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ABSTRACT

of the dissertation for the degree of Doctor of Science

NON STATIONARY NAVIGATION CONTROL SYSTEM OF AIRCRAFT

Speciality: 3324.04 - Ground complexes, launch equipment, operation of aircraft and their systems

Field of science: Technical

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GENERAL CHARACTERISTICS OF THE WORK

The actuality of the dissertation work. Aircraft (AC) are the second major contributor in flight safety after the human factor. The AC is a complex machine with all its technical, reliability, operational characteristics, and all the necessary safety criterias are worked out on the aircraft designing stage.

By applying computing techniques (CT) the quality of systems determining flight-technical performance of aircraft and unmanned aerial vehicles (UAVs) has been improved, also progress in flight safety level has been achieved.

Aircraft upgrading, which is characterized by the implementing qualitive new systems and control methods, sensors and converters, primary information devices and unified computing techniques, steps into the stage of creating "intellectual" aircraft.

According to statistics, 5-10% of general aviation accidents occur as a result of spatial disorientation, 90% of them are disastrous. Therefore, measuring of roll and pitch parameters by using alternate onboard methods and techniques, as well as alerting pilots with visual and sound signaling, is one of the most actual tasks in flight safety.

The reliability of aircraft automatic control systems is determined by various factors, one of them is the accurate installation of primary information sources. This especially concerns accelerometers and gyroscopes which primary mechanical fastening and installation conditions are disrupted as a result of more dynamic loads.

The aerometric measurement of flight and navigation parameters is of great importance in development of information informativeness and reliableness received during intercontinental flights. For example, if there is a flight in the absence of navigation signals, and ground control systems (while flying over the oceans, the Poles, High Mountain ranges), the control is fully carried out by the aircraft autonomous inertial system, which imposes additional requirements on reliability and accuracy.

According to the analysis results of constructive, functional and exploitation characteristics of air data systems (ADS) by the companies «Goodrich» and «UTC Aerospace Systems» which are succesfully operated in fifth-generation military aircraft (F-22, F-35) and civilian aircraft (Embraer ERJ-170/190, Airbus A-350, A-380) shows that, the measurement of roll, pitch, yaw and the value of lateral speed are not performed by aerometric method.

The stabilization problems of Unmanned Aerial Vehicles (UAV) are primarily related to UAV's sensitivity to wind and turbulence, and increasing the UAV’s sustainability and maneuverability without raising its speed. However, these problems could not be fully solved due to the existence of short-term operation modes of spacecraft corrective jet engines, ignoring the screw rotation direction of small-scale UAV during the maneuver with horizontal take-off and landings (with horizontal lifts).

Thus, among the main existent problems for ensuring the aircraft flight safety and the reliability of remote control of the UAV, the followings can be marked: improving the reliability of primary information sources of automatic control and monitoring systems; increasing the awareness and observation level of flight-navigation and environmental parameters; the operation capacity of stabilization systems in non-stationary flight conditions.

The dissertation on «Non stationary navigation control system of aircraft» deals with the solution of number of issues related design development problems of the piezoelectric accelerometers, increasing the informativeness and observability level of flight and navigation data through digital air data systems (ADC), improvements of gyroscopic stabilization systems of UAV and automatic mass and balance monitoring systems, as well as increased flight control safety.

The aim of the dissertation is to develop new variants of the designs of piezoelectric accelerometers (PA), to expand the functionality of the Digital Air Data Systems (DADS), which contribute to the increase the level of informativeness and observability of flight and navigation data, improvement of gyroscopic systems for stabilizing the flight of UAVs, systems of safe automatic control and monitor of flight path parameters, taking into account the factor of displacement of the AC Center of Gravity.

The main tasks that have been set and solved in the Dissertation:
1. Analysis of the main problems of improving flight safety and primary information systems, automatic flight control and DADS construction.
2. New PA developments, research and simulation of the static and dynamic performance of developed PA.
3. Develop a Universal liquid angle indicator with built-in PA, equipped with visual and audio alerting the crew to the precritical values of bank and roll angles.
4. Algorithm development, research and simulation of advanced DADS.
5. Development of a device increasing the stabilizing and maneuvering ability of UAV by using gyroscopic effect.
6. Research and modeling of static and dynamic characteristics of the gyrostabilizer with an adjustable moment of inertia.
7. Development of the automatic system of the initial PA.
8. Development, research and modeling of automatic systems providing resistance to mechanical harmonic excitation.
9. Research of the longitudinal movement stabilization system taking into account the displacement of aircraft gravity center.

Research methods are based on the use of methods of theories of mathematical analysis and physics, piezoelectric converters, aerodynamics and flight dynamics, theories of automatic control, mathematical modeling, engineering and computer graphics, also the basic methods of measurement techniques.

The object of the research is the measuring systems of flight-navigation parameters and flight control system of UAV and aircraft.

The scientific novelty of the dissertation is as follows:
1. Methodology for the development of new PA.
2. General theoretical methodology for determining the conditions for the transition process, which is based on technical optimum for the developed accelerometers and for the two-mass model "drive engine-frame gyroscope" gyrostabilizer with adjustable moment of inertia.
3. Analogue Part algorithms of the improved DADS.
4. Mathematical models of a gyrostabilizer with an adjustable moment of inertia, determining the dependence of the regulation range, the

transition time and the rotation frequency from the diametric size and density of materials of the elements of the structure.
5 Logical equations of the automatic connection as a sensor and feedback sensor, relatively to the attached surface of initial automatic alignment accelerometers systems (IAAAS) of PA.
6. A dynamic model of the aircraft automatic stability system, equipped with a stabilization circuit owning a parallel-connected corrector and compensating the mechanical fluctuations occurring during the flight.
7. Structural model of the longitudinal movement stabilization system during the take-off, flight and landing, considered as the displacement of the aircraft gravity center in the disturbance moment form.

The practical importance of the work.

The methodology proposed in the Dissertation ensuring technical optimization transition process and mathematical approach can be applied to the technical systems research described by linear differentials equations of the second and higher order. Developed new accelerometers and gyroscope-accelerometer can also be applied in measurement of acceleration, vibrations and angles in industrial facilities with various transport and technological settings.

The basic principles of IAAAS can also be successfully applied to sensors, equipment and devices that require high positioning accuracy. A gyroscopic stabilization system with a controlled moment of rotor inertia, providing orientation of an aircraft can contribute to the resources development for the electric batteries operation and gas-reactive correction engines and the maneuvering dynamism. The determination method and system for the aircraft mass and centering can be integrated into the precise navigation systems of different vehicles at the same time.

Main points of the dissertation:

1. Results of a comparative analysis of the major problems of improving flight safety systems, elements and primary information converters, automatic flight control systems and DADS construction, as well as previous theoretical research of piezoelectric micromechanical accelerometers and gyroscopes.
2.Mechanisms for the development of differential micromechanical

piezoelectric accelerometers, self-adjusting piezoelectric gyroscope-accelerometer, and a universal liquid angle indicator with a system of built-in piezoelectric converters.
3. Method and device is improved DADS.
4. Method and device to improve the stabilization and maneuverability of UAVs.
5. Developed automatic IAAAS for PA installation.
6. Automatic system to ensure the stability of the aircraft in harmonic disturbance impacts.
7. Method and system for stabilizing the longitudinal movement of the aircraft, taking into account the displacement of the center of gravity.

Implementation results of the work. According to the results of the research, 7 patents for invention and 1 utility model of the Republic of Azerbaijan, 1 granted patent for an invention of the Eurasian Patent Office (EAPO), 2 granted patents for an invention of the United States, 1 positive decision for the grant of a US patent, 1 positive decision for the grant of a European patent, 1 positive decision for the grant of a EAPO patent, 3 US and European Patent Application Publication:

- İ20060050 «Reverse piezoelectric step engine», issued on May 11, 2006;
- I20150063 «Differential micromechanical vibration accelerometer», issued 01.10.2015;
- I20170043 «Liquid angle indicator (options)», issued on September 12, 2017;
- I20190047 «Piezoelectric self-adjusting gyroscope-accelerometer», issued on September 23, 2019;
- I20190048 «Method and device for increasing the stability and maneuverability of unmanned aerial vehicles (UAV) using a gyroscopic effect», issued on September 23, 2019;
- İ20210047 «Aerometric method and device (system) for measuring aircraft spatial position, yaw and lateral velocity. Aerometric method and device (system) for measuring aircraft spatial position, yaw and lateral velocity» issued on May 31, 2021;
- F20210018 «Piezoelectric-accelerometer», issued on September 10, 2021;

- İ2023 0006 «Method and on-board device for measurement of mass and balance, attitude, yaw, and balance shifting of the aircraft» issued on February 02, 2023;
- EP3236202A2 Universeller flüssiger winkelgeber. European Patent Application, 25.10.2017
- 030859 B1 «Method and device of increasing the stabilization and maneuverability of unmanned aerial vehicles using a gyroscopic effect», issued by EAPO on 31.10.2018;
- US 10,190,878 B2 «Universal liquid angle indicator». United States Patent, Jan.29, 2019;
- EP3450989A2 «Aerometric method and device (system) for measuring aircraft spatial position, yaw and lateral velocity». European Patent Application Publication, 06.03.2019;
- US 2019/0137537Al «Aerometric method and device (system) for measuring aircraft spatial position, yaw and lateral velocity». United States Patent Application Publication, (решение для выдачи патента), May 9, 2019;
- EP3621055 A1 «Universal Virtual Simulator», European Patent Application Publication 11.03.2020;
- US 2020/0143699 Al «Universal Virtual Simulator», May. 7, 2020;
- US10737770 B2 «Method and device for increasing the stability and maneuverability of unmanned aerial vehicles (UAV) using a gyroscopic effect», United States Patent, Aug.11, 2020;

