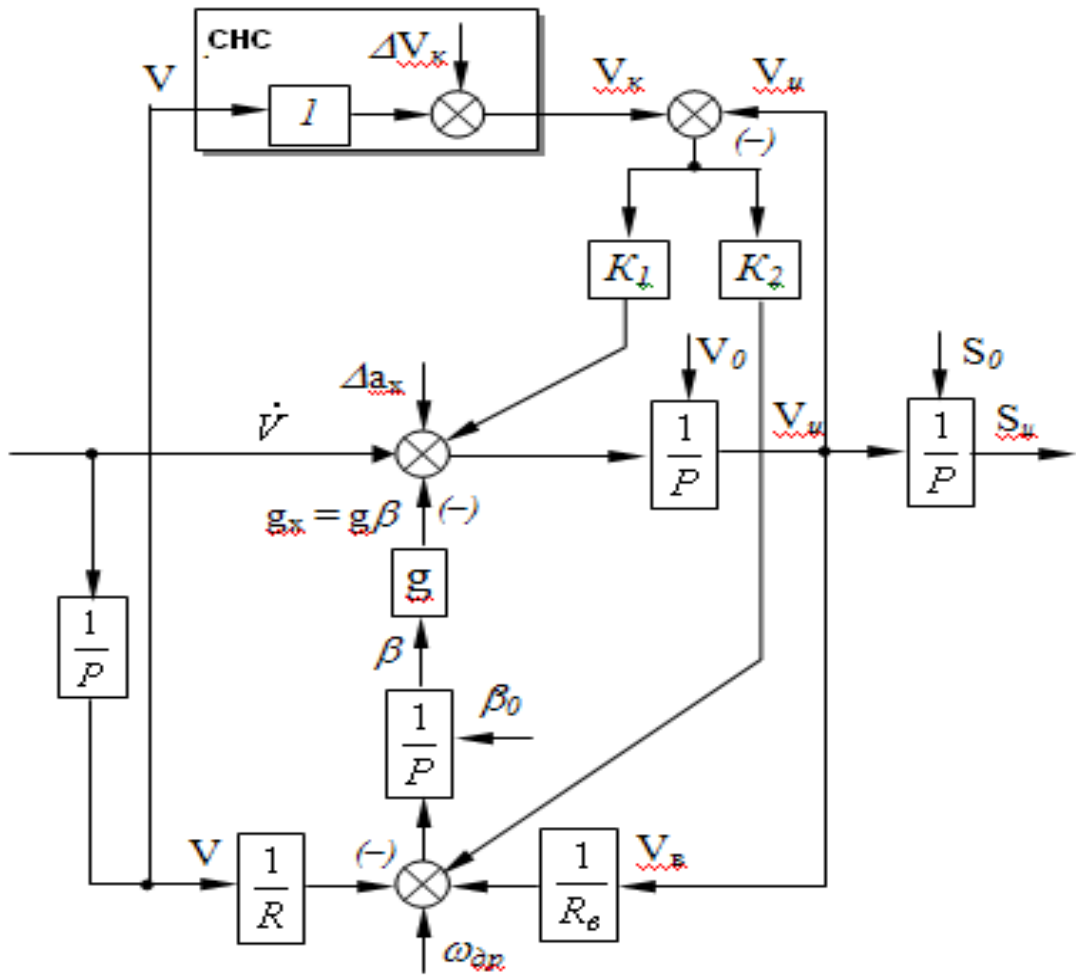


Fig 5.1

We denote the speed determination error using INS as $\Delta V_n = V_n - V$, at same time $\Delta \dot{V} = \dot{V}_n - \dot{V}$,

where V_n – speed measured INS; V – effective speed LA.

