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STABILIZATION AND CONTROL SYSTEM WITH GUARANTEED ACCURACY FOR OPTICAL AXIS

Ua Розглядається задача забезпечення гарантованої точності синтезованої системи автоматичного керування дій на неї невизначених довільних за характером збурень. Показана процедура формування та особливості структури системи керування гарантованої точності, яка при компенсації збурень забезпечує збереження якості керування (стійкості системи та якості перехідного процесу). Запропонований спосіб формування коригуючого впливу для компенсації дії збурень як функцію наближення змінної стану системи до границі її допустимого значення.

En The task of ensuring the guaranteed accuracy of the synthesized system of automatic control of the actions of undefined random disturbances on it is considered. The formation procedure and features of the structure of the control system of guaranteed accuracy are shown, which, when compensating for disturbances, ensures the preservation of control quality (system stability and the quality of the transient process). The proposed method of forming a corrective influence to compensate for the action of disturbances as a function of the approximation of the system state variable to the limit of its permissible value.

Introduction

Creation of stabilization and control systems remains an important task of precision instrument engineering. This is due to the wide scope of application of such systems. for example, in [1] there is a detailed introduction to the field of soft computing methods, and all the main methods of artificial intelligence are described in a clear and practical way. In the article [2], the structural synthesis of a robust system of stabilization of surveillance equipment, which is operated on unmanned aerial vehicles, is considered. Features of robust structural synthesis for the system under study are considered. Ensuring the accuracy of the system under various influences makes it possible to design universal control systems [3]. Approaches to the design of stabilization systems for some specified disturbances and under specified operating conditions are considered in [4]. Synthesis of systems under uncertain disturbances has a number of problems and solutions in some cases [5]. In works [6, 7], an approach to compensation of the influence of uncertain disturbances on the control system is proposed and its possibilities are shown on the examples of individual control laws. However,

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there are a number of systems with passive perturbations of a nonlinear nature, which are used to control the optical axis, and are of practical importance and require high accuracy.

Formulation of the problem

Let's consider the problem of ensuring the guaranteed accuracy of the automatic control system (ACS) under uncertain disturbances.

Mathematical model of the stabilization system

Let’s use the mathematical model of the system in stabilization and rotation of the optical axis [8]:

$$
\begin{aligned}
&\left(J_{1y}+J_{2x}\sin^2\varphi_z+J_{2y}\cos^2\varphi_z\right)\dot{\omega}_{2y2}/\cos\varphi_z+f_1\omega_{2y2}/\cos\varphi_z=\\
&\qquad=M_{m1}-\left(J_{1y}+J_{2x}\right)\operatorname{tg}\varphi_z\dot{\omega}_{1x1}-\left(J_{1x}-J_{1z}\right)\omega_{1x1}\omega_{1z1}-\\
&\qquad-\left(J_{2x}\omega_{2x2}\cos\varphi_z+J_{2y}\omega_{2y2}\sin\varphi_z+J_{2z}\omega_{1x1}\right)\omega_{2z2}-\\
&\qquad-f_1\left(\omega_{1x1}\operatorname{tg}\varphi_z-\Omega_{yo}\right)+M_{fr1}+M_{imb1}+M_{dis1}\\
&J_{2z}\dot{\omega}_{2z2}+f_2\omega_{2z2}=M_{m2}+\left(J_{2x}-J_{2y}\right)\omega_{2x2}\omega_{2y2}+f_2\omega_{1z1}+M_{fr2}+\\
&\qquad+M_{imb2}+M_{dis2}\qquad\qquad.
\end{aligned}
\tag{1}
$$

The calculation of stabilization and control circuits of gyro stabilizers is usually done separately [8], based on the fact that the natural frequencies of the control circuit are much smaller than the natural frequencies of the stabilization circuit.

Then the design of the system for ensuring the guaranteed accuracy of the two-axis stabilization system can be reduced in a linear formulation to the design of two uniaxial ones [8]. Let’s get a structural diagram of the stabilization contour of the outer frame (Fig. 1).