Approbation of work. The main results of the dissertation were reported and discussed at the following national and international scientific-technical conferences, congresses and symposiums: the Republican Conference "The Role of Education and Science in Solving the Modern Problem of Civil Aviation" (NAA, Baku, 2002); The scientific conference "Flight Safety and Current Trends in aviation Technology Development" dedicated to the 80th anniversary of The President of the Republic of Azerbaijan H.A.Aliyev (May 8-12, 2003, Baku); The fourth International Scientific and Practical Conference "Modern Information and Electronic Technologies" (Odessa-2003); International Conference "Scientific and Technical Progress and Modern Aviation" dedicated to the 75th anniversary of academician A.M. Pashayev (Baku-2009); Problems of Cybernetic and Informatics International Conference (Baku 2010); The National

Scientific and Practical Conference "Innovative Technologies in Education and Science" dedicated to the 60th anniversary of the Azerbaijan Technical University (Baku, 2010); International Federation for the Promotion of Mechanism and Machine Science (Tbilisi-2015); Second International Scientific and Practical Youth Conference "Creative Potential of Youth in Space Solutions," February Readings, (Baku, NAA, 2017); International Symposium of Mechanism and Machine Science (Baku, AzTU, September 2017); Third International Scientific and Practical Youth Conference "Creative Potential of Youth in Space Solutions," February Readings, (Baku, NAA, 2018); Fourth International Scientific and Practical Youth Conference "Creative Potential of Youth in Space Solutions," February Readings, (Baku, NAA, 2019); Seventh International Scientific and Practical Youth Conference "Creative Potential of Youth in Space Solutions," February Readings, (Baku, NAA, 2022), Eights International Scientific and Practical Youth Conference "Creative Potential of Youth in Space Solutions," February Readings, (Baku, NAA, 2023)

Publication. The main results of the dissertation are published in 64 scientific publications. The results of the research have obtained 11 patents for invention, 2 positive decisions for the grants of a US and European patents, 3 US and European Patent Application Publication, 6 World Intellectual Property Organization WIPO|PCT Patent Application Publication, 27 articles, 14 thesis and conference reports (10 International), 40 works published in republican, 24 works published in foreign publications.

The author's personal contribution. The main scientific provisions, theoretical researches, computer simulations, conclusions and recommendations in the dissertation work, were obtained by the author independently. Realization and implementation of a number of issues was carried out jointly with the staff of the National Aviation Academy.

Scientific consultants A.M.Pashayev and T.B.Gurbanov set a number of scientific issues. Analysis and discussion of the achieved results were held together with all co-authors.

The structure and summary of the dissertation. The dissertation work consists of the introduction, five chapters and conclusion and list of literature. It contains 295 pages including 122 drawings, 2 tables and a list of literature with 402 titles.

CONTENT OF THE WORK

The introduction substantiates the urgency of the problem, defines the goals and directions of research, and provides scientific novelty, practical value of the work and the basic points of the dissertation, presented a brief characteristic of the work.

The first chapter addressed the current problems of flight safety and reliability, including the main problems of improving flight safety systems, the development of primary information systems and automatic control systems of the aircraft.

The analysis of the current state of automatic piloting systems shows that, one of the factors influencing the reliability of these systems is communication with receivers, sensors and converters of various data of the air environment, flight and navigation data, including aircraft track data, which is considered as primary information sources (PIS). As strict requirements for PIS work the need for their mounting, installation, initial adjustment issues, as well as the need for automatic devices and systems, is relevant.

It has been underlined that the most important issue in the modern civil and military aviation safety and reliability are the interaction between pilots and aircraft, with significant impact, automatic control, and information exchange techniques, in addition to a number of factors determined by professional level of pilots.

These issues are so actual and vital that a comprehensive approach is required.

The second chapter is devoted to the key issues related to the development and research of multifunctional piezoelectric accelerometers (PA), outlines the basic principles of PA construction, and compares the results of existing sensors and justifies the necessity for new design options.

It has been shown that the prevailing goal in new accelerometers development is to increase the reliability of these devices by reducing the number of parasitic mechanical transmissions and their constructive elements and to reduce their mass size.

The design and operating principles of the newly developed PEA are explained in detail.

One way to achieve this is to install between inertial and transformative elements 1 and 3 (Figure 1) special elastic elements 2, made in the form of gaskets, with the inertial mass 1 located in the center, and piezoelectric sensitive elements 4 (PSE) are composite in a differential pattern, which causes the formation of a useful signal in the form of a difference in the respective frequencies. The differential micromechanical vibration accelerometer is installed through its casing 5 at the control object. With accelerated motion, the inertial element 1 shifts, with the frequency of fluctuations decreased at the upper PSE 4, and at the lower PSE 4 the frequency of fluctuations increases (or vice versa).

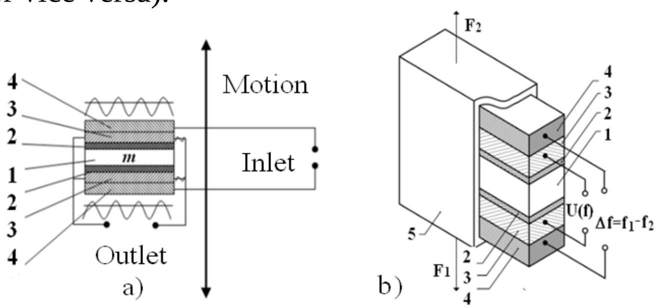


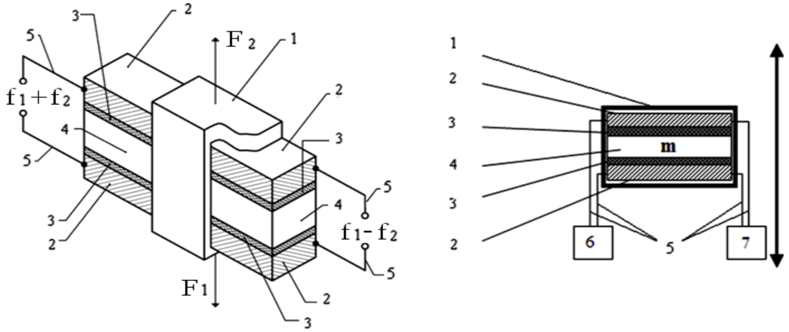
Figure 1. Elements of differential micromechanical vibration accelerometer and their electrical connections:
1-inertial element; 2- two elastic elements (insulation pads);
3-two piezoelectric converters; 4-piezoelectric sensitive elements

Based on the above mentioned argument, it is also possible to create two-channel accelerometer with PSE for measuring vibration, loading, linear acceleration, and vertical velocity and flight altitude. The PA's principle design scheme is presented in Figure 2.

The computing scheme allows measuring the vibration and overloading simultaneously (linear acceleration) (Figure 2b). For measuring vibrations in non-stationary objects, the measuring device is mounted on the front and rear supports of the engine shafts.

In the absence of acceleration or overload, the frequencies f_1 and f_2 are the same, and their difference is equal to zero ($f_1 - f_2 = 0$). The left side of the 5 electrodes connected to the summator 6 is used to measure vibration, and the right part of the 5 electrodes connected to the 7 differentiator is used to measure acceleration.

With accelerated movement, the inertial mass 4 moves downwards (or upwards), affecting gaskets 3 and piezoelectric plate 2 with power ma. In this case, the weight of the inertial mass of the piezoelectric plate 2 in the bottom part grows *m(g+a)* and increases the frequency of vibrations. At the same time, at the top of the piezoelectric plate 2 the weight of the inertial mass decreases *m(g-a)* and accordingly, the frequency of vibrations decreases.



a) b)

Figure 2. The principle design scheme of two-channel piezoelectric vibration and linear accelerometer sensor (TPVLA):
1-casing; 2-piezoelectric converters; 3-elastic elements (insulation gaskets);
4- inertial element; 5 - electrodes; 6-summator; 7-differentiator

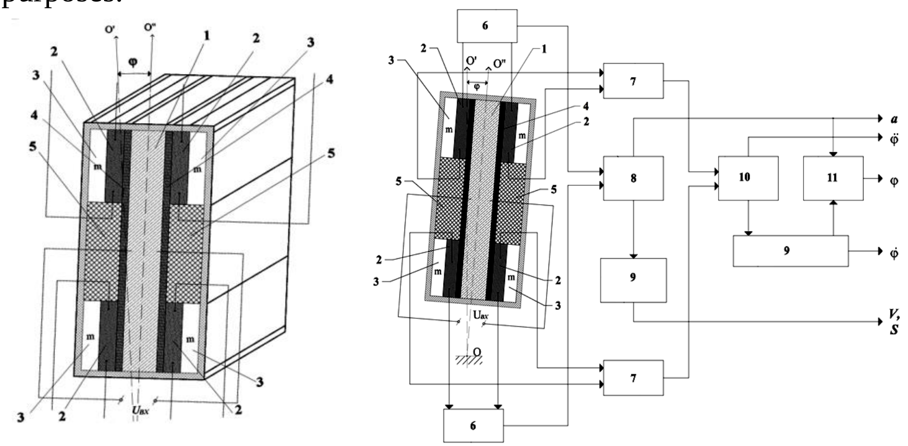
By using summator 6 measures vibration, and the 7 differentiator determines the difference of frequencies $\Delta f = f_1 - f_2 \neq 0$: that allows measurement of the level of overload, or the amplitude of linear acceleration: ($a \sim f_1 - f_2 \neq 0$).

This chapter summarizes a number of issues based on the analysis of ways to improve modern inertial-navigation systems (INS), as well as the failure of their sensors as primary sources of information:

provision of parallel measurements of different parameters (linear and angular acceleration, angular speed, angular position); increasing the linear acceleration range; correction of inclination angles by using gravitation force.

