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ORIENTATION AND STABILIZATION OF SMALL SPACE VEHICLES

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Abstract—*The possibility of using system state observers in the orientation and stabilization systems of small space vehicles is considered. A comparative assessment of systems with a system state observer and classical execution is carried out. For comparison the criteria of stability of automatic systems, criteria for assessing quality in steady-state and transient modes of operation, criteria for assessing quality under the action of random disturbing influences were used. The method of mathematical modeling is used as a research method. For its implementation, mathematical models of systems and their components have been developed. Simulation is done in state variables. The synthesis is based on the apparatus of modern control theory. It has been established that the use of a system state observer in the orientation and stabilization systems of small space vehicles will not only reduce their weight and dimensions, increase their reliability and reduce the cost of components, but also provide practically the same control quality indicators as in the classical version.*

Index Terms—Small space vehicle; orientation; stabilization; state vector; system state observer; matrix; transfer function; characteristic equation; model; polynomial; control law; subsystem; structural diagram; gyrodyne.

I. INTRODUCTION

Aerospace technologies has had an increasing impact in recent decades on the economic and social development of states and societies, finding wide application in communications, agriculture and forestry, cartography and geodesy, geological exploration, hydrometeorology, transport, for the prevention and elimination of emergencies. Aerospace systems are becoming a key element in ensuring the security of the state.

The emergence of a new class of spacecrafts – small space vehicles (SSV), allows you to move from grand space projects to inexpensive – monitoring, information gathering, surveillance, etc., which is fully accessible to a wide range of countries and individual consumers.

To perform the tasks on the SSV set the payload, onboard equipment. The main problem when using SSV is to ensure control accuracy. Because the SSV orientation and stabilization systems must include amplifiers, control units, orientation sensors, executive bodies, when creating an SSV it is necessary to decide on the choice of highly efficient orientation and stabilization system taking into account restrictions on their energy consumption, size, weight and cost. On the other hand, not all SSV will have to return to Earth after completing the tasks assigned to them. And this is an additional cost for the production of equipment to create new samples of small space vehicles.

In this regard, in order to reduce the weight and dimensions of the SSV, increase their reliability and reduce the cost of components promising direction of SSV development may be the creation of automated systems of orientation and stabilization (ASOS) with the use of system state observers.

II. PROBLEM STATEMENT

It is known that the control principle of the SSV is the formation of the input vector $\mathbf{u}(t)$ – with a change in the output vector $\mathbf{y}(t)$ of the system (Fig. 1).

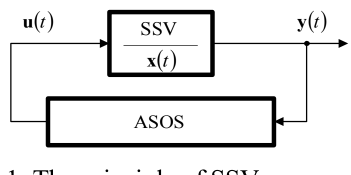
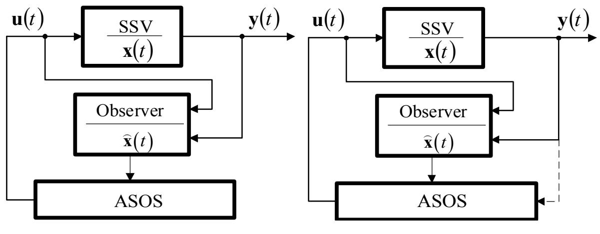


Fig. 1. The principle of SSV management

However, it may be that not all of the required SSV state variables can be determined directly, or it is impractical to do so using equipment that should be placed on board the SSV. Therefore, they can be evaluated on the basis of measured parameters using equipment located, for example, in the flight control center. The results of the lack of information assessment can be used to implement SSV management.

A system state observer that evaluates all variable states of the SSV is called a full-order observer. During the implementation of the law of management, it is enough to place the observer in the control loop of the SSV. Then the signal coming to the input of the automated system of orientation and stabilization, will be a combination of all its state variables (Fig. 2a).

If some of the state variables remain available for measurement by sensors, a low-order observer can be implemented. In Figure 2b shows a control model of the SSV with a low-order observer.



a) b)

Fig. 2. SSV with a system state observer: *a*) is the full order; *b*) is the reduced order

In connection with the above, the development of a system of orientation and stabilization of the SSV with a system state observer and its comparative assessment with the classical one is of some interest.