Writing down the results for the lower and upper computers of the structural scheme, $V_0 = 0$ i $S_0 = 0$ we get:

$$\begin{aligned} \dot{\beta} &= \omega_d + \frac{1}{R} \Delta V_n - K_2 (\Delta V_k - \Delta V_n); \\ \dot{V}_n &= \dot{V} + \Delta a_x - g \cdot \beta + K_1 (\Delta V_k - \Delta V_n). \end{aligned}$$

In order to improve this system, we derive a system of statements that describes INS errors in the form:

$$\begin{aligned} \dot{\beta} - \left(\frac{1}{R} + K_2 \right) \Delta V_n &= \omega_d - K_2 \Delta V_k; \\ g \cdot \beta + \Delta \dot{V}_n + K_1 \Delta V_n &= \Delta a_x + K_1 \Delta V_k, \end{aligned}$$

or in operating mode:

$$p\beta(p) - \left(\frac{1}{R} + K_2\right)\Delta V_n(p) = \omega_n(p) - K_2\Delta V_k(p) + \beta_0;$$

$$g \cdot \beta(p) + (K_1 + p)\Delta V_n(p) = \Delta a_x(p) + K_1\Delta V_k(p) + \Delta V_{n_0}.$$

The haptic determinant of the system can be written in the form

$$F(p) = p^2 + K_1p + g\left(\frac{1}{R} + K_2\right).$$

Analyzing the haptic performance, it can be noted that the introduction of the coupling contour with the amplification coefficient K_2 reduces the period of system oscillations, and the introduction of the coupling contour with the coefficient on the other hand, the K_1 amplifier provides damping of oscillations in the system.

At the same time, it should be borne in mind that the presence of a high-speed computer error causes an additional error in determining the vertical.

The value of the K_1 coefficient was taken from the assumption that (1) provides the best indicator of the minimum flow rate (damping factor), and the value of factor K_2 is determined from the condition that the free term of this function corresponds to the square of the natural frequency of the INS adjusted to the Shulep period. Taking into account the above, the optimal values of these coefficients are absolute. Value of the coefficient: $K_1=0,0073$, $K_2=1,6 \cdot 10^{-6}$

5.2. Research methodology

To study the model of a single-component INS, we use the Simulink visual modeling program, which is part of the universal mathematical software package *MATLAB*.

To implement the scheme shown in Fig. 5.2.1, to start work, it is necessary to create a new model by clicking on the same button in the *Simulink* window. Copying the Simulink library, we select the blocks necessary for the construction of the scheme and "drag" them into the clean window. For construction, we need the following blocks: *Integrator*, *Slider Gain*, *Sum*, *Scope*, *Constant*, *Step* (the names of the blocks are arranged in the order of their placement in the *Simulink* library). We connect the blocks as follows: press the left mouse button on the output of one block and, without

releasing the button, move the link to the input of another block. Connections can be deleted by selecting them with the mouse.

In this way, we get a block diagram of the INS-combining model. The block diagram of the model is shown in Fig. 5.2. The contour of the INS on the scheme is highlighted by dark circles, the composition scheme is lighter. In a specific case, the model is analyzed by speed compression.

Activating the *Simulation* menu, open the *Simulation parameters* dialog window. The window contains the *Solver* (calculation) tab - setting of modeling parameters (model calculation). On this tab, in the *Simulation time* group, set the value of the model time in seconds: initial value - *Start time* = 0.0 and final value - *Stop time* = 10000.

The input signal of the model is the parameters of the cup-like receiver in the form of the absolute pressure of the center of the mass $LA \dot{V}$. This signal is generated in the model by the *Step* block from the *Sources* section as a single discrete signal with set parameters. Double-clicking the LBM on the block opens the configuration parameters window. We set the following parameters of the input signal:

- *Step time* – signal strength = 100;
- *Initial value* – the value of the signal amplitude at the initial moment of the chat = 2;
- *Final value* – value of the signal amplitude at the end of the clock = 0;

With such an input signal, the turn of an aircraft with a lift $\dot{V} = 2 \text{ m/c}^2$ and a thrust of 100 c is simulated.

