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Aviation gravimetric system

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Abstract— The article analyzes the possibility of the most well-known and widely applied navigation systems assembly into the general aviation gravimetric system.

Index Terms— aviation, gravimetric system, navigation system, gyroscopic gravimeter, inertial navigation systems.

1 INTRODUCTION

Nowadays the aviation gravitation measurements are widely used in aerospace sphere to correct the indexes of inertial navigation systems (INS), in geology and geophysics to prospect and to correct the Earth's form, to forecast earthquakes, tsunami, etc. as well as in some other branches(1). In order to study the parameters of the Earth's gravitation field (gravitation acceleration g or its anomalies Δg) it is recommended to apply the aviation gravimetrical system (AGS), the gravimeter [2] being its sensor. A lot of gravimeters [3-6] have been recently studied and used [7].

But there is no analysis of the possibility to assembly the well-known and mostly used separate navigation systems into general AGS which can be able to perform the measurement of g or Δg with the specified precision (1-3) mGal [1].

The given paper is aimed to analyze the possibility to assembly the well-known and mostly used navigation systems into general AGS determining g or Δg with the precision (1-3) mGal.

The Topicality of the problem under consideration consists in the following: the specified precision of g or Δg в (1-3) mGal can be provided in case the separate assembly device parts, namely, navigation systems are able to determine the basic navigation indexes (velocity, vector, acceleration, etc.) with the required precision. The literature studied [1-9] does not suggest such solutions. AGS is known not to provide the measurement of g or Δg with the precision (1-3) mGal. That is why, the problem of assembly the known navigation components into general AGS with the specified precision has become the issue of the day.

Task Formulation. [1] shows the analysis of the methodological AGS errors based on the specified precision of its measurements (1-3) mGal. It has been found out that the errors of determining the basic navigation parameters by means of assembly device AGS components have to be as following (Table 1):

Table 1

The acceptable errors of the basic navigation parameter measurements

№	Measurement errors	Error value
1	Velocity v, m/s	0,05…0,15
2	Vector *k*, angle. min	1,56…4,66
3	Geographic latitude *φ*, angle.min	0,5…1,5
4	Height *h*, m	3,3…10
5	Vertical velocit $\Delta\dot{h}$, m/s	(0,5…1) ·10^2
6	Vertical acceleration $\Delta\ddot{h}$, m/s^2	(1,0…3,0) ·10^{-5}

The task of the given paper is to solve the problem of the analysis and selection of concrete assembly navigation components which determine the mentioned above navigation parameters with the specified precision taking into account the general measurement precision of AGS g or Δg is (1-3) mGal.

The means of airplane navigation parameter determination. Let us analyze the known systems of navigation parameter determination and offer the recommendations how reasonable it is to apply them to AGS depending on the peculiarities of the terrain the aircraft is flying over. The aircraft location coordinates (latitudeφ, longitude λ,vector k) can be determined by different methods. These methods are classified according to the definite features. The most important of them are: the way of location coordinate determination, the nature of measured physical parameters. Taking into consideration the first feature, the navigation methods are divided into following groups:

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path calculation; position methods; overview and comparative methods.

The methods of the first group are based on the measuring of the components of acceleration or the speed of the object movement and time integration of these components in order to determine the location coordinates.

The position methods of navigation are based on the physical values measurements, if it is possible to obtain the line or surface of the object location. It is necessary to have two or three intersecting location surfaces to determine two or three object location coordinates correspondingly.

The overview and comparative methods of navigation are based on the location overview and the comparison of its image with the map or landmark system which have been input into computer memory.

The selection of any method or the group of navigation methods to be applied to the definite airplane type is determined by the following conditions: the range of navigation parameter measurement (distance, speed, acceleration); the necessary precision of navigation parameter measurement; the level of autonomy, interference ability and reliability of navigation measurements, the degree of navigation method physical implementation (e.i. the possibility to design navigation devices which satisfy the operation requirements).

The comparative analysis of different methods is showed in table 2.