III. Problem Solution

Consider a symmetrical small space vehicle, an integral part of which is the gyrodyne – a three-stage power gyroscope, acting as a gyrostabilizer.

The orientation of the SSV is controlled due to the fact that the outer frame of the gyrodyne is the body of a small space vehicles on which the gyrodyne is placed. The block diagram of SSV with gyrodyne is shown in Fig. 3.

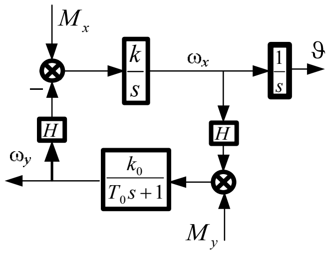


Fig. 3. Structural diagram of SSV with gyrodyne: $k = 1/J_x$ is the static transfer coefficient of SSV; $k_0 = 1/f_y$, $T_0 = J_y/f_y$ are transferable coefficient and time constant of the inner frame of the gyrodyne

Small space vehicles angular orientation and stabilization systems consist of various elements, each of which can be described by differential equations and obtain their structural images. The composition of structural images of the equations of the elements that make up the system will be equivalent to the structural image of the linear differential equation of motion of the system itself. According to [1], Fig. 4 shows a mathematical model of the automated system of angular orientation and stabilization of the SSV.

Assuming the errors of the gyroscopic angle sensor values of the second order of smallness, after turning the contour of the control object, we obtain the calculated model of the system of orientation and stabilization of the SSV (Fig. 5).

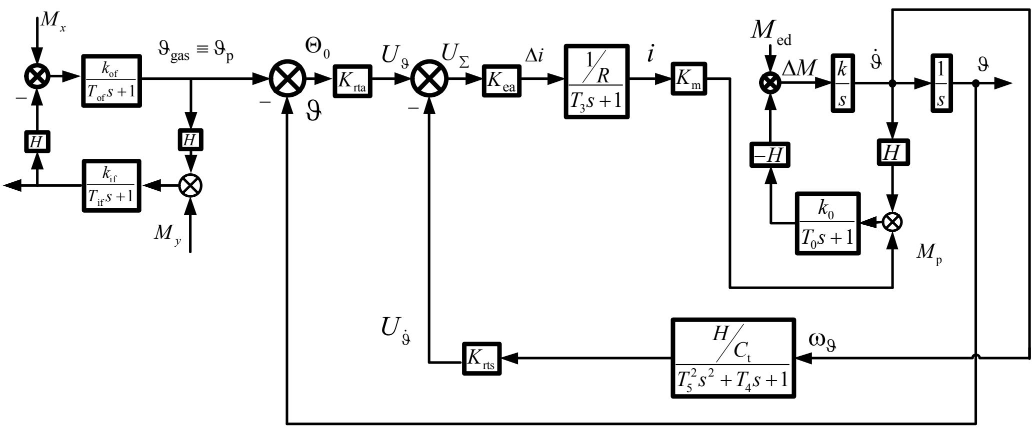


Fig. 4. Mathematical model of the automated system of orientation and stabilization of SSV: $k_{of}/T_{of}s+1$, $k_{if}/T_{if}s+1$ are transfer functions of the gyroscopic angle sensor; H is the main kinetic moment of the gyroscope of the gyroscopic angle sensor; $(H/C_t)/T_5^2 s^2 + T_4 s + 1$ is the transfer function of the gyroscopic speed sensor; K_{rta}, K_{rts} are gain coefficients of rotating transformers of sensors of an angle and speed; $(K_m/R_t)/T_3 s + 1$ is the transfer function of the aiming electromagnet; K_{ea} is the transfer function of the electronic amplifier

In order to obtain more information about the studied system of angular orientation and stabilization of the SSV and more efficient design, the transition to its description in state variables was performed. Modeling of ASOS in state variables was performed on the basis of the classical model (Fig. 5) in two stages.