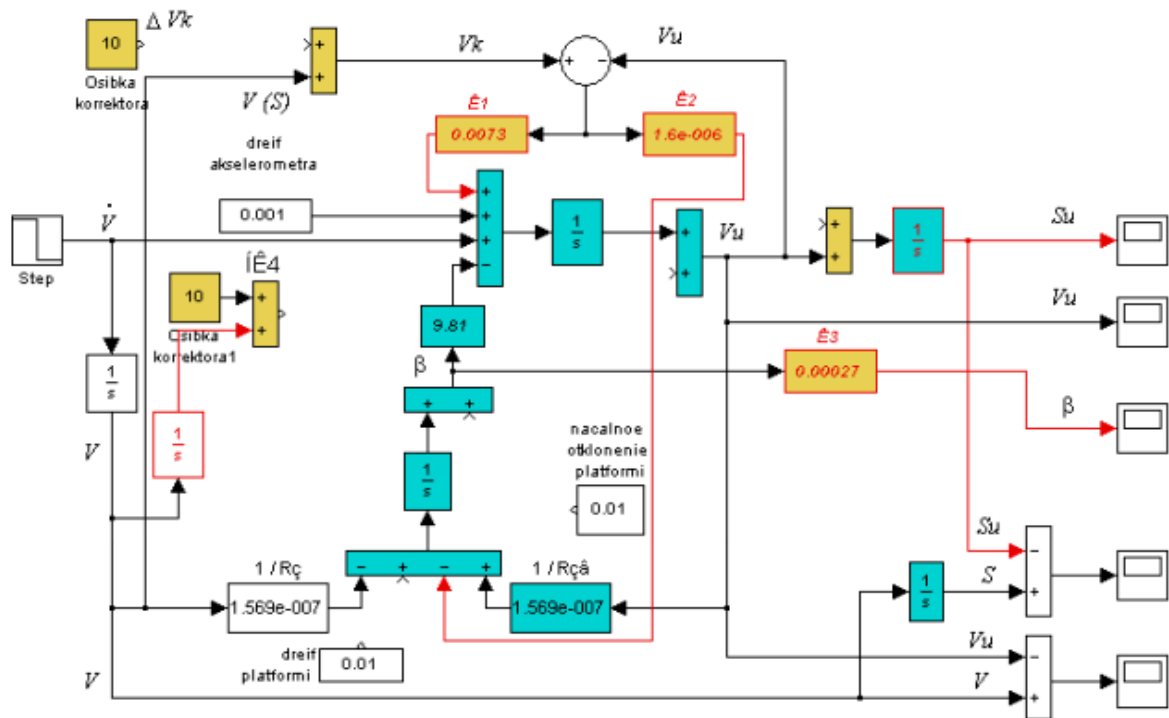


Fig.5.2.1

After the end of the simulation, we get the graphs of the current processes of all parameters:

- calculated speed V_e ;
- calculated length S_e ;
- errors in calculating the speed ΔV ;
- calculation errors are removed ΔS ;
- leveling errors β

The graphs are shown in Figures 5.2.1a-5.2.1e, respectively.

To view graphs of passing processes, double-click the LBM on the corresponding *Scope* block (oscilloscope). For managing the parameters of the *Scope* window, it has a toolbar that flashes next to the buttons. Main buttons that control scales:

Zoom - change the scale of this graphic;

- *Zoom X-axis* - scale change by the eye of the alphabet;
- *Zoom Y-axis* - scale change by the eye of the axis;
- *Autoscale* - setting the optimal scale of eyes.