Table 2

The comparative analysis of navigation methods

System name	Brief description	System adantages	System disadvantages
1	2	3	4
Dead reckoning systems			
Aerometric navigation machines	The initial navigation parameters are measured to calculate the path. The aerometric sensor information and route sensor data processing is performed basically with analogue calculating devices	Measurement autonomy; continuous obtaining the initial navigation information.	Air speed sensors do not measure the wind speed. It is the main cause of errors.
Doppler machines	They are based on the automatic path calculation in regard to the Earth's	The measurement precision is not dependent on	The route sensor is the main source of errors; the
1	2	3	4
	surface. Radiolocation Doppler device measuring the path speed and drift angle is used as a speed sensor. It works due to the Doppler effect: the radio signal with the definite frequency is sent from the plane board to the Earth, it is reflected from its surface and is received with changed frequency on the board. This change depends on the plane speed.	meteorology and on the Earth's surface type; The measurements can be conducted over water; the speed rang measurements are not limited; the path speed measurements are precise; the level of interference is low.	phenomenon of «dead height" is present on fold height when the reflected signal comes at the moment that is close to the moment of the next sensor impulse. Here, the reflected impulse can be suppressed
Inertia navigation systems	The velocity of coordinate and location is determined as a result of single and double integration of outcome signals of the accelerometers.	Autonomy, the low level of interference, the unlimited range of navigation parameter measurements.	The necessity to design highly précised accelerometers. Instrumental errors; zero signals, platform tilt, gyroscope care.
Position navigation systems			

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Astronomical landmarks	They are aimed to determine the location coordinates on the basis of astronomical measurements	High precision of navigation measurements which are not dependent on the duration, height and speed of the flight; the measurements can be conducted in all geographical zones of the Earth.	Partial autonomy because of the limited star visibility. The need of information about coordinates of star location.
1	2	3	4
Radio goniometric systems	They are base d on the application of radio finders and beacons. Radio waves are propagated along the shortest way between the source and the receiver. The coordinates are determined on the bases of the parameter measurement results.	High level of precision, continuous values.	They are not easy to use in mountainous areas.
Difference range finders	They determine the position location by measuring the difference of distance from the plane to two land stations (main and supporting).	They do not accumulate the errors in time and are applied at takeoff and landing as well as during the flight.	Map usage; discrete, the exposure to interference, the absence of autonomy.
Overview and comparative systems			
Navigation globe, panoramic radars	They determine location by comparing the area image on the map or in the memory systems with the physical view of the Earth's surface. If the location image and its real view coincide, the plane is considered to be determined.	High reliability and precision of measurement results; these systems are used at approaching to the airport or landing.	The application of these systems is possible at visibility of the Earth's surface and presence of specific landmarks. The systems are not applied while flying over seas, deserts and in bad weather conditions.

The features of some well-known and widely applied navigation systems among developed and designed in accordance with the methods showed in table 2 , are presented in table 3.

Table 3

The comparative analysis of navigation methods

System name	Principle of system operating	Range km/h	Precision	Error
Navigation indicator NI-50BM	The indicator consists of the air speed sensor, vector device, junction box, coordinate counter, temperature receiver.	200-1100	3-5% of the passed way from initial point	Instrumental error is 5-7% of rate
Doppler device DISS-013	The principle is based on Doppler effect	180-1300	—	Not more than 0,35%
Central gyro vertical CGV	The principle is based on three-stage astatic gyroscope and angle signal sensor usage.	—	—	± 20
Astro-tracker	$\varphi = \varphi_0 + \int_0^t \frac{V_N}{r} dt$, where φ – is latitude, V_N – northern component of aircraft ground speed.	200-1100	—	1,75%

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Range navigation radio system RNRS-2S	The range is determined by the time of request signal spread from the ground beacon to the plane and vice versa.	—	± 200 m of the range	—
Electronic telemeter ET-2	It consists of one master station (installed on the plane) and three drift stations. The location coordinates are determined by distance difference to the stations.	Up to1500	—	D·1·10^5, D – measured distance,

The means of navigation parameter determination at aviation gravimetric measurements. Having analyzed the advantages, drawbacks and technical characteristics of the presented methods of navigation parameter determination (table1, table2), having compared them to the requirements of plane movement parameter precision determination, it is possible to conclude that such navigation systems as Doppler navigation systems, geodesic electronic telemeters and azimuth radiofrequency systems are appropriate to use for aviation gravimetric measurements.

Let us compare the technical parameters of some basic systems developed in the CIS and the USA and focus on the possibilities to apply these systems in AGS depending on the terrain over which the aircraft flying (table 4) .