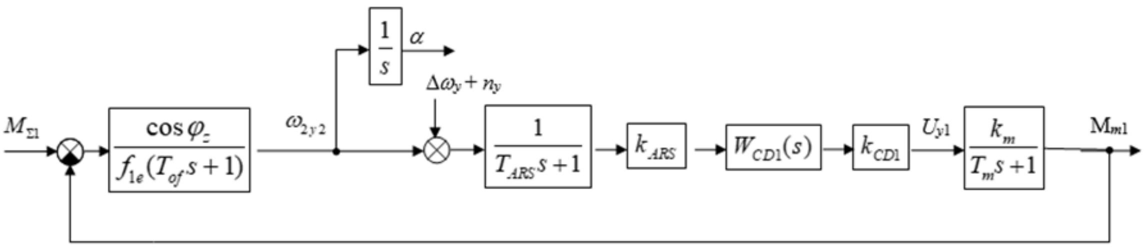


Fig. 1. Structural diagram of the external frame stabilization circuit

We believe that current disturbances are limited only by their magnitude, which is determined by the possibility of their compensation by executive bodies of the ACS.

Application of the algorithm for the formation of a control system of guaranteed accuracy

Ensuring the quality of the control system, or stabilization, in many cases requires achieving a certain speed and the necessary accuracy.

No requirements are imposed on the control object. It can be an object of any structure, including a pre-synthesized optimal system [9], which allows the existence of an inverse model:

$$W_a(s) = \left[W_y^g(s)\right]^{-1}. \tag{2}$$

To ensure guaranteed accuracy in conditions of arbitrary disturbances, we introduce an additional link with a transfer function into the control system, which is the inverse dynamic model of the control object and the adjustment coefficient (2) [6, 7]:

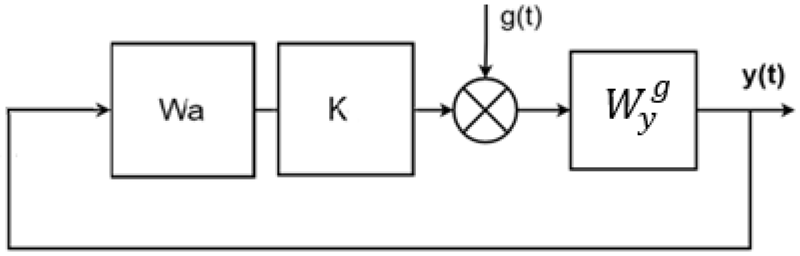


Fig. 2. Structural diagram of the circuit of the automatic control with the algorithm for ensuring guaranteed accuracy

The adjustment coefficient *K* (Fig. 2) is formed to compensate for the effects of disturbances as a function of the approximation of the ACS state variable to the limit of the permissible value [10].

To apply and further study the algorithm, it is necessary to find the inverse transfer function of the synthesized automatic control system (Fig. 1). From the structural diagram in Fig. 1, we get:

$$W_y^g = \frac{W_{dl}}{1+W_{dl}}, \tag{3}$$

where W_{dl} – transfer function of the direct link of the automatic control system (Fig. 1)

$$W_{sl} = \frac{K_{sum} \cdot \cos(\varphi) \cdot (T_{11}s+1)}{(T_{12}s^2+s)(T_m s+1)(T_{of}s+1)(T_{ARS}s+1)}, \tag{4}$$

where T_{11} T_{12} – time constants of the correction device, T_m – electromagnetic time constant of the motor, T_{of} – the mechanical time constant of the outer frame, T_{ARS} – time constant of the filter angular rate sensors (ARS), K_{sum} – the product of the transfer coefficient for the control voltage of the motor, transmission ratio ARS, the transmission coefficient of power amplifiers and the gain coefficient of the correcting device.

From expressions (3) and (4), we get the transfer function of the synthesized automatic control system written in the form

$$W_y^g = \frac{K_{sum}\cos(\varphi) + K_{sum}T_{11}s\cos(\varphi)}{b_5 s^5 + b_4 s^4 + b_3 s^3 + b_2 s^2 + b_1 s + b_0} \qquad (5)$$

where $b_5 = T_{12}T_m T_{of} T_{ARS}$, $b_4 = T_{12}T_m T_{of} + T_{12}T_m T_{ARS} + T_{12}T_{of}T_{ARS} + T_m T_{of} T_{ARS}$, $b_3 = T_{12}T_m + T_{12}T_{ARS} + T_m T_{ARS} + T_{of}T_{ARS} + T_m T_{of} + T_{12}T_{of}$, $b_2 = T_{12} + T_m + T_{of} + T_{ARS}$, $b_1 = K_{sum}T_{11}s\cos(\varphi) + 1$, $b_0 = K_{sum}\cos(\varphi)$ – transfer function coefficients.

