On a Calibration Accuracy of the Control Device Complexes

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Abstract: This paper considers the control device complex parameters calibration by Kalman filtering method with application of decomposition of estimated parameters vector.

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1. INTRODUCTION

Article deals with aspects of accuracy assurance while solving tasks of error calibration of control devices complex and initial settings for gyro-stabilized platform with reference to boosters and accelerating units control devices complexes. Solution methods of researched tasks and the main mathematical relations are considered. The estimation of efficiency of the incorporated solutions is represented.

2. ASPECTS OF CALIBRATION ACCURACY ASSURANCE

Concerned control devices complex (CDC) represents the three-axis gyro-stabilized platform (GSP) with three gyroscopic integrators (GI) for linear accelerations and three command angular sensors (CS_v, CS_ψ, CS_φ). Given orientation of axes of sensitivity (AS) of GI determines a base inertial system of coordinates (SC) - SC $OX_0Y_0Z_0$ (Fig. 1), in which the navigation task is solved.

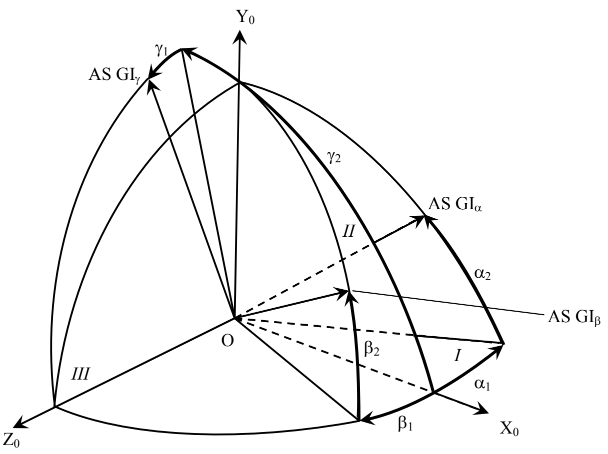

Fig. 1. Method of definition of instrument SC of CDC.

Information from command angular sensors determines orientation of GSP on axes of gimbals suspension. GSP stabilization in inertial space is carried out by means of installed on it three two-axis gyroscopic units (GU), having orthogonal axes of stabilization, thus forming coordinate system OXYZ, rotated relatively to SC $OX_0Y_0Z_0$ on angle θ_y (Fig. 2).

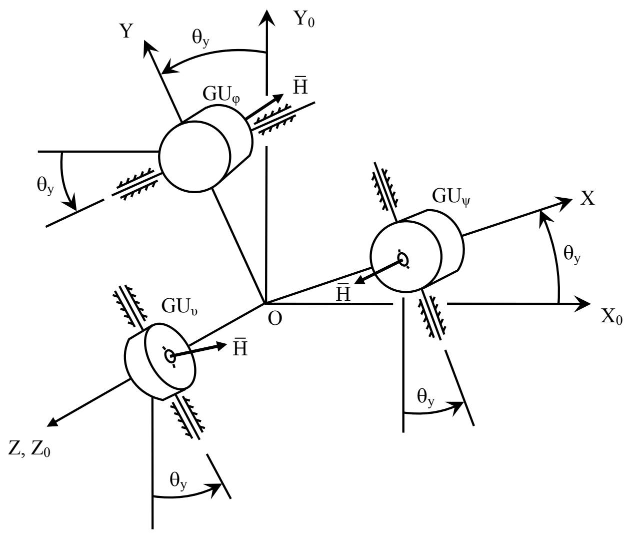

Fig. 2. Orientation of axes of sensitivity of gyroscopic units relatively to instrument SC.

It is obvious, that accuracy of solution of the navigation task is essentially influenced by CDC instrumental errors. Generally these errors are stochastic processes, which can be presented with a sufficient degree of accuracy in the form of the sum of three components:

$$x(t) = x_c + \Delta x(t) + \delta x(t)\,, \qquad (1)$$

where

x_c – systematic component of error x(t), being constant on unit life-cycle;

$\Delta x(t)$ - random component of error x(t), being constant during one power on/off cycle (unit start/initialization) and varying from one CDC power on/off cycle to another;

$\delta x(t)$ - instability of error x(t), being a variable inside one CDC power on/off cycle.

The calibration task consists of the definition and the registration of CDC parameters most influencing on the solution of the navigation task accuracy during pre-launch procedure, e.g. random component $\Delta x(t)$ during the same CDC start in which the process of AU ascent is accomplished.

The values of parameters, generated on the results of calibration, are used during flight as systematic values of these parameters. In this case accuracy of ascent, obviously, is not influenced (accurate within calibration errors) by random components of instrumental CDC errors.

Generally the following parameters are calibrated during a pre-launch procedure:

- errors of scale factors GI (ρ_α, ρ_β, ρ_γ);
- errors caused by the GI withdrawing moments (τ_α,τ_β, τ_γ);
- GSP drifts independent on overload (ω_{21}, ω_{22}, ω_{23});
- GSP drift on axis OZ_0, linearly depending on overload and provided by radial unbalance GU_υ ($\omega_{11}^{(n)}$) .