To measure such movements of proportional linear and angular accelerations, it is enough to use four outputs of the upper side of two PSE and four outputs of the lower side of the two PSE (two elements for linear and angular acceleration, in each side), as well as two different (one for linear, one for angular) measuring channel, implemented in a common design (Figure 3).

Developed a new piezoelectric self-adjusting gyroscope-accelerometer (PSGA) can be functionally classified as information-measuring equipment and is designed to measure linear and angular accelerations, angular velocity, angular positions (including their correction), and angles of the tilt of dynamic objects for different purposes.



a) b)

Fig. 3. Piezoelectric self-adjusting gyroscope-accelerometer:
Principle design scheme; b) the functional layout of the measuring system.
on scheme a): 1-excitatory piezoelements (PE); 2-sensitive piezoelements (PSE); 3-inertial masses; 4-elastic gaskets; 5-limiter; on scheme b): 6-module of acceleration definition; 7-module of linear accelerations; 8-module (computer) of linear acceleration formation; 9-integrator; 10-module (computer) of angular acceleration formation; 11-module of angular correction

The obvious advantages of the presented PSGA can be considered as followings: the simultaneous measurement possibility of linear and angular accelerations, as well as angular speed; significant growth of measurement efficiency, high linear acceleration; continuous and autonomous correction (self-adjusting) of measured tilt angles

The static characteristic equation in the generalized form is below mentioned:

$$U = \frac{1}{2} K_E m(g \pm u), \tag{1}$$

where the permanent K_E coefficient is as follows:

$$K_E = \frac{1}{1.776\varepsilon\omega Sk} \sqrt{\frac{(R_m X_a)^2 + (X^2{}_a)^2}{(R_m X^2{}_a)^2 + (R^2{}_m X_a)^2}} E \tag{2}$$

Here ε-is the permeability of the environment between the electrodes; *S*- active area of electrodes; R_m - active and X_a - reactive resistance of PSE replacement scheme; ω - the circular frequency of electro motive force (EMF) E.

Statistical characteristic of the measurement scheme (1) takes into account the piezoelectric effect capacity in the PSE substitution scheme.

The functional scheme of the PA is given in the absence of cross-connection in generalized coordinates (Figure 4).

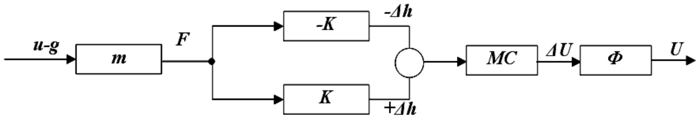


Fig. 4. PA`s functional scheme:
m - inertial mass (Sensitive Element- SE); K-elastic connection between SE and piezoelements; MC- bridge diagram of the measuring part; F-second-order filter

The transmission function (TF) of PA is found in the following form:

$$W_a(s) = \frac{K_a}{a_0 s^4 + a_1 s^3 + a_2 s^2 + a_3 s + 1}, \tag{3}$$

wher: $a_0 = T_f^2 T_m^2$; $a_1 = 2(\xi_f T_f T_m^2 + \xi_m T_m T_f^2)$; $a_2 = T_m^2 + T_f^2 + 4\xi_m T_m \xi_f T_f$;

$a_3 = 2(\xi_m T_m + \xi_f T_f)$; $K_f = -(R_5 / R_3)$; $\xi_f = 0.5C_4\left(R_4 + R_5 + \left(R_4 R_5 / R_3\right)\right) / \sqrt{R_5 R_4 C_3 C_4}$;
T_m -constant of time of SE; ξ_m- the relative damper coefficient of SE; ($\omega_m = 1/T_m$ -personal frequency of non damper vibrations of SE).
Formulas for these parameters: $K_m = 1/G_0$; $T_m = \sqrt{m/G_0}$;
$\xi_m = k_{dm} /(2m\omega_m)$; $k_{dm} = \frac{2\mu a_m^3 b_m^3}{h^3 (a_m^2 + b_m^2)}$; $K_a = \frac{1}{2} m K_{f\,m} \sqrt{\frac{\left(R_m X_a\right)^2 + \left(X^2{}_a\right)^2}{\left(R_m X^2{}_a\right)^2 + \left(R^2{}_m X_a\right)^2}} EX_{\Delta Cm}$

where G_m -linear rigidity of elastic connections in the direction of linear movement of SE; m-inertial mass in the form of a rectangle, a_m and b_m - respectively, the length and width of the SE($a_m \neq b_m$); κ_{dm} - absolute damping factor of SE; μ-dynamic viscosity coefficient of damping environment; h-size, which determines the thickness of the damping environment; K_a - total coefficient of TF.

In order to obtain a working area with high stable sensitivity, it was decided to apply the principle of a normalized characteristic equation for the total measurement scheme:

$$64 \cdot T^4 \cdot s^4 + 64 \cdot T^3 \cdot s^3 + 32 \cdot T^2 \cdot s^2 + 8 \cdot T \cdot s + 1 = 0 \qquad (4)$$

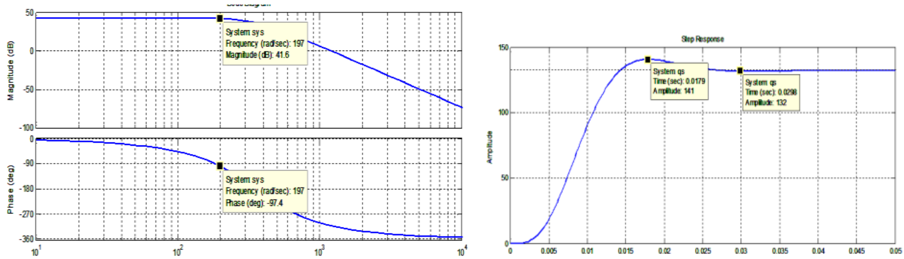
After solving the equation, which is based on the comparison of the respective equation coefficients (3) and (4) relative to the filter parameters ξ_f and T_f , we will get the values of these parameters, providing the necessary stability of dynamic sensitivity.

Based on these examples, $a_m=0.02m$; $b_m=0.01m$; $\rho_m=1786kg/m^3$; $h=0.0001m$; $\Delta h=10^{-8}m$; $\mu=0.000125Ns/m^2$; $G_0=2571N/m$; $t_f=0.001$ s; $\xi_f=0,707$ appropriate calculations were made in the MATLAB software environment, resulting in the simulated transmission function of the piezoelectric accelerometer and the following numerical results: m = 0.011*кг*; K_m = 3.8895e-004 ; ξ_m =0.38; ω_m=1000000 *rad/sec*; K_{dm} = 4; T_m=0,0018 *sec.*

In particular, using the above numerical data, we will get: $T_f = 7.1139 \cdot 10^{-2} T$; $\xi_f = 2.842 \cdot T$. When $T=0,001s$, $T_f = 7.1139 \cdot 10^{-5}$ s and $\xi_f = 0.0028$, TF of PA will be recorded as:

$$W_a(s) = \frac{132.34}{64 \cdot 10^{-12} s^4 + 64 \cdot 10^{-9} s^3 + 32 \cdot 10^{-6} s^2 + 0.008 s + 1}. \qquad (5)$$

As can be seen from the amplitude phase frequency characteristics (APFC) (Figure 5a), dynamic sensitivity is stable in the frequency range of 0-197rad/s, the transition time is: t=0.035s, and the amount of overregulation is equal to 7% (Figure 5b).



a) b)

Figure 5. Charts derived from the numerical solution of the equation:
a) frequency characteristics; b) the transition of the piezoelectric accelerometer with a filter, tuned to the technical optimum

Thus, it has been revealed that to provide a wide frequency range of the working area with stable dynamic sensitivity, it is necessary to apply an active filter of the second order, for the synthesis of TF of PA for the first time used a method of normalization a characteristic equation that provides the technical optimization of the transition process.

The second chapter for the first time offered a design composition version of the universal liquid angle indicator (roll and pitch angles) with built-in piezoelectric accelerometers, equipped with visual and aural alarms warning the flight crew about roll and pitch angles pre-critical values for the first time, which contribute to improved flight safety (Figure 6).

The Universal liquid angle indicator (ULAI) is designed in several design options. In one the options, the ULAI contains a semicircular transparent tube 1, liquid 2 and air bubble are located in the cavity of it (Figure 6a, b, c, d).

Figure 6d presents an autonomous bank and pitch meter with visual and aural alarm.

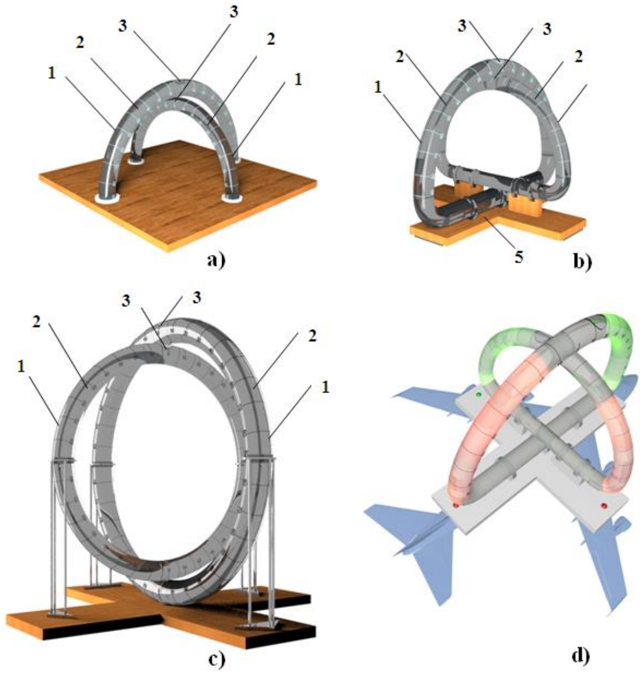
When the free fall acceleration of the aircraft approaches to zero, air bubbles cannot display the appropriate roll of the bank and pitch.