The transfer function (5) allows you to create an inverse dynamic model (2) for applying the guaranteed accuracy algorithm (Fig. 2).

Mathematical simulation

To check the correct application of the algorithm [10] to ensure guaranteed accuracy, we will simulate the reaction to a single disturbing signal $g(t)$ **(**Fig. 2).

Let's take the adjustment coefficient in the form $K = \frac{1}{y_{ad} - |y|}$. The permissible value y_{ad} of the angle of deviation of the sighting axis is assumed to be equal to 1.3 degrees.

The analysis of the simulation result (Fig. 3) shows the fulfillment of the conditions for ensuring guaranteed accuracy without exceeding the permissible limit of the deviation of the imaging axis during disturbance.

One of the main tasks of the optical axis control system is to work out the set angle of the line of sight [8]. The parameters that are decisive for this process are the working error and the transition time.

In order to check the operation of the algorithm for ensuring guaranteed accuracy for the mode of working out the viewing angle, we will simulate (Fig. 4) the working out of the control signal U_{y1} (Fig. 1) rotation of the sighting axis to an angle of 40 degrees.

Analysis of the process in Fig. 4 shows a reduction in the time of the transition process by two times without loss in the accuracy of working out the angle of the line of sight.

In the stabilization system, there is dry friction of the mechanical parts of the system as a component of the total disturbing moment $M_{\Sigma 1}$ (Fig. 1). Consider the effect of dry friction on the behavior of the system (Fig. 5).