Table 4

Doppler system technical parameters

Navigation system type	Determination error			Measurement range		Operating altitude range, m	Transmitter power, W
	Ground speed, %	Location, degree	path, %	Ground speed, km/h	Drift angle, degree		
AN ACN-105	0,7 (0,588 км), Duration of flight 200 km	± 0,3	± 0,3	180…1300	± 30	100…15000	10
DISS-013	0,35 at impulse output; 0,5 at analogue output	-	± 3	180…1300	± 30	100…15000	8
DISS-013 134	0,35 at impulse output; 0,5 at analogue output	-	± 2,5	-	± 30	-	8
NAS-1A	0,5	-	± 3	500…1100	± 20	500…15000	5,5
NAS-1Б	0,5	-	± 3	300…800	± 20	500…15000	5,5

Modern Doppler systems which are developed in the USA include AN ACN-105 and DISS- 013, DISS-013-134, NAS-1A, NAS-1B developed in the CIS. It is important to notice that all domestic navigation systems have drift angle error 15 ' at impulse output and 20' at analogue output. The range of accounting path for all the systems does not exceed 10 thousand km at the lateral deviation ± 1000 km. It is known that radio technical angle measuring navigation system RSNB-2 is frequently used. It is developed in CIS and allows determining the plane location with precision ± 200 m at range and ± 0,250 at azimuth. .

It is important to notice that presented parameters of navigation systems (table 3) correspond to the adverse conditions of their usage. Aviation gravimetric measurements are conducted only in favorable flight conditions. So, it is grounded that the precision parameters of navigation systems are much higher.

Electronic telemeters or angle measuring navigation systems which function within medium wave, short wave and ultra-short wave range provide necessary precision of current coordinates of plane. However, the application of these systems should start at the initial point prior to surveying work. Besides, such systems are impossible to use in mountainous area where the stable phase field is hard to create. And in case of measuring over sea it is not always possible to supply the needed number of known radio stations.

Doppler navigation systems can also have some drawbacks. These systems are not easy to apply either at the sea side or in mountains because of the lack of navigation parameters precision. That is why; INS is the basic source of navigation information. The precision of modern INS is normal to apply them in AGS. The precision of modern course system satisfy the needs of aviation gravimetric measurements. For example, TKS-6 error does not exceed 5 angle/min at the most adverse conditions. So, it is reasonable to use different systems of navigation parameter determination depending on the terrain over which the aircraft is flying (Fig.1)

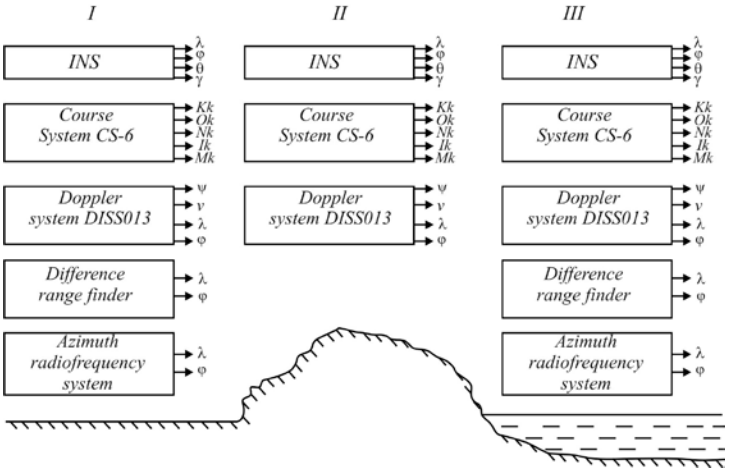

Fig.1 The application of different systems of determination of the navigation parameters depending on the terrain: λ- is longitude; ψ – is drift angle; φ – is latitude; θ – is tangae; γ – is tilt; Kk – compass course; Ok – is great circular course ; Nk – is magnet course, Ik – is real course , Mn – is magnetic bearing; v – is ground speed; I –is takeoff , II – area increase; III – is sea level

Conclusions:

Having analyzed navigation systems and their application in AGS it is possible to conclude: the navigation parameters can be determined by means of IGS when flying over mountains and also using Doppler and course systems together and taking aerial photography of control points along the path. IGS can be used in flat areas as well as difference range finders and angle measuring systems or Doppler systems alongside with course systems. The combination of the mentioned above systems can be used over sea.

The given recommendations of the definite navigation types depending on area type have been successfully proved by the experimental research of AGS with gyroscopic gravimeter [8].

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