This deficiency is compensated by electrical measurements and alarms, as the meter includes ULAI and micromechanical accelerometers installed on the cruciform bases of the ULAI, converting the angles of the roll and pitch into electric signals on the basis of which electrical measurements are carried out and the alerting of the limits of the bank and the pitch of the aircraft.

When reaching critical bank and pitch angles (e.g. critical right bank and critical pitch up) electrical signals and logical elements then trigged corrective light emission diode (LED) and sound alarms to alert the crew, with to prevent the emergency spatial position of aircraft.

LED alarm illuminates the unrecommended critical angle with red, and the recommended angle with green light.

At the same time, the signals of micromechanical accelerometers turn on the audio alarm (for example, Turn pitch down, Turn left wing down etc.).



Options for UALI: (a) two-axle with semicircular open tubes on a rectangular base; b) two-axle with semicircular closed tubes on the cruciform base; c) two-axle with circular closed tubes on the cruciform base;
d) autonomous bank and pitch meter with visual and aural alerting

The third chapter explains the issues surrounding the development of a comprehensive DADS, and to that end a comparative analysis of the typical devices of modern aircraft has been carried out and the need to improve these systems are justified. It worth mentioning that, the modern DADS has a fairly high technological level, there are still problems with the more accurate and accurate measurement of air and flight -navigation parameters such as angles bank, pitch, yaw and lateral velocity, based on aerometric measurement methods.

The development of such a multifunctional DADS could provide the aircraft on-board control system with an additional information channel on current flight values and air conditions, which would improve the reliability and authenticity of the relevant information to manage aircraft in an environment where there is no reliable connection to ground and space navigation systems.

For this purpose, the creation of comprehensive DADS measuring angles of pitch, bank, yaw and lateral speed parameters based on signals from air pressure sensors was proposed for the first time and simulated computer modeling was performed.

Figure 7 shows the developed scheme for placing air pressure probes. The proposed comprehensive DADS is based on a modified element base of current operating systems, justifying the growths of number of pressure probes.

Components of device with air data are installed in six design points (figure 7a): in the front and tail parts of the aircraft fuselage on the left and right sides, as well as at the wing tips. Each of them includes a static pressure probe (P_{st1},P_{st6}), and the devices installed on the front and tail parts of the fuselage are also equipped with lateral static pressure probe ($P_{lateralst1}$, $P_{lateralst4}$).

Devices installed at the front of the fuselage are equipped with total air pressure probe (P_{t1},P_{t2}), differential air pressure probe (P_{dif1}, P_{dif2}) and air temperature sensors (t_1, t_2).

Figure 7 b-g presents the developed schemes of air pressure probes. Located at the front of the fuselage are four smart probes 1 (total, static, differential and lateral static air pressures), two air temperature sensors 2 (total air temperature), four smart probes 3 (static and lateral static air pressure probes), as well as four air data computers form the basis of the comprehensive DADS (figure 7a).

Figure 7b presents a scheme of pressure probes, which are designed for non-maneuverable aircraft (for civilian), in figure.8b- for maneuverable aircraft (for aircrafts flying at large angles of attack). Pressure receivers consist of a total air pressure probes 4, its pipeline 5 and de-icing system.

Pressure probes installed on the wing tips and tail of the aircraft consist of static pressure probes 12, its pipeline 13 and de-icing system, the probe of the lateral static pressure 14, its pipeline 15 and de-icing system.

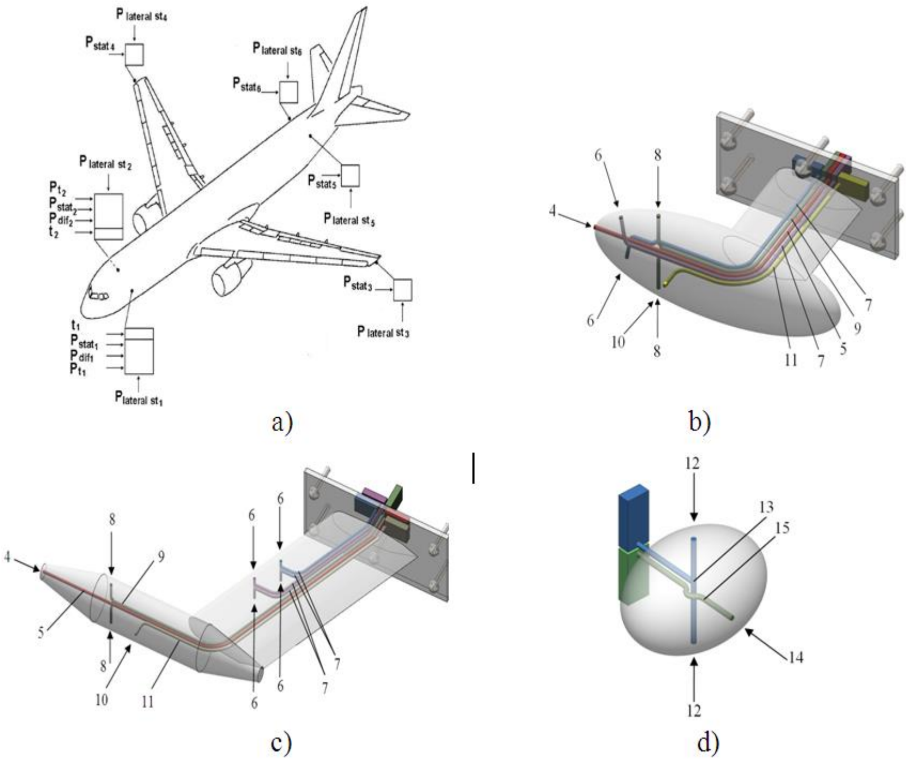


Figure 7. Comprehensive DADS: (a) the scheme for the placement of DADS and pressure probes; b) design schemes of total, static, differential, lateral static pressures; c) the scheme of static and lateral static pressure receivers

Logical algorithms for obtaining information about flight and navigation parameters have been compiled and a simulation of the computer model has been performed.

Logical algorithms for obtaining information about flight and navigation parameters have been designed and a simulation of the computer model has been performed.

In the process of spatial evolutions of aircraft associated with its roll, you should use the output signals of static pressure probes installed at the the wing tips - (P_{st3}, P_{st4}). In this case, the value of the angle of the bank will be determined by the difference of these signals. In determining the value of the pitch angle, you should use the difference in output signals of static pressure probes installed on the nose and tail parts of the fuselage surface - (P_{st5}, P_{st1}) and (P_{st6}, P_{st2}). In the process of yawing and determining the lateral speed of aircraft the difference in output signals of lateral static pressure probes ($P_{lateralst3}$, $P_{lateralst1}$) and ($P_{lateralst2}$, $P_{lateralst4}$) should be used.

In summary of the above, the algorithm of the operation of the comprehensive DADS can be obtained by the following formulas:

1. Determining the value of the bank angle:

If: $U(P_{cm4}) = U(P_{st3})$ *then:* $U_\gamma = 0$, *or:* $U_\gamma = abs(U(P_{st4}) - U(P_{st3}))$;
and his sign: If: $U(P_{st4}) \neq U(P_{st3})$ *and* $U(P_{st3}) < U(P_{st4})$ *then:*
$SIGN(U_\gamma) = plus$, *or:* $SIGN(U_\gamma) = minus$.

2. Determining the value of the pitch angle:

If: $U(P_{st5}) = U(P_{st1})$ *and* $U(P_{st6}) = U(P_{st2})$ *then:* $U_\upsilon = 0$, *or:*
$U_\upsilon = abs(U(P_{st5}) - U(P_{st1}))$, *or:* $U_\upsilon = abs(U(P_{st6}) - U(P_{st2}))$,

and his sign: *If:* $U(P_{st1}) \neq U(P_{st5})$ *and* $U(P_{st1}) < U(P_{st5})$ *or:*
$U(P_{cst2}) \neq U(P_{st6})$ *and* $U(P_{st2}) < U(P_{st6})$ *then:* $SIGN(U_\upsilon) = plus$, *or:*
$SIGN(U_\upsilon) = minus$.

3. Determining the value of the yaw:

If: $U(P_{lateralst4}) = U(P_{lateralst1}) = U(P_{ateralst2}) = U(P_{lateralst3})$; *and*
$U(P_{бcm4}) = U(P_{ateralst3}) = (P_{ateralst2}) = (P_{ateralst1}) = 0$ *then:* $U_\psi = 0$, *or:*
$U_\psi = f(abs(U(P_{ateralst4}) + U(P_{ateralst1})))$, *or:* $U_\psi = f(abs(U(P_{ateralst3}) + U(P_{ateralst1})))$.

and his sign:

If: $U(P_{\text{lateralst}4}) = U(P_{\text{ateralst}1})$ *and* $U(P_{lateral}st_1) < U(P_{lateralst3})$ *, or:* $U(P_{lateralst3}) = U(P_{lateralst2})$ *and* $U(P_{\text{ateralst}4}) < U(P_{\text{ateralst}2})$ *then:* $SIGN(U_\psi) = plus$ *, or:* $SIGN(U_\psi) = minus$.

4. Determining the value of the lateral velocity:

If: $U(P_{lateralst1}) = U(P_{lateralst3}) \neq 0$*, and:* $U(P_{lateralst2}) = U(P_{lateralst4}) = 0$*, or* $U(P_{lateralst1}) = U(P_{lateralst3}) = 0$*, and:* $U(P_{lateralst2}) = U(P_{lateralst4}) \neq 0$ *then:* $U_V = f(U(P_{lateralst2}), U(P_{lateralst4}))$*, or:* $U_V = 0$;

and his sign:

If: $U(P_{\text{lateralst:}1}) \neq U(P_{\text{lateralst}2})$ *and* $U(P_{\text{lateralst}1}) > U(P_{\text{lateralst}2})$ *or:* $U(P_{\text{lateralst}3}) \neq U(P_{\text{lateralst}4})$ *and* $U(P_{\text{lateralst}3}) > U(P_{\text{lateralst}4})$ *then:* $SIGN(U_V) = plus$*, or:* $SIGN(U_V) = minus$

On the basis of these algorithms, a generalized functional scheme of the comprehensive DADS is drawn up, as well as a computer model of the subsystem for determining the direction of the angle.