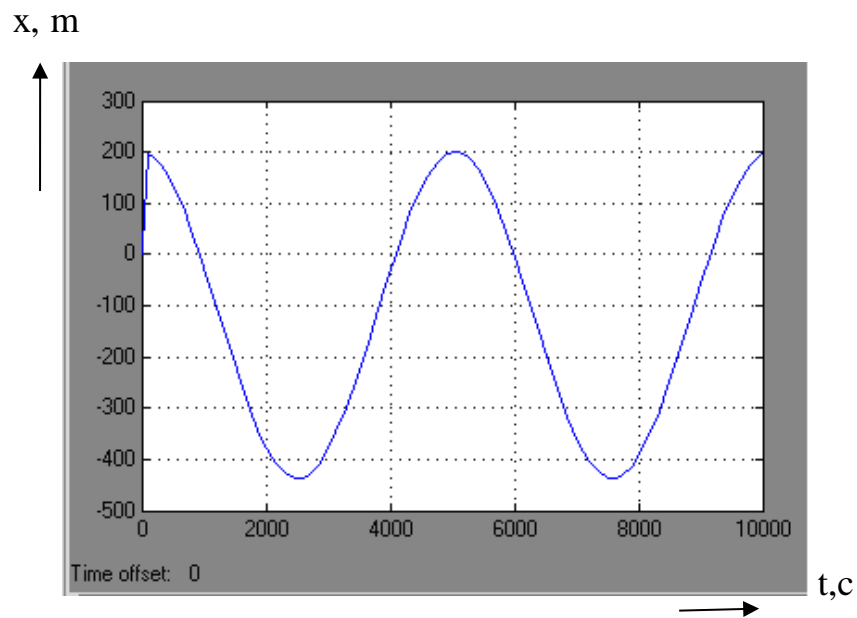


Fig. 5.2.1a

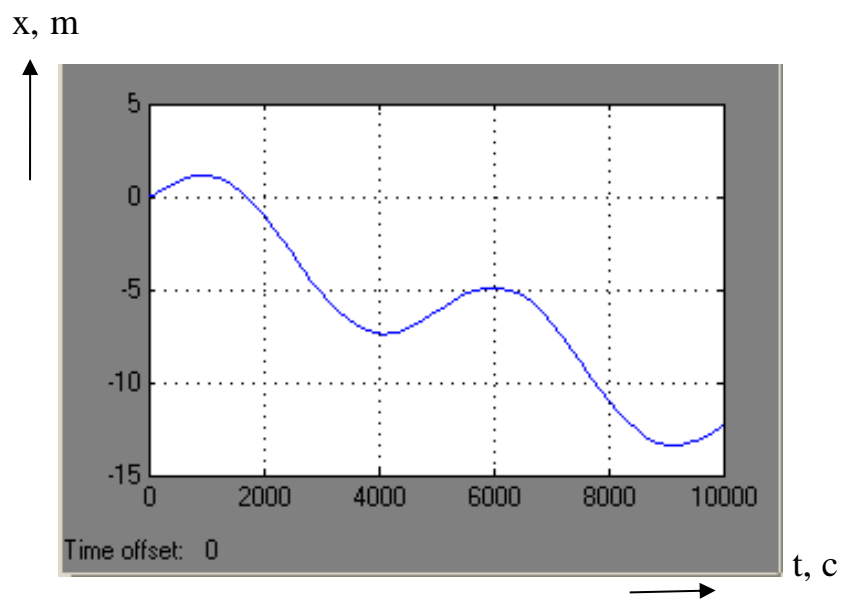


Fig. 5.2.1b

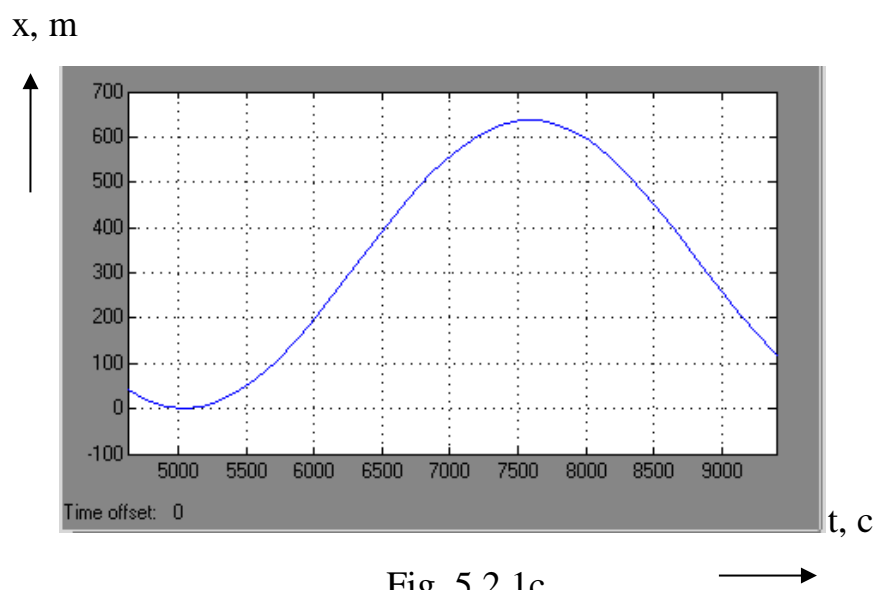


Fig. 5.2.1c

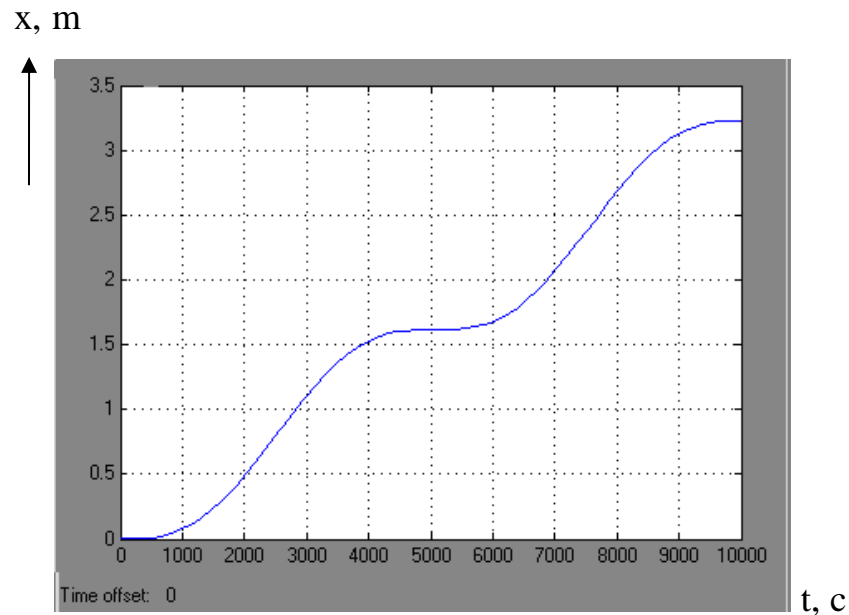


Fig. 5.2.1d

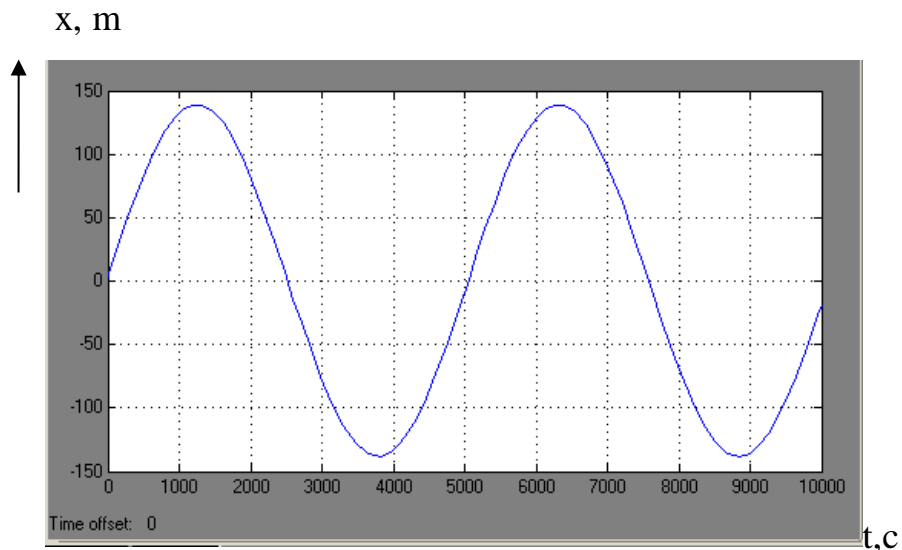


Fig. 5.2.1e

By activating the settings window of the *Constant* - "Accelerometer draft" block, set the exact draft value to $2^{m/c^2}$. (*Constant value* = 2). We connect the block to the computer.

Having made sure that all other blocks of the model that simulate events are disabled, let's start the model for writing. After the end of the simulation - graphs of the flow processes (Fig. 5.2.2a-5.2.2c):

- errors in calculating the speed ΔV ;
- calculation errors are removed ΔS ;
- leveling errors β