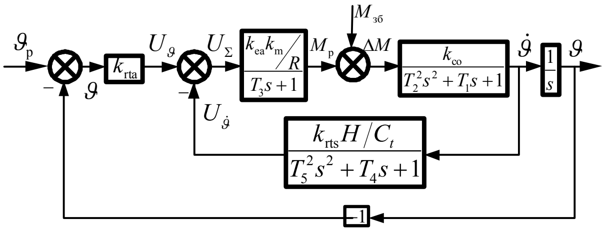


Fig. 5. Calculation model

First, the transfer function (1) of the open circuit, including an electronic amplifier, a guidance electromagnet and an SSV with a gyrodyne, was calculated.

$$W_{\text{oc}}(s)=\frac{k_{\text{rta}}k_{\text{ea}}k_{\text{m}}k_{\text{co}}\big/T_3T_2^2R}{s^4+\frac{\left(T_3T_1+T_2^2\right)}{T_3T_2^2}s^3+\frac{\left(T_3+T_1\right)}{T_3T_2^2}s^2+\frac{1}{T_3T_2^2}s}. \quad (1)$$

Based on the transfer function (1), the simulation of an open system is performed.

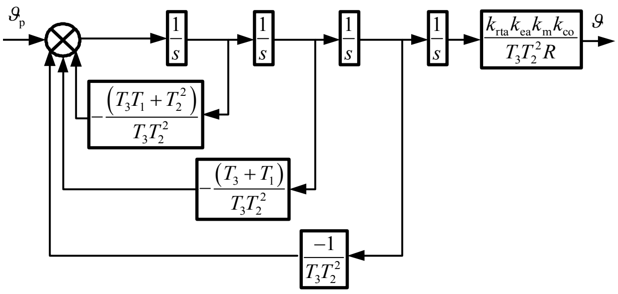


Fig. 6. Block diagram of an open-loop system

It remains, following the rules of modern control theory, to add to the model the main feedback on the angle of rotation of the SSV, realized through k_{rta} and local feedback on the speed of deviation of the SSV, realized through $-k_{\text{rts}}H/C_t$ (T_5, T_4 time constants will be considered second-order values). The block diagram of the closed ASOS in state variables is presented in Fig. 7.

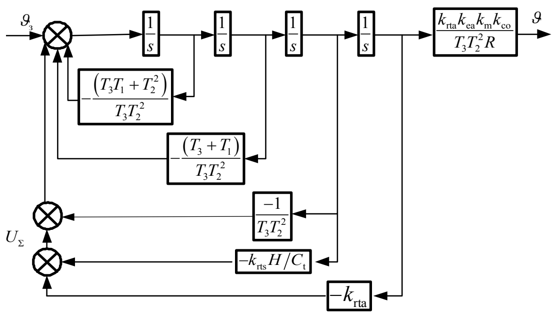


Fig. 7. Block diagram of a closed-loop system

The model (Fig. 7) makes it possible to find the matrices of coefficients $\mathbf{A}_f$, $\mathbf{B}$ input and $\mathbf{C}$ output of the linear matrix equation of the closed ASOS SSV

$$\dot{\mathbf{x}}=\mathbf{A}_f\mathbf{x}+\mathbf{B}\vartheta_{\text{p}},\qquad \vartheta=\mathbf{C}\mathbf{x}. \quad (2)$$

We find

$$\mathbf{A}_f=\begin{bmatrix}0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ -k_{\text{rta}} & \frac{-1}{T_3T_2^2}-k_{\text{rts}}H/C_t & -\frac{(T_3+T_1)}{T_3T_2^2} & -\frac{(T_3T_1+T_2^2)}{T_3T_2^2}\end{bmatrix},$$

$$\mathbf{C}=\begin{bmatrix}\frac{k_{\text{ota}}k_{\text{ea}}k_{\text{m}}k_{\text{co}}}{T_3T_2^2R} & 0 & 0 & 0\end{bmatrix},\quad \mathbf{B}=\begin{bmatrix}0\\0\\0\\1\end{bmatrix}.$$

The simulation results based on the obtained model are shown in Fig. 8.

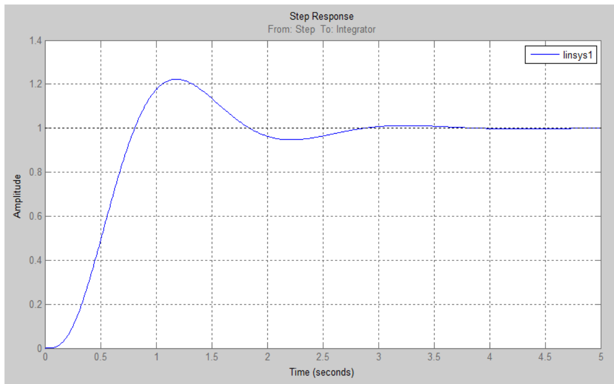


Fig. 8. Dynamics of ASOS behavior based on simulation results

The analysis of the obtained data allows us to conclude that it is necessary to optimize the model in order to ensure the dynamics of the system behavior in accordance with the requirements of the technical conditions for SSV.