The theoretical basis for the operation of the comprehensive DADS has been presented and a computer model has been drawn up to determine qualitative parameters.

In the fourth chapter presented and resolved issues related to the static and dynamic properties of the gyroscopic stabilization system with an adjustable moment of inertia.

For this purpose, the beginning of the chapter addresses the general issues of unmanned aerial vehicle (UAVs) flight stabilization systems and substantiates the use of the method and device to enhance the stabilization and maneuverability of UAVs operating on the basis of gyroscopic effect.

The objective of the proposed gyroscopic stabilization system with adjustable momentum of inertia (GSS AMI) of the rotor is to reduce the sensitivity of UAVs to the impact of wind and turbulence without increasing flight speed, as well as increasing stability and at the same time maneuverability, and to solve it proposed to install a gyroscope relative to the center of gravity of the UAV opposite the location of the propeller.

The gyroscope should be mounted on the rotor axis, and the rotation of the gyroscope rotor should be directed against the rotation of the propeller (figure 9).

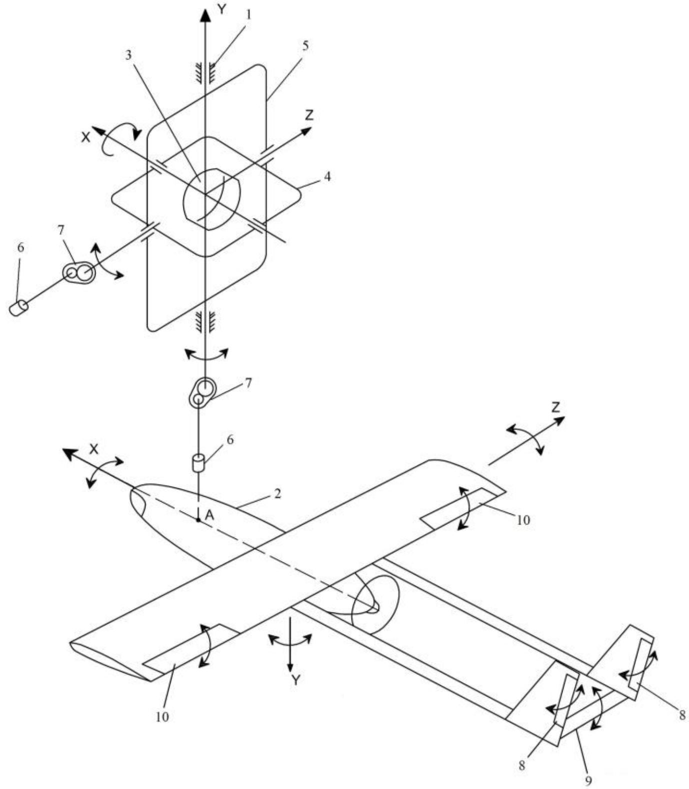


Figure 9. GSS AMI of UAV:
1-gyroscope casing; 2-fuselage; 3-gyroscope; 4-frame; 5-external frame; 6-electric engine (stabilization and moment engine); 7-gearbox;
8-rudder; 9-elevator; 10-ailerons

A device with a high kinetic moment increases flight stability by decreasing the sensitive to the influence of wind and turbulence. To control the flight path, the rotation axis of the gyroscope rotor is rotated using electric motors and gearboxes, which are stabilization engines and moments on the axis of rotation of the rotary frames so that direction created by gyroscopic moments coincided with the direction of the UAV turn.

The casing of the gyroscope 1 is rigidly connected at point A of the fuselage 2 on the same line with the axis of the propeller. Opposite the propeller in the movable (up or down) inner frame 4 is installed rotating with high speed rotor gyroscope 3.

The inner frame is installed in the outer frame 5, which can turn left or right, and is installed in the casing of the gyroscope. On the outer frame is an electric engine 6 (stabilization and moment engine) and a gearbox 7, rotating the axis of rotation of the inner frame.

For example, if the rotor of the gyroscope rotates clockwise (against the direction of the propeller rotation), then when the inner frame is deflected by an electric motor and gearbox upwards, the created gyroscopic moment deflects the UAV to the right, and when deflected the inner frame down deflects the UAV to the left, which helps to increase the efficiency of the rudder 8, especially at low flight speeds and in critical stability modes.

The electric engine 6 (stabilization and moment engine) installed in the gyroscope casing, the gearbox 7 and the rotating axis of the outer frame provide stabilization and the moment of control of the UAV pitch.

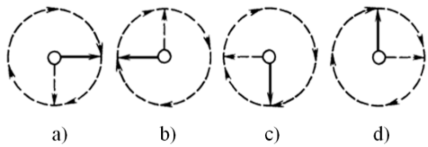


Figure 10. Locations of rotor deviations and gyroscopic moment influences:
a) If the gyroscope rotor deviates to the right; b) left; c) down; d) up

Figure 10 shows directions of created controlling gyroscopic moments (if propeller is installed at the tail section, while the gyroscope is installed at the nose section) when changes the gyroscope rotor rotational plane.

When the gyroscope rotor (figure 10a) turns to the right, the gyroscopic moment creates a UAV pitch-down moment. When the gyroscope rotor (figure 10b) turns to the left, the gyroscopic moment creates a UAV pitch-up moment. When the gyroscope rotor (figure 10c) moves down, the gyroscopic moment turns UAVs heading to the left. When the gyroscopic rotor (Figure 10d) moves up, the gyroscopic moment turns UAVs heading to the right. These controlling gyroscopic moments are added to aerodynamic moments of the rudder 8 and elevator 9 and increase the UAV maneuverability.

The device (figure 11) consists of the axis 11, inner disk 12, guiding tubes 13, spring 14, heavy balls 15, tuning screws 16 and outer disk 17. The rotor, installed on the axis, consists of the inner disk 12, guiding tubes 13, wherein springs 14 are located, which provide an increase in the rotor responsiveness, moving depending on the controlled number of axis rotations, moving balls 15, and tuning screws 16, designed to balance the rotor. Guiding tubes are fastened along the radius to the outer disk 17.

When starting the gyroscope rotor with adjustable inertial moment, due to the positioning of heavy balls of mass *m* near radius R_1: the minimum value of the inertial moment J ($J = mR_1^2$) helps to increase the rotor acceleration, i.e. start-up time of the gyroscope rotor is reduced. The rotor axis rotates with the help of the engine with an adjustable speed of rotation (is not shown in scheme).

When the gyroscope rotor increases its revolutions due to centrifugal forces, heavy balls overcoming the spring elastic force, move to the outer disk at a distance R_2 , the controlling gyroscopic moment and the rotor's reverse reaction moment has a maximum value ($J = mR_2^2$), as a result increasing the stability of UAV flight.

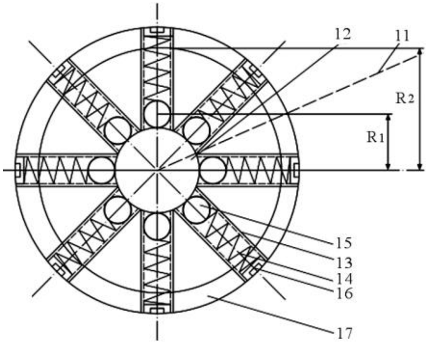


Figure 11. Gyroscopes rotor with adjustable momentum of inertia:
11- axis; 12- inner disk; 13- guiding tubes; 14- springs; 15- heavy metallic balls; 16- tuning screws; 17- outer disk.

The rapid acceleration and rapid braking of the rotor allows to control the opposing in the direction of the rotor reaction, which is used in the control of the UAV on the bank.

Based on the study of fundamental theoretical sources, mathematical equations for the gyrostabilizer with the regulated moment of inertia are compiled:

$$J = J_1 + J_2 + J_3 + J_4, \tag{6}$$

where J -common, or total moment of inertia; J_1 - a moment of inertia
the ball; J_2-the moment of inertia of the inner disk; J_3- the moment of inertia of cylindrical guides; J_4-moment of inertia of the outer disk.
According to the principle of work, the moment of inertia of the device consists of the following components: $J = J_0 + J(t,R)$, where J_0- its constant $J_0 = J_2 + J_3 + J_4$, and $J(t,R)$ - variable components.

According to the principle of the parameter range adjustment, the D range is:

$$D = \frac{J_{max}}{J_{min}} = \frac{J(t)_{max} + J_0}{J(t)_{min} + J_0}\ , \tag{7}$$

or:

$$\frac{J(t)_{\max}}{J(t)_{\min}} - D = \frac{J_0}{J(t)_{\min}}(D-1)\ , \tag{8}$$

The formula is derived, determining the pattern of forming the range of regulation of the moment of inertia of this device depending on its geometric parameters, as well as the density of the main structural elements.