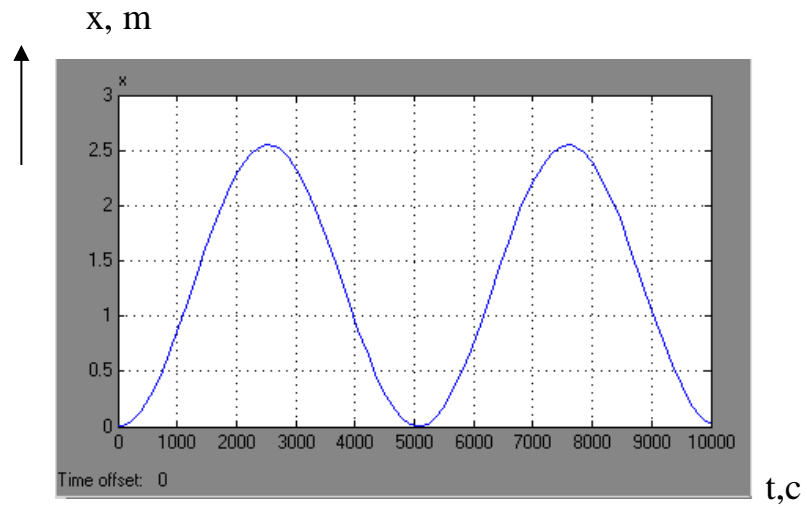


Fig. 5.2.2a

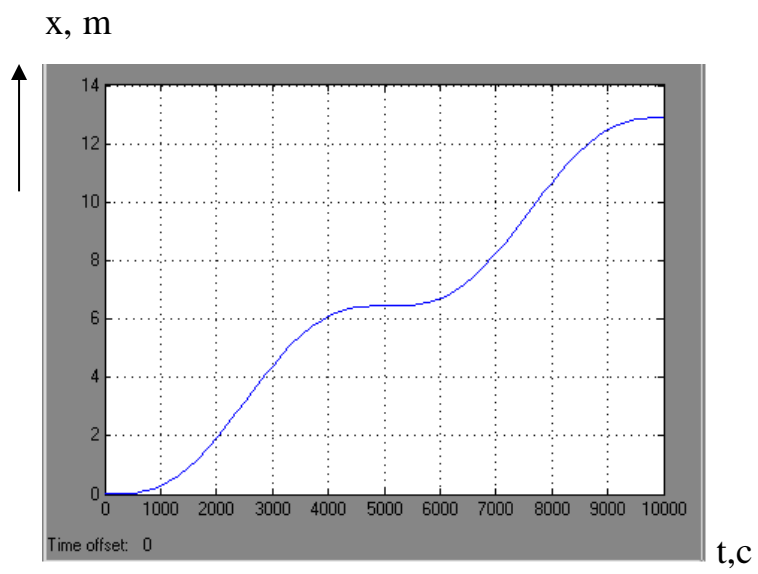


Fig. 5.2.2b

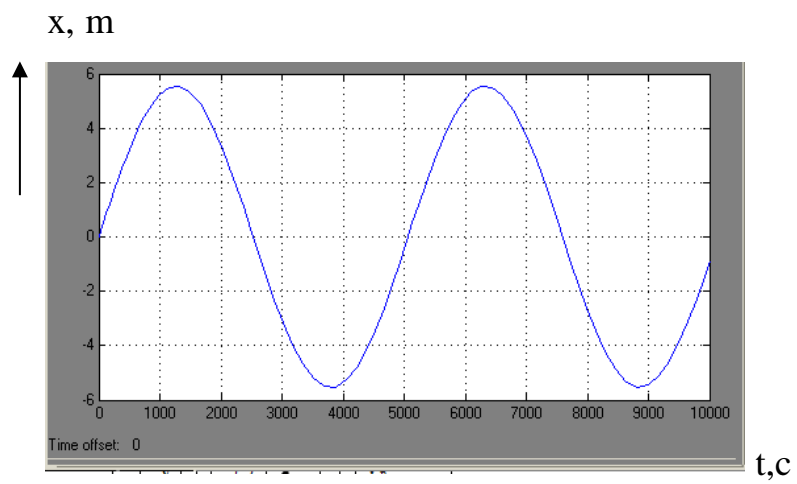


Fig. 5.2.2c

Let's connect the quick coupling scheme, that is, blocks K_1 and K_2 in accordance with the block-diagram model, having established the optimal values of the coefficients $K_1 = 0.0073$ and $K_2 = 1.5e^{-6}$.

Having made sure that all other blocks of the model that simulate events are disabled, let's start the model for writing.

Graphs of flow processes (Fig. 5.2.3a-5.2.3c):

- errors in calculating the speed ΔV ;
- calculation errors are removed ΔS ;
- leveling errors β