In the synthesis for the purpose of optimization, the control law is defined as $u(t)=-\mathbf{K}\mathbf{x}(t)$, where $\mathbf{K}$ is the vector of dimension (1×4) of constant coefficients. Thus, the signal coming to the ASOS input is a linear combination of all its state variables.

The task of the synthesis was to determine the desired position of the roots of the characteristic equation of the system and find the coefficients K_i that provide it.

Ackermann's formula was accepted as an algorithm for calculating the matrix

$$\mathbf{K}=\begin{bmatrix}0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}\mathbf{A} & \mathbf{AB} & \mathbf{A}^2\mathbf{B} & \mathbf{A}^3\mathbf{B}\end{bmatrix}^{-1} A_{\text{d}}(\mathbf{A}),$$

where $A_{\text{d}}(\mathbf{A})=\mathbf{A}^4+a_3\mathbf{A}^3+a_2\mathbf{A}^2+a_1\mathbf{A}+a_0\mathbf{I}$ is a matrix polynomial formed by using the coefficients of the desired characteristic equation.

We know the matrices $\mathbf{A}$ and $\mathbf{B}$ of a small space vehicle

$$\mathbf{A}=\begin{vmatrix}0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ 0 & \dfrac{-1}{T_3T_2^2} & -\dfrac{(T_3+T_1)}{T_3T_2^2} & -\dfrac{(T_3T_1+T_2^2)}{T_3T_2^2}\end{vmatrix},\ \mathbf{B}=\begin{bmatrix}0\\0\\0\\1\end{bmatrix}.$$

The coefficients of the desired characteristic equation of the system may be found from the transfer function of the desired system

$$W_{\text{d}}(s)=\frac{34.67}{s^4+8.67s^3+30s^2+44.44s+34.67},$$

which provides the optimal dynamic characteristic shown in Fig. 9.

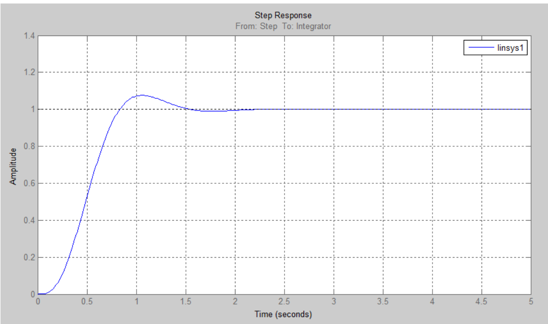


Fig. 9. Optimal dynamics of ASOS

As a result of the performed calculations, we find the components of the matrix

$$K_4=-\frac{T_3T_1+T_2^2}{T_3T_2^2}=0.8;$$
$$K_3=-\frac{T_3+T_1}{T_3T_2^2}=8; \qquad (3)$$
$$K_2=-\frac{1}{T_3T_2^2}=17.77;$$
$$K_1=34.67.$$

The model of the optimal ASOS SSV in the application package takes the form shown in Fig.10.

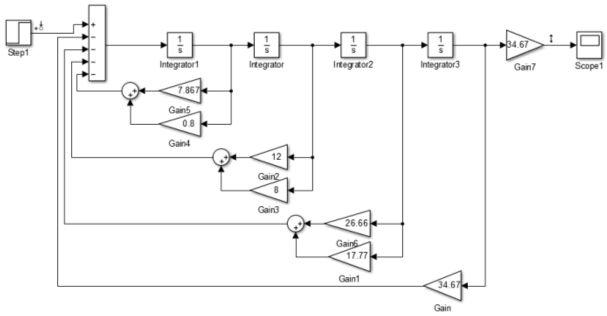


Fig. 10. Model ASOS in Matlab

Let's now move on to ASOS with a system state observer.