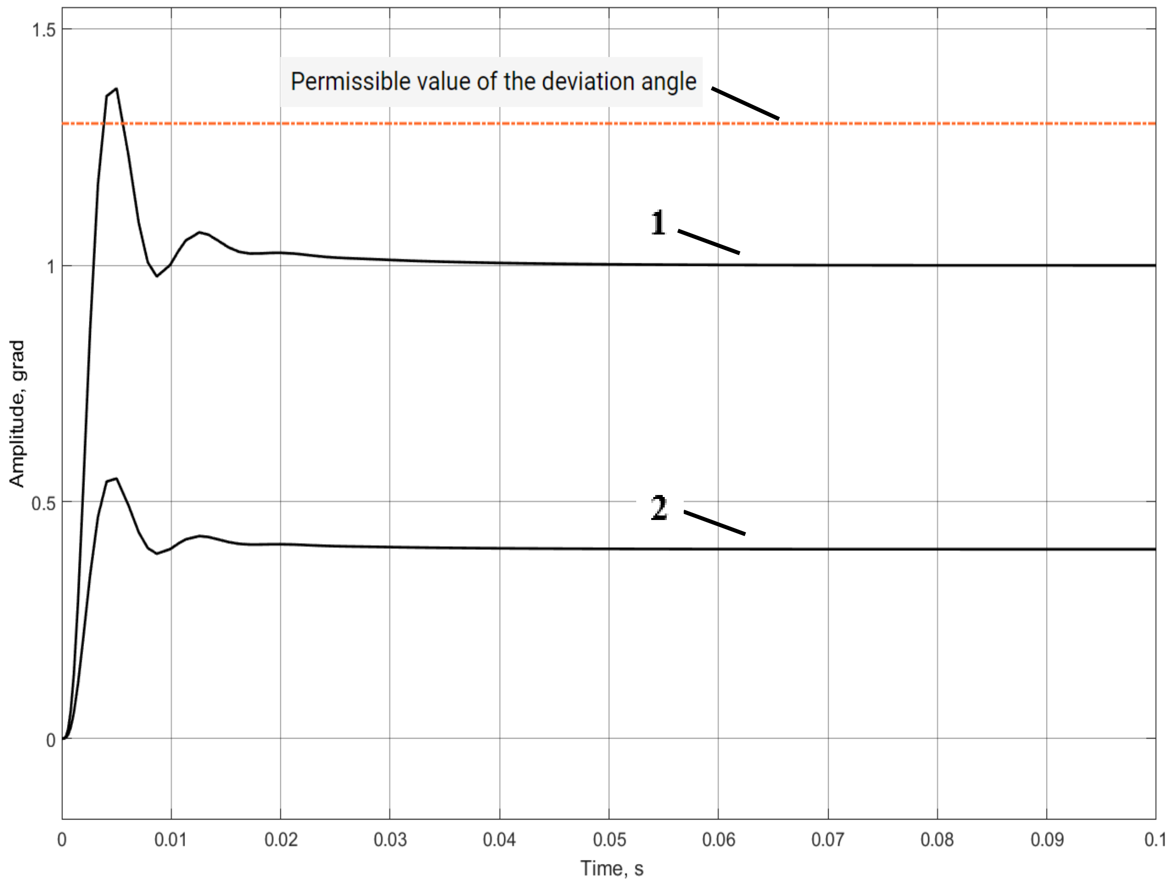
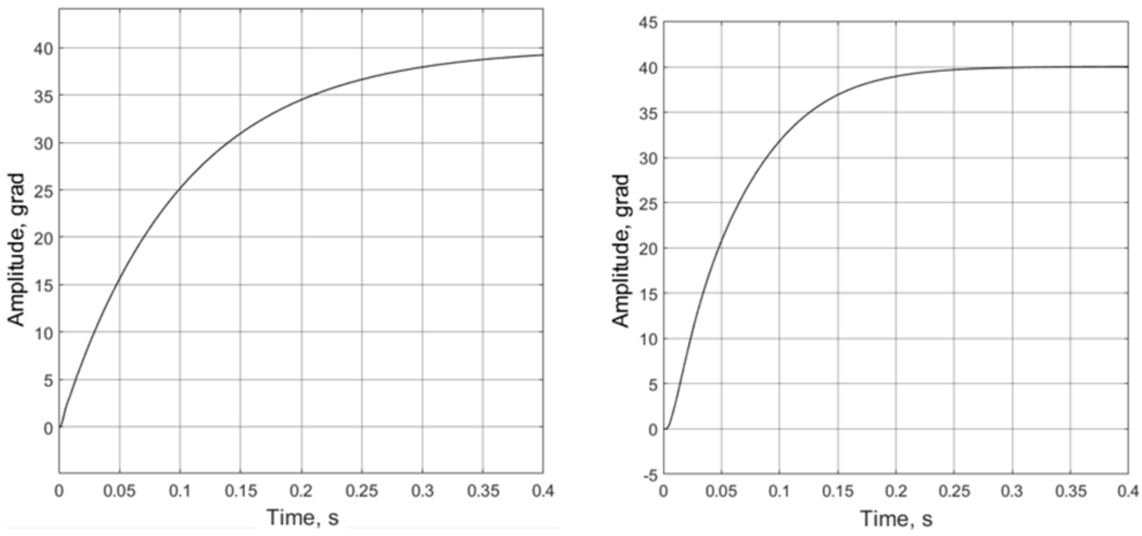


Fig. 3. The result of applying the guaranteed accuracy algorithm: without the algorithm (curve 1); with its application (curve 2)



***a*)** ***b*)**

Fig. 4. Application of the guaranteed accuracy algorithm for working out the control angle ***a*)** without the algorithm; ***b*)** with the algorithm