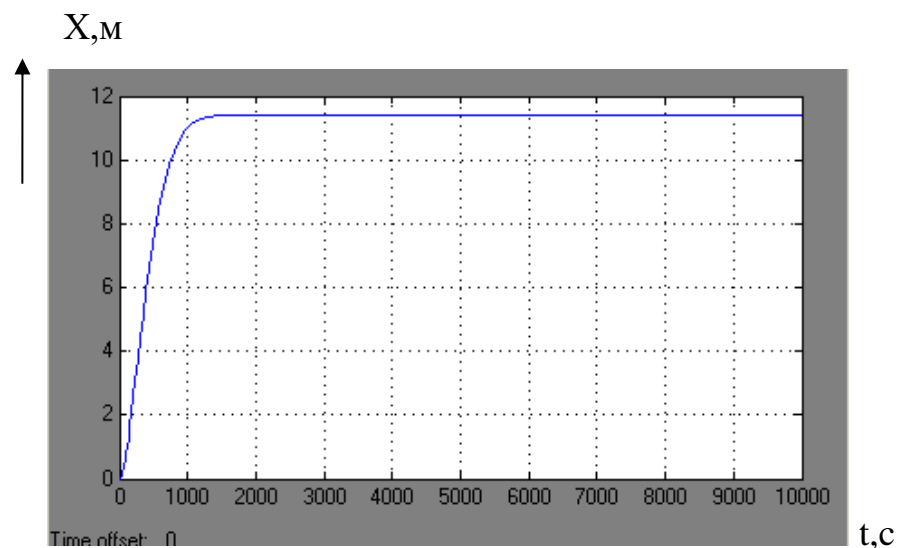


Fig. 5.2.3a

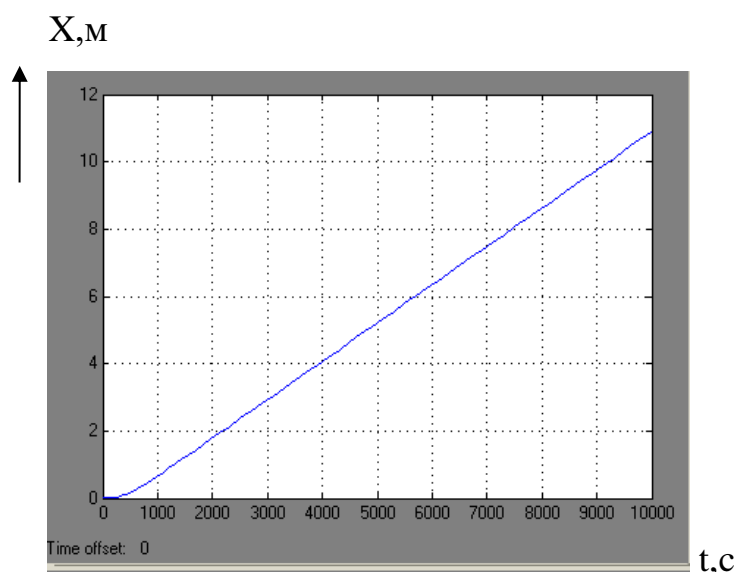


Fig. 5.2.3b

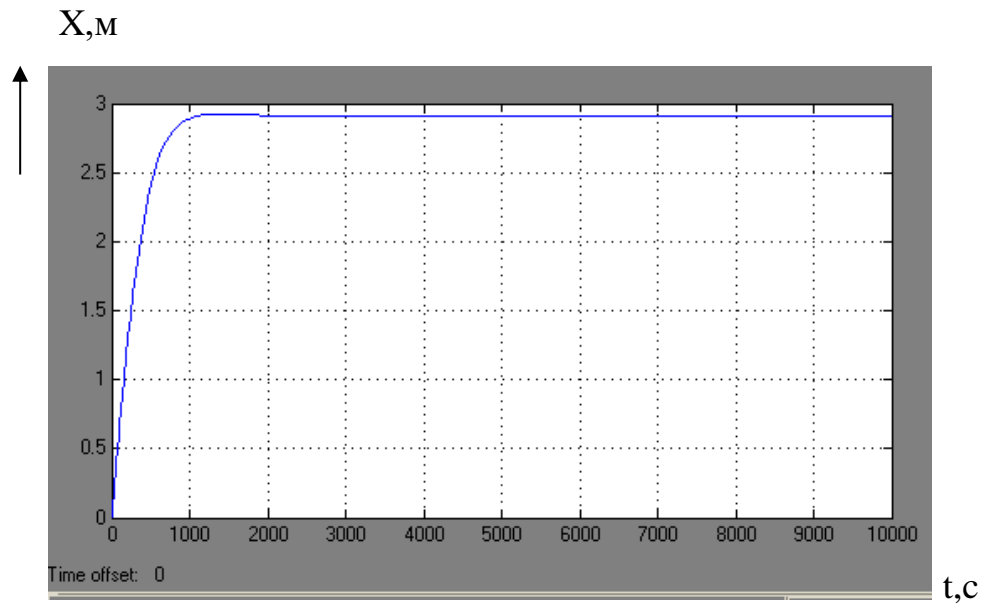


Fig. 5.2.3c

It is possible to change the values of the single optimal coefficients (recommended - $K_1 = 0.0013 \dots 0.0093$ i $K_2 = 5e^{-5} \dots 6.5e^{-6}$), analyse the change in the flow rate graphs in the same graphs at the optimal values of K_1 and K_2 .

Conclusions on the fifth chapter

The simulation results showed that inputting information from the speed corrector allows damping of INS oscillations.

CONCLUSIONS

The thesis proposed a structural diagram of an automated aircraft refueling system in the air.

A scheme for complex processing of speed correction from an inertial navigation system and a satellite navigation system has been developed.

The main goal of the work is to find the value of the estimates of the measured parameter at the specified values of the correction coefficients and to conduct research on the effect of the correction coefficients when their values deviate from the specified values and to find their optimal values based on the simulation results.

The research results showed that the processing of navigation information by the proposed method allows obtaining reliable estimates of navigation parameters with increased accuracy.

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