Suppose we have an SSV controlled by the original coordinate. The equations of its motion have the form

$$\dot{\mathbf{x}}=\mathbf{Ax}+\mathbf{B}\vartheta_{\text{p}},$$
$$\vartheta=\mathbf{Cx}. \qquad (4)$$

It is necessary to obtain an estimate of the SSV state vector $\mathbf{x}(t)$, which we denote as $\hat{\mathbf{x}}(t)$. The functional diagram of the state vector estimation is shown in Fig. 11. In the evaluation process, all available information can be used, i.e. the input signal $\vartheta_{\text{p}}(t)$, the measured value of the output $\vartheta(t)$ and the matrices $\mathbf{A}, \mathbf{B}, \mathbf{C}$.

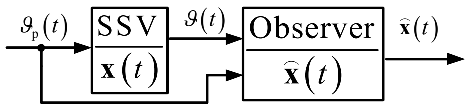


Fig. 11. Functional diagram for estimating the SSV state vector

Since the system state observer must have the same dynamics as the SSV, we will write its equation as

$$\dot{\hat{\mathbf{x}}}(t)=\mathbf{F}\hat{\mathbf{x}}(t)+\mathbf{H}\vartheta_{\text{p}}(t)+\mathbf{G}y(t). \qquad (5)$$

Matrices $\mathbf{F}, \mathbf{H}, \mathbf{G}$ should be chosen so as $\hat{\mathbf{x}}(t)$ to give an accurate estimate $\mathbf{x}(t)$. Then in the control system the vector can be used in the formation of the control law

$$\vartheta_{\text{p}}(t)=-\mathbf{K}\hat{\mathbf{x}}(t).$$

Equations for determining matrices $\mathbf{F}, \mathbf{H}, \mathbf{G}$ can be obtained in different ways. Let's use the method of transfer function. Its essence is that the transfer function from the input $\vartheta_{\text{p}}(t)$ to the variable state of the observer $\hat{x}_i(t)$ must be equal to the transfer function from the input $\vartheta_{\mathrm{p}}(t)$ to the variable state $x_i(t)$, i.e.

$$\frac{\hat{X}_i(s)}{J_{\mathrm{p}}(s)}=\frac{J(s)}{J_{\mathrm{p}}(s)},\quad i=1,2,3,\ldots\ .$$

The Laplace transform of equations (4) gives

$$s\mathbf{X}(s)=\mathbf{A}\mathbf{X}(s)+\mathbf{B}J_{\mathrm{p}}(s)$$
$$J(s)=\mathbf{C}\mathbf{X}(s).$$

Solve these equations for $\mathbf{X}(s)$:

$$\mathbf{X}(s)=(s\mathbf{I}-\mathbf{A})^{-1}\mathbf{B}J_{\mathrm{p}}(s),\qquad (6)$$

where $(s\mathbf{I}-\mathbf{A})^{-1}\mathbf{B}=\dfrac{\mathbf{X}(s)}{J_{\mathrm{p}}(s)}$ is the matrix transfer function.

Transforming the system state observer equation (5) according to Laplace, we find its matrix transfer function

$$\frac{\hat{\mathbf{X}}(s)}{J_{\mathrm{p}}(s)}=(s\mathbf{I}-\mathbf{F})^{-1}\left[\mathbf{H}+\mathbf{GC}(s\mathbf{I}-\mathbf{A})^{-1}\mathbf{B}\right].\qquad (7)$$

We equate the matrix transfer functions (6), (7)

$$(s\mathbf{I}-\mathbf{A})^{-1}\mathbf{B}=(s\mathbf{I}-\mathbf{F})^{-1}\left[\mathbf{H}+\mathbf{GC}(s\mathbf{I}-\mathbf{A})^{-1}\mathbf{B}\right]$$

and find the system state observer matrices

$$\mathbf{F}=\mathbf{A}-\mathbf{GC};\quad \mathbf{H}=\mathbf{B}.\qquad (8)$$

With the selected values of the matrices, the matrix transfer functions of the SSV and the system state observer will be equal regardless of the matrix $\mathbf{G}$

$$(s\mathbf{I}-\mathbf{A})^{-1}\mathbf{B}=(s\mathbf{I}-\mathbf{A}+\mathbf{GC})^{-1}\mathbf{B}\left[\mathbf{I}+\mathbf{GC}(s\mathbf{I}-\mathbf{A})^{-1}\right]$$
$$\Rightarrow(s\mathbf{I}-\mathbf{A})^{-1}\mathbf{B}=\mathbf{IB}(s\mathbf{I}-\mathbf{A})^{-1}.$$