Formula (8), taking into account the accepted conditions, will take the form:

$$\frac{1}{(D-1)}\frac{(a+b)^2}{(b+1)^2} - \frac{D}{D-1} = \left[\begin{array}{l}\dfrac{3(1+\delta)\rho_2 b^4}{4n\rho_1(b+1)^2} + \dfrac{\rho_2 a^3\delta(\delta+2)}{4\rho_1(b+1)^2} + \\ + \dfrac{(1+\delta)\rho_2(a+b-1{,}2607)}{4n\rho_1(b+1)^2}\end{array}\right]\ , \tag{9}$$

In the formula (9):

$a = \frac{l_3}{r}$; $b = \frac{r_2}{r}$; $c = \frac{l_2}{r} = \frac{l_4}{r}$; $r_{31} = r$; $r_{32} = (1+\delta)r$

and $c = 2(1+\delta)$. (10)

Where is the r-radius of the ball; ρ_1, ρ_2 - the density of the balls and other parts of the device; l_2, r_2 - width and radius of the inner disk; l_3, r_3, δ- length, inner radius and thickness of the cylindrical guide tube; l_4 -

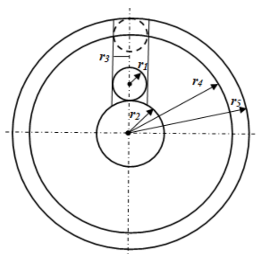


Figure 12. Main geometric size scheme

width, r_4, r_5 - inner and outer radius of the disk (figure 12).

The necessary condition for the expression to have both mathematical and physical meaning has been defined:

$$a = (b+1)\sqrt{D} - b. \quad (11)$$

If the coefficient a is according to (11), then the right part of the formula (9) should also be zero. Thus, a solution to the equation was found in the known ρ_1, ρ_2, n and at a given D value: $\delta_0 = f(b)$. δ_0 - the minimum thickness of the cylindrical guide tube, which provides the physical meaning of the equation (9).

The main scientific result of the abovementioned theoretical researches is that for the first time for such mechanisms found a mathematical expression that determines the relationship between one of the geometric sizes and the range of regulation inertia at the permanence of other parameters and the proportionality of diametric size.

To research the dynamics of a device with an adjustable moment of inertia, a differential equation has been compiled and transitions are analyzed, taking into account the various parameters that may in one way or another influence the dynamic processes that arise in the start-up process, as well as speed and braking adjustment of the analyzed device.

As its known, such actions can be mathematically described by a differential equation of the second order:

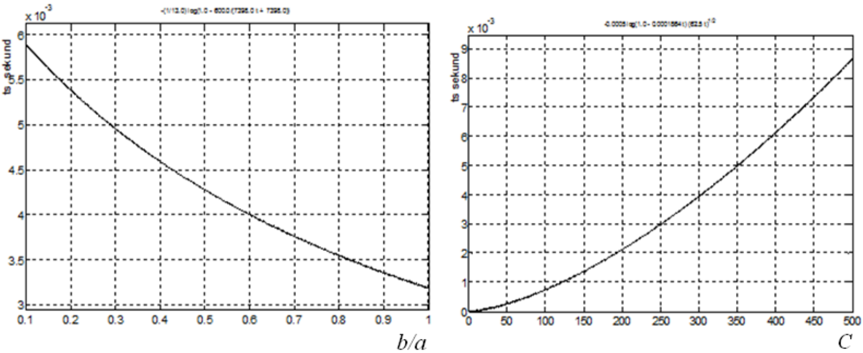
$$m_1 \frac{d^2 r(t)}{dt^2} + C \frac{d\, r(t)}{dt} + kr(t) = mR\omega^2 \quad (12)$$

Here m_1 - is the mass of the ball; k - the "ball-spring" rigidity coefficient; C - the spring elasticity factor; m - the mass of the entire device; R - the outer radius of the outer disk; ω - angular speed of rotation of the device.

To avoid the impact of vibration components of the ball's own movement, it is necessary to realize the condition $D > \sqrt{C^2 - 4km_1}$ or $C = 2\sqrt{km_1}$. At the end of the transition process, the ball will reach the distance of $l_3 = ar$ and reach the external position. The solution to the equation is to find t_s the time during which the ball reaches the distance farthest from the center:

$$t_s = -\sqrt{\frac{k}{m_1}}\, ln\left(1 - \frac{2ak}{m(a+b)\omega^2}\right). \qquad (13)$$

On the basis of expression (13), the transition time is based on the diametric size of the device (a, b) and the spring elasticity coefficient (figure 13a, b).



a) b)

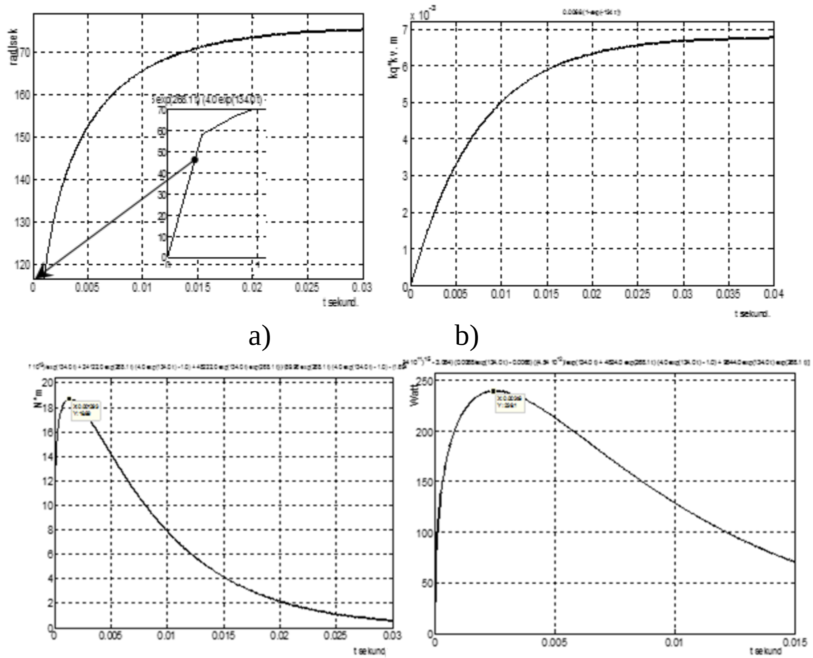
Figure 13. The transition time curves depending from different parameters: (a) from diametric sizes; b) from the spring elasticity coefficient

Next, the equation of moments for the gyrostabilizer with the adjustable moment of inertia is compiled:

$$m_1\left(\frac{m(a+b)r\omega^2}{k}\left(1-e^{-\sqrt{\frac{k}{m_1}}t_s}\right)\right)^2 \frac{d\omega}{dt} = M \quad . \qquad (14)$$

The solution of the equation (14) was obtained taking into account the parameters of the diametric sizes and densities of the rotor materials, and using the same data that was used in the formation of the static model built transitional processes (Figure 14a, b).

By applyig the MATLAB Funtool toolbar, curves of torque and expendable power are constructed by graphic differentiation of the curve of $\omega=f(t)$ (figure 14a) and multiplication by $J=f(t)$ (figure 14b). The resulting curve $M=f(t)$ is represented in the figure 14c. It is obvious that the product $M=f(t)$ and $\omega=f(t)$ is the $P=f(t)$ (figure 14d).



a) b)

c) d)

Figure 14. Dynamic characteristics of a gyroscopic device with an adjustable inertial of moment: the transition curve of rotation; b) the curve of the transitional process of the moment of inertia; c) the curve of the torque transition process; d) the power change curve

Based on the two-dimension model of the mechanical system (TM MS) dynamic mathematical model gyrostabilizer with adjustable moment of inertia was developed a dynamic mathematical model of the, compiled computer models and dynamic characteristics with an adjustable moment of inertia was built.

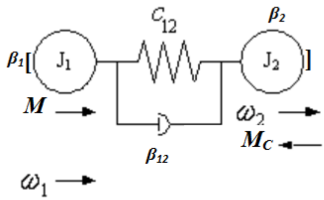


Figure 15. Two-mass model of the mechanical system

In the TM MS scheme, shown in figure 15: J_1, ω_1, β_1 - moment of inertia, angular speed of rotation, friction coefficient of the rotor stabilizing engine respectively; J_2, ω_2, β_2 - - moment of inertia, angular speed of rotation, friction coefficient of the suspended frame of the gyroscope, c_{12} - friction coefficient of mechanical transmission between the rotors of the engine and the suspension frame, *γ*- the coefficient of mass ratio, *α* - the real part of the root, the *M* -torque of the engine, the M_c -moment of resistance (J_1 = *const* and J_2 = *const.*).

Based on the well-known TF equations for mechanical conductions of the TM MS, compiled on the condition of the condition $\beta_1=\beta_2=\beta_{12}=\beta$ (the value *β* is small enough to avoid the non-linearity factor), for the first time research of the "stabilizing engine-frame of the gyroscope suspension" system was proposed, using the principle of technical optimum to obtain optimal transitional processes. In this case, the main objective is to determine the necessary ratio of parameters that ensure the normalization of the characteristic equation, which is included in the denominators of TF for mechanical conductions of the TM MS. After comparing the ratios of characteristic and normalized equations, it was obtained:

$$\begin{cases} J_1 + J_2 = 4T\beta \\ J_1 J_2 = 4T^2\beta^2 \\ C_{12} = \dfrac{2\beta}{T} = \dfrac{J_1 + J_2}{2T^2} \end{cases}, \qquad (15)$$

from where: $J_1 = J_2$.

For the numerical calculation, approximate data are used: $J_2=1.036\ 10^{-5}$ *кgm*^{2}. $J_1 = J_2 = 2T\beta = 1.036 \cdot 10^{-5}$ *кgm*^{2}; and transition time: 0.1sec (figure 16).

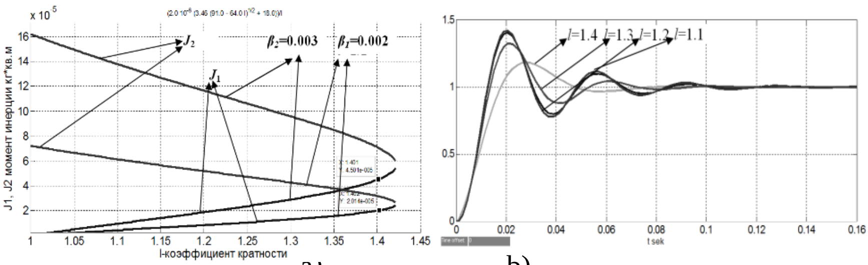


Figure 16. Computer simulation curves: a) depending moments of inertia J_2=*f(l)* and stabilizing engine J_1=*f(l)* of the suspending frame from the non-dimensional parameter *l*, at friction coefficient values β_1=0.002 и β_2=0.003; b) transition prosesses at different coefficent of multiplicity values

Thus, for the first time, the direct and inverse tasks of determining the time of the transition process have been formulated and it has been revealed that in order to ensure a transition al-technical optimum, a two-mass system must be formed from the masses, which have moments of inertia should be the same.

