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SYNTHESIS OF STABILIZATION SYSTEM

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Abstract**—***Stabilization system is an integral part of the guidance system and creates comfortable conditions for using the guidance system sensitive element (for example, optical sensor). Stabilization and guidance system used on movable objects of civil and military assignment to get information about the line of sight angular parameters of the optical devices in the stabilization mode.*

Index Terms—Stabilization system; gyrostabilizer; guidance system; transfer function; stabilized platform; synthesis.

I. INTRODUCTION

The instruments and devices, which arranged on the platform, needed to stabilize at the object's movement. Gyroscopes together with various electromechanical devices (such as, amplifiers, torque devices) carry out the platform stabilization [4].

At present, the task of improving the accuracy of controlled gyrostabilizer that operate in stabilization mode, is very important.

The main sphere of use of this system is military, but there are variants of its use for civilian tasks (such as videography on stabilized platform) after some reconfiguration of the system.

To solve the problem of effective guidance of element of guidance system (for example, optical sensors), keeping it fixedly relatively targets and providing minimize angular deviations. It is important to create complexes with smaller overall dimensions characteristics, but with the necessary accuracy class. For this, necessary to use a reduced size angular rate sensor (ARS), built on MEMS technology [5].

The main problems at the gyrostabilized platform development with MEMS sensor arise because error and noisy output signal of ARS, which has a tendency to great drift and dry friction in the stabilization actuators. If the friction problem can be solved by increasing engine power and to use high-quality bearings for reduce it, then the error of ARS output signal can only assess and consider in the future, using processing of sensor output signals [2].

Thanks to the system synthesis can be concluded about the possibility and impossibility of using this gyrostabilizer for the platform stabilization.

The results of this investigation can have practical application for solving the guidance task that emphasizes its actuality and importance.

Synthesis task requires a simulation. This process for the studied system may be realized on the basis of the computing system Matlab, which is widely used now for design of measuring and electronic systems.

II. OPERATIONAL PRINCIPLE OF GYROSTABILIZER

Operating principle of the system is the following: first of all is the initial exhibition of platform of a given GS. Since the platform is stabilize relatively inertial CS, the initial exhibition goes relatively geographical CS. After leveling and beginning of stabilization system work – the guidance at the target of sighting line of sensor (for example, optical) passes with the help of manual regulation method [3].

Control of turns the platform by the yaw and pitch axes occurs due to sending control signals, which are proportional to necessary angles of platform deviation to control channels, after that targets fixation occurs (Fig. 1).

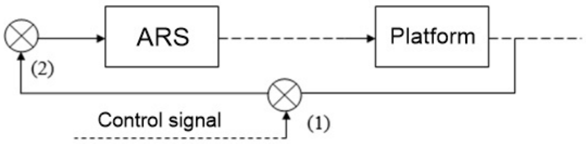

Fig. 1. Stabilization contour of gyrostabilized platform

A control signal applied to the channel 1 the general stabilization channel and "inform" ARS about platform deviation. ARS sends an output signal to the TD for practice of rotation the platform relatively of shifted position and stabilizer begins to work in mode of stabilization external harmonic disturbance.

III. STABILIZATION SYSTEM SYNTHESIS

Like any dynamic system, automatic control system (ACS) can be in one of two modes - stationary (steady state) and transient. There are two types of stationary regimes of ACS – static and dynamic. Static mode (static) is a mode in which the system is in a state of rest due to the fact that all external actions and parameters of the system do not change in time. Dynamic stationary mode occurs when the external actions, which applied to the system, change by any established law. As a result, the system comes to a steady forced motion mode.

Important static problems are to provide a given static accuracy, and also the study of the elements and systems static characteristics. By view of these characteristics distinguish static and astatic regulation.

Consider the problem of stabilization system design, a block diagram of which is shown in Fig. 2. Where x, σ are input and output (stabilization angle) variables; m is the disturbance; W_0 is the transfer function of the control object; W_* is the transfer function of the regulator.