Beside listed three angular parameters $\Delta\varphi$, $\Delta\psi$, $\Delta\upsilon$ are determined, characterizing errors of positioning of GSP to the needed orientation and used for computation of directing cosines matrix SC $OX_0Y_0Z_0$ in a geographical co-ordinate system at a moment t_0 of control system (CS) navigation task solution starting.

For this purpose GSP is positioned sequentially in 16 orientations concerning gravitational vectors (g) and an angular velocity of the Earth (Ω), characterized by GSP turn angles on axes of gimbals suspension, represented in Table 1.

In GSP stabilization mode the information on projection of apparent velocity on GI axes of sensitivity α, β, γ is measured in each of orientations. Knowing the a priori information on a vector g in a place of measurements and the a priori information on a vector of required parameters X_0, it is possible to build a linear system of equations concerning a vector $Y = X - X_0$, , which looks like

$$\Delta W_j = W_j - W_{pj} = A(t_j, X_0)Y + \varepsilon_j \, , \qquad (2)$$

where ΔW_j - a difference between measured W_j and calculated W_{pj} values of increments of apparent velocity in projections on on GI axes of sensitivity α, β, γ for operation cycle ***j*** of the information processing.

A_j – matrix of coefficients of influence;
ε_j - a random noises vector.

The standard approach for determining Y with this system is usage of recurrent on ***j*** procedure of construction of a probability estimation Y of vector Y, according to the following algorithm

$$Y_{j+1} = Y_j + S_{j+1}(\Delta W_j - A_{j+1}Y_j) \qquad (3)$$
$$j = 1,..., N; \;\; Y_0 = 0,$$

where filter S amplification factor is a function of correlation matrix of an error of estimation X_0 and a correlation matrix of an error ε_j, that is a particular case of Kalman filter for static systems.

This procedure gives an unbiased estimation with the minimum dispersion (that is a sum of dispersions of vector components) Y provided that ε_j represents digital "white noise". The number of steps is determined by a time of observations.

The relation (3) allows specifying a complete vector of estimated parameters both in process of arrival of measurements in orientation ***I***, and at transitioning to measurements in orientation ***I + 1***.

Such procedure optimally uses metrological CDC possibilities, however in the presence of limitations of on-board computers computational capabilities its application is at a loss due to high dimensionality of the task.

Practically, decomposition algorithm is implemented and according to it the collection of all orientations is divided into four groups, where instead of complete vector X in each group its separate components are evaluated. (Table 1).

Futhermore estimations of errors of orientation $\Delta\varphi$, $\Delta\psi$, $\Delta\upsilon$, built on results of measurements in orientations 1-4, are taken into account during estimating of GSP drifts values in orientations 11-12 in the assumption, that the mentioned estimations of orientation are constant.

Generally this assumption is incorrect, since GSP re-orientation brings additional orientation errors, caused by CS errors and non ideal geometry of gimbals suspension, leading to calibration errors of GSP drift.

Tests results allows to estimate errors of calibration values of GSP drifts independent from overload, using decomposition algorithm at a level, not enough to guarantee needed accuracy of GSP ascent, to geosynchronous orbits in particular.

Rise in accuracy of calibration of GSP drifts is possible at the expense of additional specification of GSP position on axes υ and ψ suspension $(\Delta\upsilon, \Delta\psi)$ in calibrating orientations at which drifts are estimated, with their subsequent accounting while estimating drift values. Such improvement of algorithm allows to lower calibration errors of GSP drifts, independent from overload, on about (30-40) %.

The further rise of accuracy of this algorithm is possible by increasing the of number of calibrated GSP`s drifts taking into account the following improvement of estimated parameters vector model in calibration orientations 11-12:

Table 1. Operations of initial and improved algorithm of CDC calibration

N orient.	GSP turn angles, grad. on axe			Time meas., c	Evaluating Vector, Basic algorithm	Evaluating Vector, Improved algorithm
	Φ	ψ	Y			
1	0	0	0	180	$\|\Delta\vartheta, \Delta\psi\|$	$\|\Delta\vartheta, \Delta\psi\|$
2	180	0	0	180		
3	180	0	0	1800	$\|\Delta\varphi, \Delta\psi, \Delta\vartheta\|$	$\|\Delta\varphi, \Delta\psi, \Delta\vartheta\|$
4	0	0	0	1800		
5	α_1	0	α_2 - 90	300		
6	-α_1	0	α_2 + 90	300	$\|\Delta\rho_\alpha, \Delta\tau_\alpha\|$	$\|\Delta\rho_\alpha, \Delta\tau_\alpha\|$
7	-β_1	0	β_2 - 90	300		
8	-β_1	0	β_2 + 90	300	$\|\Delta\rho_\beta, \Delta\tau_\beta\|$	$\|\Delta\rho_\beta, \Delta\tau_\beta\|$
9	0	0	γ_2 - 90	300		
10	0	0	γ_2 + 90	300	$\|\Delta\rho_\gamma, \Delta\tau_\gamma\|$	$\|\Delta\rho_\gamma, \Delta\tau_\gamma\|$
11	0	0	90-θ_y	3600	$\|\Delta\omega_{23}, \Delta\omega_{11}^{(н)}\|$	$\left\|\begin{matrix}\Delta\omega_{23} - \Delta\omega_{11}^{(\mu)}, \\ \Delta\omega_{21} + \Delta\omega_{11}^{(н)} + \Delta\omega_{1}^{(Q)}\end{matrix}\right\|$
12	0	0	-θ_y	3600	$\|\Delta\omega_{22}, \Delta\omega_{21}\|$	$\|\Delta\omega_{22} + \Delta\omega_{12}^{(\mu)}, \Delta\omega_{21} - \Delta\omega_{11}^{(\mu)},\|$
$11_{доп}$	0	0	-90-θ_y	3600	-	$\left\|\begin{matrix}\Delta\omega_{23} + \Delta\omega_{11}^{(\mu)}, \\ \Delta\omega_{23} - \Delta\omega_{11}^{(н)} + \Delta\omega_{1}^{(Q)}\end{matrix}\right\|$
$12_{доп}$	0	0	-θ_y	3600	-	$\|\Delta\omega_{22} - \Delta\omega_{12}^{(\mu)}, \Delta\omega_{21} + \Delta\omega_{11}^{(\mu)},\|$
13	0	0	0	600	$\|\Delta\vartheta, \Delta\psi\|$	
14	180	0	0	600		
15	$A_п$+180	0	0	1800	$\|\Delta\varphi, \Delta\psi, \Delta\vartheta\|$	
16	$A_п$ *)	0	0	1800		

*) - flight direction

$$\begin{cases} \Delta\omega_y^{(f)} = \Delta\omega_{23} - \Delta\omega_{13}^{(\mu)} & f = 11 \\ \Delta\omega_z^{(f)} = \Delta\omega_{21} + \Delta\omega_{11}^{(H)} + \Delta\omega_1^{(Q)} & f = 11 \\ \Delta\omega_x^{(f)} = \Delta\omega_{22} + \Delta\omega_{12}^{(\mu)} & f = 12 \\ \Delta\omega_z^{(f)} = \Delta\omega_{21} - \Delta\omega_{11}^{(\mu)} & f = 12 \end{cases}, \qquad (4)$$

where $\Delta\omega_{x,y,z}^{(f)}$ – estimated drift values around axes OX_0, OY_0, OZ_0 in orientation ***f***;

$\Delta\omega_{2i}$ $(i = 1,2,3)$ - deviations of actual values of calibrated drifts ω_{2i} from their a priori (passport) values;

$\Delta\omega_{1i}^{(\mu)}$ $(i = 1,2,3)$ - random drift component $\Delta\omega_{1i}^{(\mu)}$ linearly depending on the overload operating along an axis of GU precession;

$\Delta\omega_1^{(Q)}$ - random drift component GU_υ $\omega_1^{(Q)}$, proportional to the difference of squares of overload ($1g^2$) operating along axes of sensitivity and GU angular momentum.

As it follows from relations (4), the initial calibration algorithm random components $\Delta\omega_{1i}^{(\mu)}$ $(i = 1,2,3)$, $\Delta\omega_1^{(Q)}$ are directly included into calibrated drifts error $\Delta\omega_{2i}$ $(i = 1,2,3)$. This error can be excluded by the following correction of initial algorithm.

Two additional orientations are added to the calibration mode cycle 11.1 and 12.1, which differs from initial algorithm orientations 11 and 12 by a turn of GSP around suspension axis υ on a 180º corner (Tab.1). In this case, along with estimations (4), it is possible to construct similar estimations in additional orientations:

$$\begin{cases} \Delta\omega_y^{(f)} = \Delta\omega_{23} + \Delta\omega_{13}^{(\mu)} & f = 11.1 \\ \Delta\omega_z^{(f)} = \Delta\omega_{21} - \Delta\omega_{11}^{(H)} + \Delta\omega_1^{(Q)} & f = 11.1 \\ \Delta\omega_x^{(f)} = \Delta\omega_{22} - \Delta\omega_{12}^{(\mu)} & f = 12.1 \\ \Delta\omega_z^{(f)} = \Delta\omega_{21} - \Delta\omega_{11}^{(\mu)} & f = 12.1 \end{cases}, \qquad (5)$$

from which besides parameters $\Delta\omega_{2i}$ $(i = 1,2,3)$ it is possible to calculate parameters $\Delta\omega_{1i}^{(\mu)}$ $(i = 1,2,3)$, thus allowing to exclude the influence of random errors of parameters $\omega_{1i}^{(\mu)}$ on calibration drift errors ω_{2i}.

Besides, the specified algorithm allows to raise accuracy of drift calibration $\omega_{11}^{(H)}$, influencing on problem decision accuracy of GSP azimuth initial set, due to elimination of influence of a random component of parameter $\omega_1^{(Q)}$ `on its definition error.

Taking into account presented improvements of decomposition algorithm, an expected error of GSP drifts calibration, independent from overload, decreases twice.

CONCLUSION

Thus, optimum employment of CDC metrological opportunities allows approximately doubling the GSP drift calibration accuracy.

REFERENCES

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