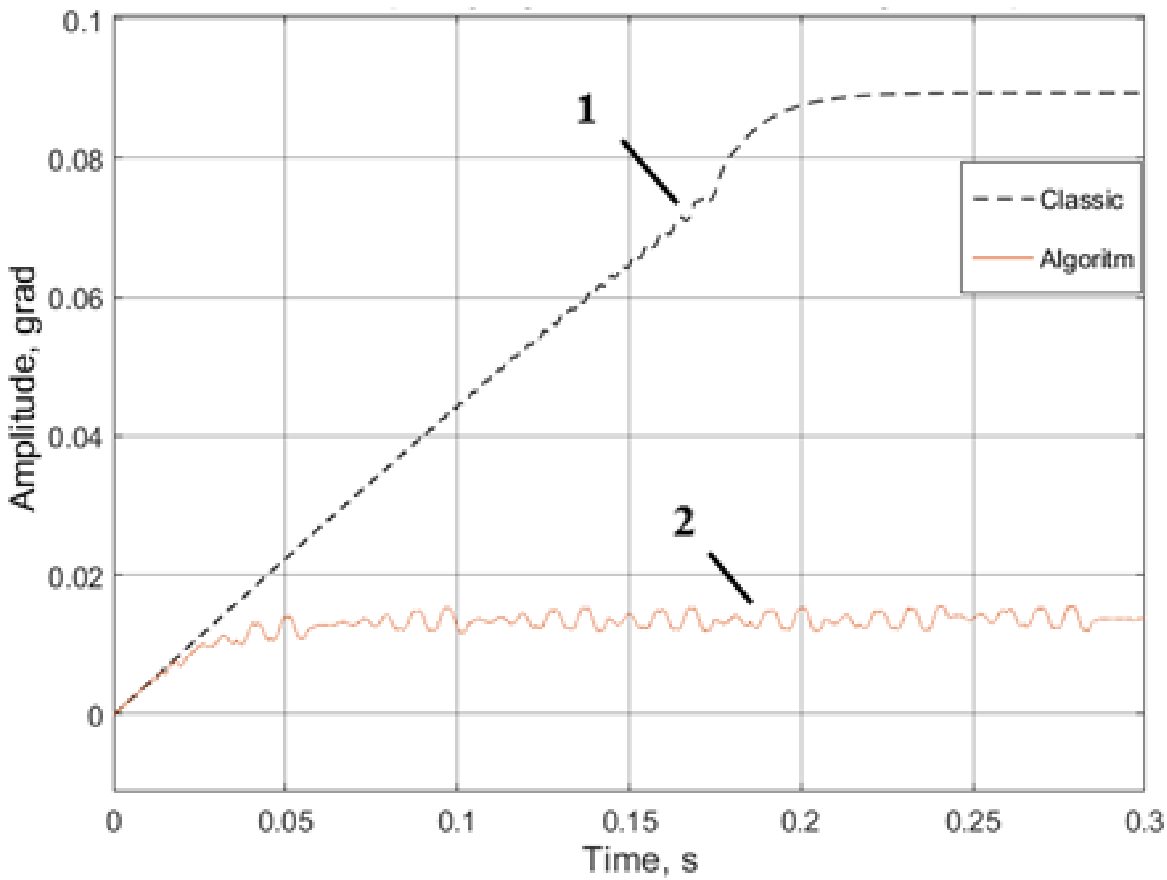


Fig. 5. Error of the stabilization system in the presence of increased dry friction without the algorithm (curve 1) and with its application (curve 2)

The simulation (Fig. 5) shows a six-fold decrease in the stabilization error and an eight-fold increase in the speed of the system.

The simulation results (Fig. 3-5) show the effectiveness of the proposed method for the synthesis of ACS with guaranteed accuracy. The variability of the selection of the functions of the adjustment coefficient and the values of its numerical coefficients makes it possible to create universal ACSs with a given guaranteed accuracy and to influence the necessary parameters of the transition process in the presence of various types of external disturbances.

Conclusions

The application of the proposed algorithm of guaranteed accuracy to compensate for the action of undefined disturbances as a function of the approximation of the state variable of the ACS to the limit of the permissible value shows the fulfillment of the conditions for ensuring the guaranteed accuracy without exceeding the permissible limit of the deviation of the axis of vision during control, a significant improvement in the quality of control for working out the control angle (Fig. 4) , and also the algorithm showed its efficiency in the fight against dry friction.

It is shown that the structure of the algorithm of guaranteed accuracy ensures that the permissible limit of deviation of the sighting axis is not exceeded, the stability and quality of the transient process of the ACS is preserved when compensating for disturbances in the presence of increased dry friction, and it provides an increase in the quality of the transient process when working out a given angle of the sighting line of the optical axis.

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