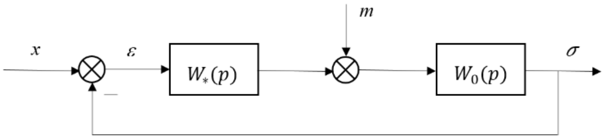

Fig. 2. Structural scheme of stabilization system

Further, we will assume, that x, i. e. will be consider the stabilization angle as an error of functioning of stabilization system. The TF of the object we will write in the form

$$W_0(p) = \frac{K_0}{p(Tp+1)},$$

where K_0, T are parameters.

Consider the synthesis of regulator of two types: static and astatic (in next chapter). In the analysis, we will use the synthesis method proposed by V.A. Besekersky [1].

IV. ASTATIC SYSTEM SYNTHESIS

We will use the method of synthesis of astatic systems [1] and synthesizing system that corresponds the specification requirements to the gyrostabilizer characteristics. Due to the symmetry of the platform and the similarity of the moments of inertia, will consider one of the channels, for the other one result will be similar.

Given that the gyroscopic stabilization systems error determined typically by disturbance, the analysis will be performed relative to disturbances. Since the system must be astatic by the disturbances and the error, in order to compensate the action of external disturbing moment, using executed notation will hold transformation of described block diagram (Fig. 3) to the form, where M_{DIST} will be the main input (block diagram by the disturbances).

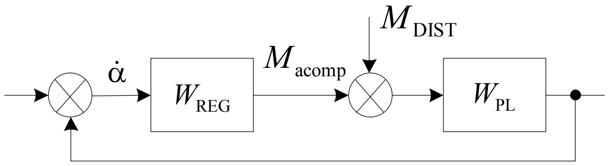

Fig. 3. Simplified structural diagram of the gyrostabilizer pitch channel

Denote $W_{PL}(p) = W_0(p)$. Then transfer function of open-loop reference system has the following view:

$$W_{op\varepsilon} = K_\varepsilon \frac{T_2 p + 1}{p^2 \left(T_3 p + 1\right)^2}, \tag{1}$$

where

$$K_\varepsilon = \omega_c^2 \frac{M-1}{M},\ T_2 = \frac{M}{\omega_c\left(M-1\right)},\ T_3 = \frac{M}{2\omega_c\left(M+1\right)}; \tag{2}$$

ω_c is the cut-off frequency; M is the oscillation index.

Will set parameters, which should be present in the synthesized system and define the coefficients for $W_{op\varepsilon}$ according to the described formulas. By the Bessekersky method [1], we will accept M = 1.5, disturbances at the input of the system will be $M_{\mathrm{DIST}} = m = 1$, will define the value of time constants and cut-off frequencies of the system.

$$\omega_c = \lambda \sqrt{\frac{mK_0}{\alpha_e \frac{1}{J}}},$$

where $\lambda = 1.485$ for M=1.5, α_e is the given value of output signal amplitude, angle min, $\alpha_e = \frac{10}{60 \cdot 2\pi} \Rightarrow$

$$\omega_c = 1.485 \frac{1 \cdot 357}{\frac{10}{60 \cdot 2\pi}\left(\frac{1}{0.13}\right)} = 319.4558, \frac{1}{\mathrm{s}}.$$

In accordance with equations (2), we will have:

$$K_\varepsilon = 3.4017 \cdot 10^4;\ T_2 = 0.0094;\ T_3 = 9.3910 \cdot 10^{-4}.$$

After that, let us write the numerical view of (1)

$$W_{op\varepsilon}\left(p\right) = \frac{3.4017 \cdot 10^4 (0.0094p+1)}{p^2 (9.3910 \cdot 10^{-4} p + 1)^2}.$$

With respect to reference system, will hold synthesis of open-loop system so that the characteristics will coincide. Transfer function of regulator we will write in the following form:

$$W_{\mathrm{REG}}(p) = \frac{1}{p} W_1(p) = \frac{1}{p} K_1 N(p),\ = N(p)\big|_{p\to 0} = 1.$$

Then the block diagram by the disturbances will has the following form (Fig. 4)

In this case, the TF of open-loop system looks like

$$W_{op}(p) = W_{\mathrm{REG}}(p) W_0(p). \tag{3}$$

The cut-off frequency of the system lies within the permissible limits of frequencies, which do not superimposed on the frequencies of the work of gyroscope. Therefore, it does not need in correction (Figs 5 and 6).