The fifth chapter presented and resolved some of the applications of new developed micromechanical piezoelectric accelerometers in aircraft, control systems, particularly in initial alignment system (IAS) of accelerometers, in the automatic ensuring system of the aircraft stability to the effects of disturbance harmonic signals and in the automatic control systems of the aircraft mass center.

For the first time it was proposed to create an automatic system of the initial alignment of accelerometers (IAAAS) without the use of additional devices for feedback, a functional scheme was drawn up and the principle of work was presented (figure 17).

IAAAS`s work consists of two subsequent stages: a rough alignment and an accurate alignment. The rough alignment is performed for the high-speed approach of the platform P to the wall of the N casing on the X axis and ends with the touch of one of the mechanical contacts K1, K2 on the A1 or A2 accelerometer. Completion of the rough alignment occurs automatically, when the signal is received from the exit of one of the accelerometers A1 or A2. This signal in the rough mode, is designed to simultaneously disable the PD1's servo electric drive and start on the PD2 rotary drive. Thus, the outlet signals of the A1, A2 accelerometers are the command for the second stage start, i.e. the stage of the exact alignment.

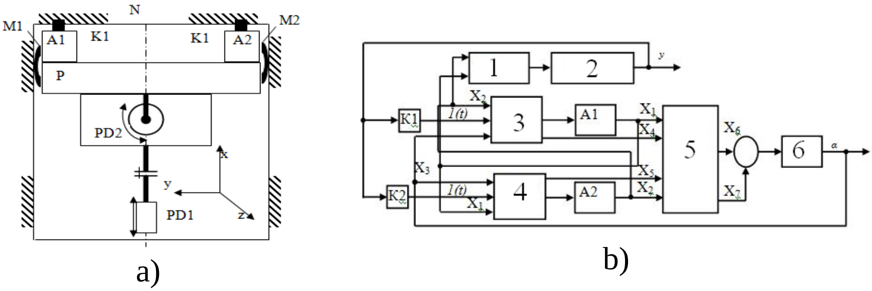


Figure 17. Principal scheme and composite parts of IAAAS:
scheme of constructive layout; b) functional scheme of control.
A1, A2-piezoelectric accelerometers; K1, K2- mechanical contacts with inertial masses of accelerometers, M1, M2- electromagnetic brakes; P-moving platform that has a linear movement along the symmetry axis; PD1-servo electric drive with DC engine, PD2-piezoelectric drive engine of turn table; N- casing of a mobile object; A1, A2-piezoelectric accelerometers; 1- scheme for start and disable of electric drive of a mobile platform; 2 - electric drive of a mobile platform; 3, 4 - scheme of banning accelerometers; 5- scheme of selection of the setting device and feedback;
6 - drive of the turn table

At this stage, the PD2 reverse engine turn the table on which the platform P is rigidly fixed with PA A1, A2 around the z axis on or counterclockwise until the output of the comparison device, where the output signals from the A1, A2 does not form a zero signal. Since the accelerometers are completely identical and with identical orientation relative to the stationary case, the difference in their output signals will be zero. This means that their longitudinal axis is sufficiently perpendicular to the established surface and they do not have a transverse sensitivity effect.

he scheme of banning accelerometers 3, 4 receives signals *X1*, *X2*-output signals of accelerometers *A1*, *A2*, respectively, and X_3-signal feedback system of the servo system of the drive of the accurate alignment 6, which performs an accurate alignment of accelerometers.

Operation of IAS begins with the starting of the 2 - electric drive of a mobile platform (EDMP) of the rough alignment mode (RAM). The disability of the RAM occurs after touching one of the *A1*, *A2* contacts *K1*, *K2*. Let's say that after a rough alignment, the *A1* accelerometer first touched the *K1* contact. Its output signal *X1* enters the *1* scheme and the 2 are disconnected, thus ending the RAM. Its output signal X1 enters the *1* scheme and the *2* are disconnected, thus ending the RAM. Further, this signal arrives at 3, prohibits the connection of A2 to the PPP entrance and prepares its connection to the 6 feedback channel: the *X3* input is connected to the *X5* output. A similar thing will happen if, after a rough alignment the first mechanical contact *K2* touches the accelerometer *A2*: the *X3* input will be connected to the output of *X4*, and *1* will prepare the inclusion of A1 in the 6 feedback channel.

Thus, four signals are received on the scheme of selection of the setting device and feedback 5: X1, X2 - outputs of accelerometers A1, A2 respectively, and X4, X5 - preparatory signals for the inclusion of accelerometers in the feedback channel of the servo system. Obviously, the 5 should work in such a way that if the A1 is connected as a setting device, the A2 should be connected to the feedback channel, and vice versa.

Based on the work principle and control algorithms have been developed and a computer model of IAS has been compiled.

In the structural scheme of the servo system with turn table of piezoelectric engine, setting device and position sensor are performed by the accelerometers $W_{a1}(s)$, $W_{a1}(s)$, each of which is connected to a frequency discriminator (inverter) that converts the frequency signal into voltage (Figure 18). And the accelerometer, which will first touch one of the mechanical contacts K1, K2, will connect as a command device, and the other - to the position feedback channel. This mode of connecting accelerometers performs logical circuits.

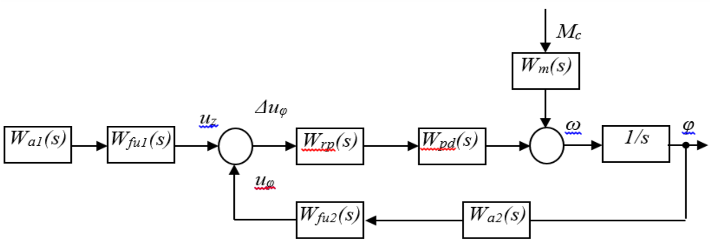


Figure 18. Structure of the servo system with a piezoelectric engine of the turn table of IAS

Piezoelectric engine (PE) with TF $W_{pd}(s)$ will rotate to reduce the output of accelerometer signals. The regulator with TF $W_{rp}(s)$ should provide a non periodic performance of the transition process to avoid speed errors.

Preliminary researches used the following numerical data for approximate calculations. $K_{\partial} = 1.1$, $K_y = 105$; $d_{13} = 2{,}31 \cdot 10^{-12}$ C/N; $\omega_0 = 100000$ rad/s; $\xi_f = 0{,}175$; $C_0 = 1930$ pF; $R_в = 25$ Om; $m_0 = 0.05$; $m_к = 0{,}035$. The following coefficients and parameters are found: $K_n = K_y d_{33} = 2.42 \cdot 10^{-12}$ C/N; $K_o = K_y d_{33} = 2.55$; $m_\Sigma = m_0 + 0{,}4 m_к = 0.65$; $T_э = C_0 R_в = 0.0048$; $T_f = 0.001s$; $a_0 = 1 \cdot 10^{-12}$; $a_1 = 3.5 \cdot 10^{-7}$; $b_0 = 3.5 \cdot 10^7$; $c_0 = 2.98 \cdot 10^{-8}$; $c_1 = 0.6191 \cdot 10^{-4}$; $c_2 = 0.011477$.

Using the software environment, MATLABSymbolic is compiled

Hurwitz matrix for the structural scheme of the servo system with PE and received the following calculated expression:

*2.83104*10^(-45)*y^6*x - 2.55302*10^(-46)*y^5*x^2 + 4.84613*10^(-47)*y^5*x - 9.00542*10^(-55)*y^4*x^3 - 2.4816*10^(-49)*y^4*x^2 + 1.90951*10^(-49)*y^4*x + 2.16898*10^(-70)*y^3*x^4 - 1.0756*10^(-60)*y^3*x^3 - 6.1075*10^(-53)*y^3*x^2 + 8.91194*10^(-53)*y^3*x - 1.43499*10^(-66)*y^2*x^3 - 3.20363*10^(-58)*y^2*x^2 + 4.71854*10^(-58)*y^2*x - 8.29888*10^(-73)*y*x^3 - 1.65557*10^(-64)*y*x^2 + 2.43226*10^(-64)*y*x - 3.39835*10^(-79)*x^3 - 2.9877*10^(-70)*x^2 + 4.40495*10^(-70)*x)*

In this expression, given in a format corresponding to the MATLABSymbolic software environment, there are two unknowns: *x* (transfer coefficient of position regulator) and *y* (constant of time of regulation position). By equating them with zero and solving the resulting equation, you can find the values of these parameters, in which the servo system will always have a stable state, but with different transitions (figure 19, 20).