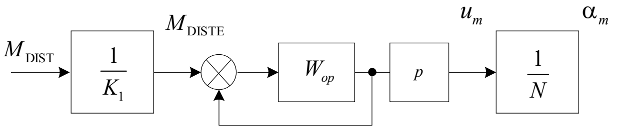

Fig. 4. Block diagram of the pitch channel by the disturbances

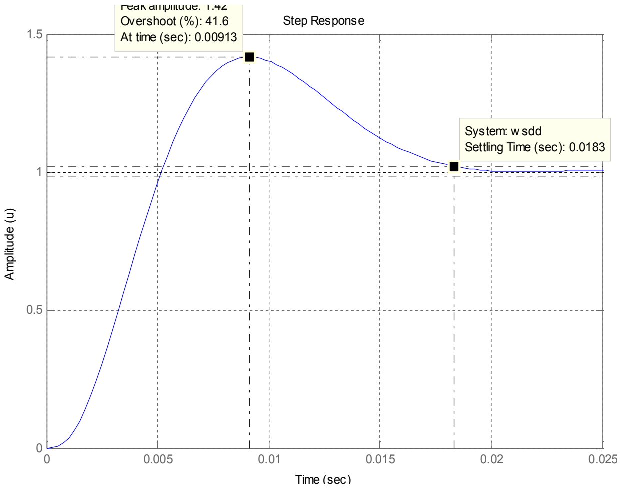

Fig. 5. Graph of normalized output signal of closed-loop reference system with TF $W_{op\varepsilon}(p)$

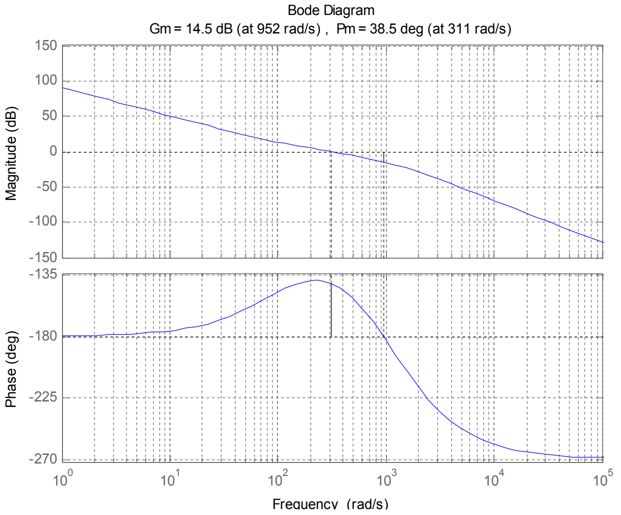

Fig. 6. Bode plot of the open-loop reference system

For reference system the extreme value of variable $u(t)$, we can estimate by the formula

$$u_m = m\frac{1}{K}\omega_c\rho,$$

where $\rho = \lambda\sqrt{\frac{M-1}{M}}$.

Taking $\alpha_m = u_m$, we obtain an expression for the gain of the regulator

$$K = \frac{m\rho\omega_c}{\alpha_m}.$$

Making sure, that the system meets the requirements by time of the transition process and overshoot, we can use (3) for the synthesis of regulator for real system.

Transfer function $N(p)$ written in the following form

$$N(p) = \frac{(T_{11}p+1)(T_{12}p+1)(T_2p+1)}{(T_{21}p+1)(T_3p+1)^2}.$$

Transfer function of open-loop system

$$W_{op}(p) = W_{\text{REG}}(p)W_0(p) = E(p)W_{op\varepsilon}(p),$$

where $E(p) = R\frac{(T_{11}p+1)(T_{12}p+1)}{(T_{21}p+1)(Tp+1)}$; $R = \frac{KK_0}{K_\varepsilon} = \frac{mK_0\lambda^2}{\alpha_m\omega_c\rho}$.

The parameters of the transfer function $E(p)$ will be chosen so, that in cut-off frequency field, the ratio will performed:

$$(T_{11}\omega_c)^2 >> 1;\ (T_{12}\omega_c)^2 >> 1;\ (T_{21}\omega_c)^2 >> 1;$$
$$\left|E(i\omega_c) = 1\right|.$$

Then $R = \frac{T_{21}T}{T_{11}T_{12}}$.

We consider requirement $\alpha_m = u_m$, which is determined by the parameters of the transfer function $\frac{1}{N(p)}$. Since, oscillations are carried out at a frequency closed to the base frequency ω_0, the effect of this block to the signal amplitude can be measured as

$$\frac{1}{N(\omega_0)} = \frac{(T_{21}p+1)(T_3p+1)^2}{(T_{11}p+1)(T_{12}p+1)(T_2p+1)}$$
$$\approx \frac{T_{21}}{T_{11}T_{12}\omega_0\sqrt{(T_2\omega_0)^2+1}}$$
$$= \frac{T_{21}}{T_{11}T_{12}\omega_c\sqrt{\frac{M-1}{M}}\sqrt{\frac{M}{M-1}+1}}$$
$$= \frac{T_{21}}{T_{11}T_{12}\omega_c}\sqrt{\frac{M}{2M-1}} \approx \frac{T_{21}}{T_{11}T_{12}\omega_c}\rho.$$

From the condition $\frac{1}{N(\omega_0)} = 1$ we can find

$$\frac{T_{21}}{T_{11}T_{12}} = \frac{\omega_c}{\rho},$$

which is imposed on parameters of regulator. Then, the formula must be written as

$$R = \frac{\omega_c T}{\rho}$$

Then expression for cut-off frequency will be following form

$$\omega_c = \lambda\sqrt{\frac{mK_0}{\alpha_m}}.$$

This expression will be used for finding a time constants T_{11}, T_{12}, and T_{21}.

$$T_{11} = \frac{\gamma_1}{\omega_c}\frac{M}{M-1}, \quad \gamma_1 = \gamma_2 = 10 \Rightarrow$$

$$T_{11} = T_{12} = \frac{10}{319.25}\cdot\frac{1.5}{1.5-1} = 0.0939,$$

$$T_{21} = \frac{\gamma_1\gamma_2}{\rho\omega_c}\left(\frac{M}{M-1}\right)^2 = \frac{100}{0.858\cdot 319.25}\cdot 3^2 = 3.2836.$$

Then we will write the expression for open-loop system (3) with synthesized regulator.

$$W_{\text{REG}}(p) = \frac{1}{p}K\frac{(T_{11}p+1)(T_{12}p+1)(T_2p+1)}{(T_{21}p+1)(T_3p+1)^2};$$
$$W_0(p) = \frac{K_0}{p(Tp+1)}. \tag{4}$$

Equations (4) substituted in (3):

$$W_{op}(p) = \frac{1}{p}K\frac{(T_{11}p+1)(T_{12}p+1)(T_2p+1)}{(T_{21}p+1)(T_3p+1)^2} \times \frac{K_0}{p(Tp+1)}. \tag{5}$$

Numerical view of the (5):

$$W_{op}(p) = \frac{195.1p^3 + 2.49e004p^2 + 4.64e005p + 2.35e006}{5.378e-007p^6 + 0.001148p^5 + 0.6163p^4 + 3.471p^3 + p^2}.$$

Let us write the transfer function by disturbances, according to scheme, which shown by Fig. 4, we have:

$$W^f(p) = \frac{W_0(p)}{1 + W_0(p)W_{\text{REG}}(p)} = \frac{W_0(p)}{1 + W_{op}(p)}$$

Let’s substitute the value of TF that the general view was obtained

$$W^f(p) = \frac{W_0(p)}{1 + W_{op}(p)}.$$

Substituting (4), we obtain the transfer function $W^f(p)$ by disturbances in numerical form

$$W^f(p) = \frac{0.0001921p^6 + 0.4101p^5 +}{9.987e-008p^8 + 0.0002138p^7 + 0.1156p^6 + 37.49p^5 +}$$
$$\frac{+220.1p^4 + 1240p^3 + 357.1p^2}{+4829p^4 + 1.112e005p^3 + 9.02e005p^2 + 2.356e006p}.$$

Let us give the results of synthesis – graphs of output signals of received astatic system (Figs 7 – 9).