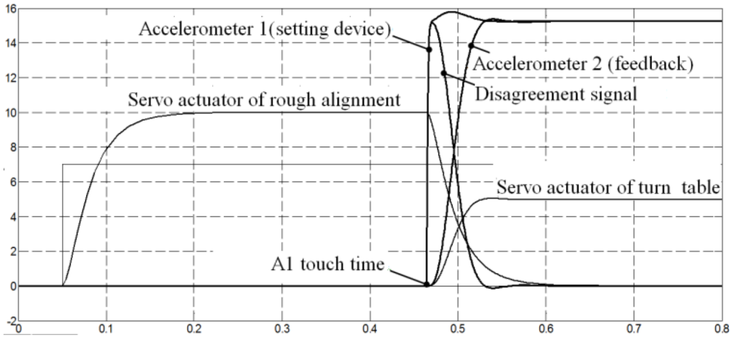


Figure 19. Curves from computer model simulations of IAAAS control system

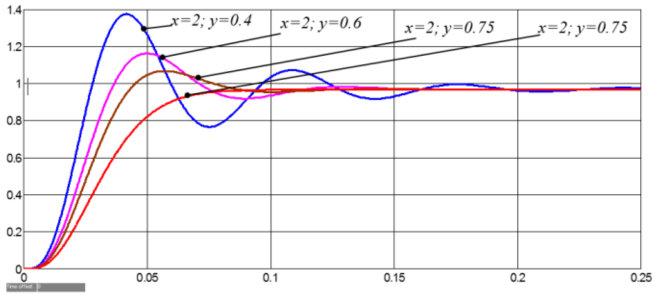


Figure 20. Curves obtained from a simulation of a computer model of a servo system with a piezoelectric engine of the IAAAS turn table

Further in the fifth chapter, an automatic system of ensuring resistance to the effects of disturbance harmonic signals is built by using a compensator of disturbance vibrations acting on the surface of the aircraft.

As it was revealed, during the performance of difficult flight maneuvers, the generated vibrations acting on the fuselage of aircraft create harmonic vibrations that can have a significant negative impact on the stability of aircraft. The amplitudes of these fluctuations and vibrations can take such large values that with periodic impact on the fuselage of aircraft can create destructive force.

Similar to this problem, it is also noted, that when the aircraft speed changes, the occurrence of mechanical fluctuations in the fuselage becomes one of the disadvantage in solving the problems of aircraft with autopilot.

Among these mechanical fluctuations, the first harmonica, which has a relatively small frequency and a large amplitude, is the most influential.

In order to eliminate this problem, the aircraft with autopilot used a gyrocompass, for which the issue of stability in the impact of vibrations is relevant. For this purpose, an automatic control system of aircraft with the gyrocompass stabilization (figure 21) was created.

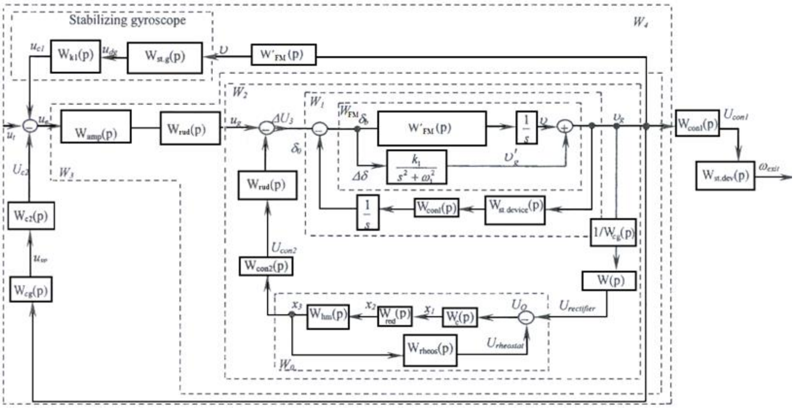


Figure 21. Structure scheme of simplified dynamic model of aircraft with autopilot

The developed system is modeled and after the simulation of the structural model revealed some of its features.

Thus, it is necessary to consider the effect of reducing the setting signal of the rudder on the quality of aircraft control, for example, when oscilating with harmonics:

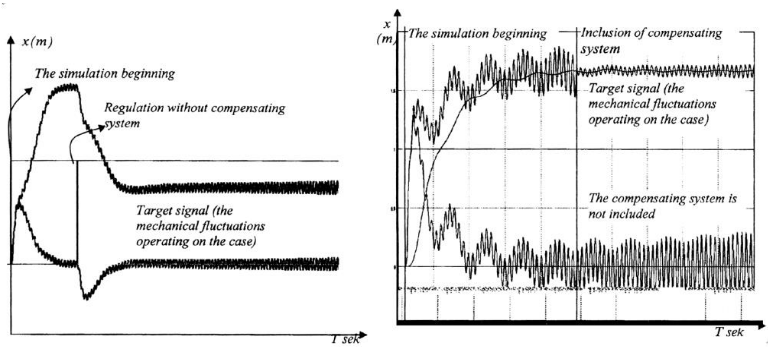
$$W_{har1}(p) = 15\frac{10}{s^2+100},\; W_{har2}(p) = 5\frac{30}{s^2+900},\; W_{har3}(p) = 3\frac{50}{s^2+900}$$

The aircraft's stable condition can be maintained with the W (s)=k_g amplifier, while reducing its gain factor from 1.2 to 0.8.

Imitation of vibrations:

$$W_{har1}(p) = 60\frac{10}{s^2+100},\; W_{har2}(p) = 20\frac{30}{s^2+900},\; W_{har3}(p) = 12\frac{50}{s^2+900}$$

should automatically connect the compensation system, and further disturbance action to increased fluctuations in the destructive direction. The above is presented in figure 22.



a) b)

Figure 22. Curves obtained by aircraft simulation with compensation systems: a) regulation without a compensation system; b) regulation, including the compensation system

At the end of the fifth chapter, a comparative analysis of the automatic control systems of the aircraft's mass center was carried out and a structural scheme was proposed in which the displacement of the center or the side effects derived from the displacement of the center of mass were added in the form of disturbance moment - M_z^{mb} (Figure 23). On the figure 23 transmission ratio - $\Delta L_1 / \Delta L_2$ determines the proportional dependence of the disturbance moment on the change in the position of the center of mass, in which ΔL_1 , ΔL_2 are the distances between the center of mass and accelerometers installed in the forward and aft parts of the aircraft, and coefficient - $K(P_{Wi})$ determines the dependence of the same disturbance moment of the relative value of take-off speed.

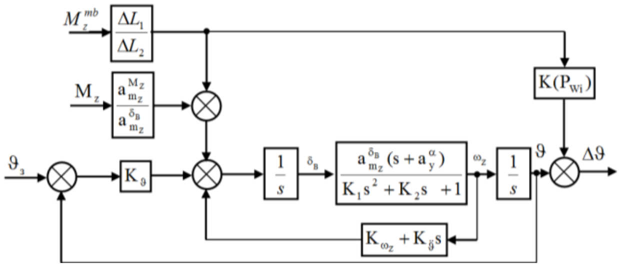


Figure 23. Structure of the closed system of “aircraft-autopilot” given the displacement of the center of the masses in the form of an disturbance moment

A common goal is formulated, according to which it is necessary to find algorithms for determining coefficients k_{ω_z} and $k_{\ddot{\vartheta}}$, which are included in the law of management, ensuring the stability of longitudinal movement, and applied a methodology for determining the condition of performance of technical transitional optimization: in this way, the solutions obtained ensure the passing technically optimal transitional process concerning disturbance (figure 24).

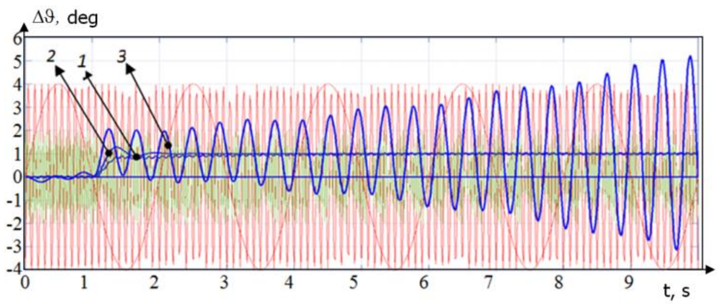


Figure 24. Oscillations simulation of a computer model of a longitudinal motion control system when exposed to disturbance moments

As the transmission number increases in pitch K_ϑ, the transition time decreases, and vice versa. With further increases K_ϑ, the transition process becomes overregulated and in the future has a vibration character. Transitional processes 1 and 2 correspond to the fluctuations of the disturbance moment with the frequency of ω=30 rad/s. Curve 1 corresponds $K_{\vartheta} < 30$, curve 2 $K_{\vartheta} > 30$. Curve 3 corresponds to the oscillations of the indignant moment with the frequency of $\omega \approx 15$ rad/sec and as seen from the figure 24, the system goes into auto-oscillation mode, leading to the loss of stability of the aircraft, which in practical sense is tantamount to mechanical destruction of the aircraft.

The conclusion includes the most important achievements of the dissertation, as well as formulated the main results, following from the presented methods and the results obtained.

MAIN RESULTS AND CONCLUSION

1. The designs and principles of the new developed piezoelectric accelerometers are presented and described in detail.
2. For the first time, the design composing version of the universal liquid angular indicator with a system of built-in piezoelectric accelerometers has been proposed in order to increase the informativeness of the crew.
3. An advanced digital air data system has been developed to further identify the angles of the roll, pitch, yaw and lateral speed of the aircraft based on the processing of signals sensed from air pressure probes.
4. For the first time, a method and device has been developed to enhance the stabilization and maneuvering of UAV flight based on the gyroscopic effect with an adjustable moment of inertia, mathematical expressions are obtained, which are the relationship between the range regulation of the moment of inertia and relative geometric size, elasticity of spring elements, as well as plotted corresponding static and dynamic characteristics.
5. For the first time, an automatic IAS of accelerometers has been developed without the use of additional feedback devices, with the aim of reducing the error of installing PA on an aircraft.
6. An automatic system has been developed to ensure resistance to the effects of disturbance harmonic signals using a compensator of disturbance fluctuations on the fuselage of the aircraft.

7. A new principle has been proposed to increase the reliability of mass and centering measurements by placing pressure and nitrogen temperature sensors in tyres.
8. For the first time, the displacement of the aircraft center of the mass in the form of an additional disturbance moment was taken into account, a structural scheme for the stabilization of longitudinal movement was developed, and computer models confirming the reliability of theoretical research were carried out.

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