This graph shows that the stabilization system fulfills external disturbances correctly according to the synthesized characteristics.

That is, at maximum disturbance, that used in the calculation of a system and equals to M = 0.07 Nm, the extreme value of output signal according to requirements is 10'.

As a result, we have stabilization output signals, which correspond to input disturbances (Fig. 9).

According to the graph, the system has high quality indices, sufficient phase and gain margins. In addition, it is necessary noting that the cut-off frequency of the system located in the permitted interval and equals $\omega_c = 312\,\frac{\text{units}}{\text{s}}$.

At synthesis astatic stabilization system a signal will not supplied to the input of the system, i. e. control will be absent, and the angle of stabilization will be considered as an error of the system stabilization. Let us show graphs system operation by the main channel and by error, $W_{cl}(p)$ and $W^e(p)$ correspondingly:

$$W_{cl}(p) = \frac{W_o(p)W_{\text{REG}}(p)}{1 + W_o(p)W_{\text{REG}}(p)} = \frac{W_{op}(p)}{1 + W_{op}(p)};$$

$$W^e(p) = \frac{1}{1 + W_o(p)W_{\text{REG}}(p)} = \frac{1}{1 + W_{op}(p)}.$$

These graphs show that the system keeps high quality characteristics of transient process and it is astatic by disturbance and error (Figs 10, 11).

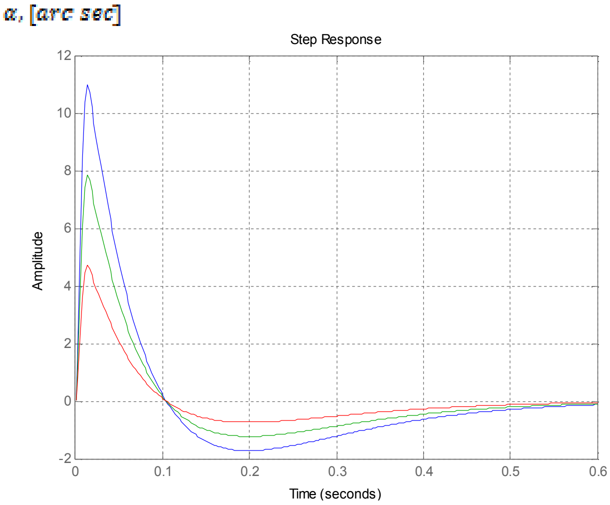

Fig. 7. Graph of the output signal $\alpha(t)$ of the TF $W^f(p)$ by the action of disturbing moment ($M_1 = 0.07$; $M_2 = 0.05$; $M_3 = 0.03$ Nm)

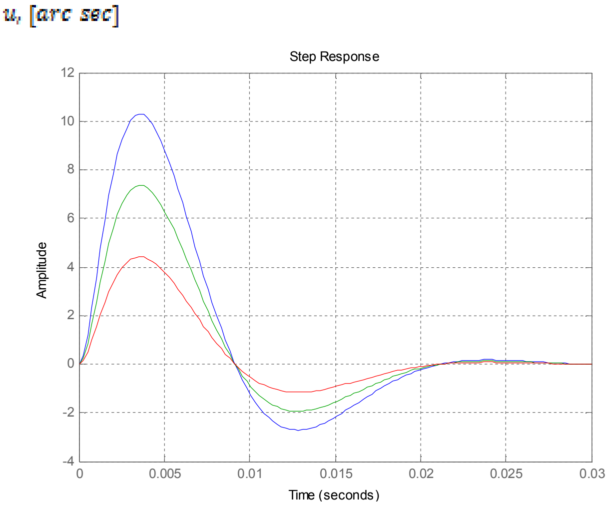

Fig. 8. Graph of the output signal $u(t)$ of the TF $W^f(p)$ by the action of disturbing moment ($M_1 = 0.07$; $M_2 = 0.05$; $M_3 = 0.03$ Nm)

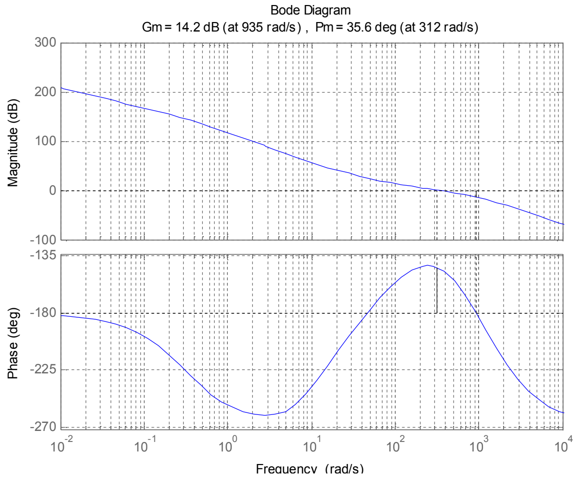

Fig. 9. Bode plot of the TF $W^f(p)$

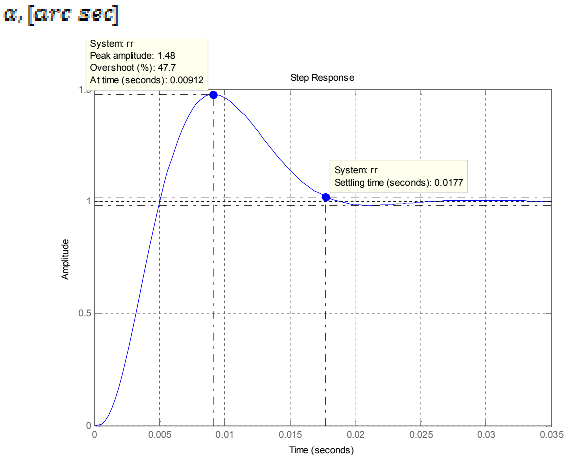

Fig. 10. Output signal of closed-loop system $W_{cl}(p)$

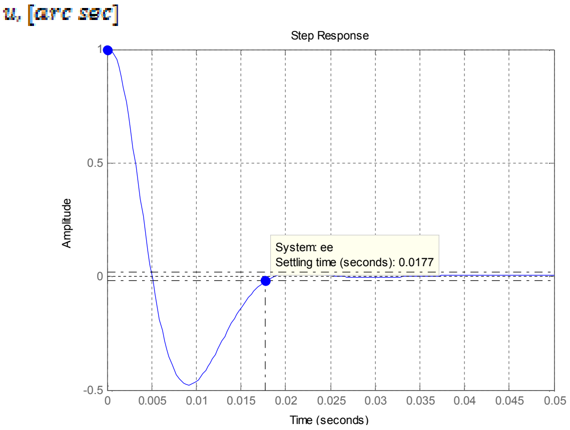

Fig. 11. Output signal of the system by error $W^e(p)$

V. CONCLUSIONS

Development of two-axis gyrostabilizer using MEMS sensor according to the initial data and system requirements was carried out.

The astatic regulator by the Besekersky method was synthesized. This allowed to achieve the necessary accuracy requirements of stabilization platform $\Delta \le 10'$ relative to the maximum disturbing moment $M = 0.07$ Nm during the transient process $t = 0.5$ s.

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Л. М. Рижков, В. С. Грекова. Синтез системи стабілізації

Представлено систему стабілізації, що побудована на МЕМС гіроскопі. Ця система є невід'ємною частиною системи наведення і створює комфортні умови для роботи чутливого елемента (наприклад, оптичного датчика). Виконано синтез астатичної системи стабілізації.

Ключові слова: система стабілізації; гіростабілізатор; система наведення; передатна функція; стабілізована платформа; синтез.

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Л. М. Рыжков, В. С. Грекова. Синтез системы стабилизации

Представлена система стабилизации, которая построена на МЭМС гироскопе. Эта система есть неотъемлемой частью системы наведения и создает комфортные условия для работы чувствительного элемента (например, оптического датчика). Выполнен синтез астатической системы стабилизации.

Ключевые слова: система стабилизации; гиростабилизатор; система наведения; передаточная функция; стабилизированная платформа; синтез.

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