On the basis of (5) and (8) we find the equation of the system state observer

$$\dot{\hat{\mathbf{x}}}(t)=(\mathbf{A}-\mathbf{GC})\hat{\mathbf{x}}(t)+\mathbf{B}\vartheta_{\mathrm{p}}(t)+\mathbf{G}\vartheta(t),$$

where $\mathbf{G}$ matrix is to be determined.

When implementing the control law of the SSV, the observer is placed in the control circuit, and the signal received at the input of the automatic control system is a combination of all variables of the SSV state.

It is easy to show that the state estimation error has the same dynamics as the system state observer.

Thus, the task of observer synthesis is only to determine the matrix $\mathbf{G}$ by the desired characteristic polynomial $A_{\mathrm{od}}(s)$ of the observer and the known $\mathbf{A}$ and $\mathbf{B}$ matrices of SSV.

We find the characteristic equation of the system state observer

$$\det(s\mathbf{I}-\mathbf{A}+\mathbf{GC})=0.$$

Since the speed of the observer should be in 2-4 times higher than the speed of the system [2] then we choose his desired characteristic equation

$$A_{\mathrm{od}}(s)=s^4+26{,}01s^3+90s^2+133{,}32s+104{,}01.$$

Then the matrix $\mathbf{G}$ can be found from the equation

$$\det(s\mathbf{I}-\mathbf{A}+\mathbf{GC})=A_{\mathrm{od}}(s).$$

In the end, we get the result

$$\mathbf{G}=A_{\mathrm{od}}(\mathbf{A})\begin{bmatrix}\mathbf{C}\\ \mathbf{CA}\\ \mathbf{CA}^2\\ \mathbf{CA}^3\end{bmatrix}^{-1}\begin{bmatrix}0\\0\\0\\1\end{bmatrix},$$

where $A_{\mathrm{od}}(\mathbf{A})$ is a matrix polynomial formed by using the coefficients of the desired characteristic of the system state observer

$$A_{\mathrm{od}}(\mathbf{A})=\mathbf{A}^4+26.01\mathbf{A}^3+90\mathbf{A}^2+133.32\mathbf{A}+104.01\mathbf{I}.$$

After calculating all the required matrices and determine the matrix $\mathbf{G}$

$$\mathbf{G}=\begin{bmatrix}0.006\\0.569\\-3.493\\21.548\end{bmatrix}.$$

Since the matrix $\mathbf{G}$ is known, we find the final equation of the SSV system state observer

$$\begin{bmatrix}\dot{\hat{x}}_1\\ \dot{\hat{x}}_2\\ \dot{\hat{x}}_3\\ \dot{\hat{x}}_4\end{bmatrix}=\begin{bmatrix}0.14 & 1 & 0 & 0\\ -11.832 & 0 & 1 & 0\\ 72.656 & 0 & 0 & 1\\ -469.007 & -26.67 & -12 & -7.87\end{bmatrix}\begin{bmatrix}\hat{x}_1\\ \hat{x}_2\\ \hat{x}_3\\ \hat{x}_4\end{bmatrix}+\begin{bmatrix}0\\0\\0\\1\end{bmatrix}\vartheta_{\mathrm{p}}+\begin{bmatrix}0.006\\0.569\\-3.493\\21.548\end{bmatrix}\vartheta.$$

The last algorithm allowed us to simulate the state observer and conduct research on its capabilities as part of the orientation and stabilization system of the small space vehicles.

Let us transform the linear matrix equation of the system state observer of the ASOS SSV into a system of four equations

$$\begin{cases} \dot{\hat{x}}_1 = 0.14\hat{x}_1 + \hat{x}_2 - 0.006\vartheta, \\ \dot{\hat{x}}_2 = -11.832\hat{x}_1 + \hat{x}_3 + 0.569\vartheta, \\ \dot{\hat{x}}_3 = 72.656\hat{x}_1 + \hat{x}_4 - 3.493\vartheta, \\ \dot{\hat{x}}_4 = -469.007\hat{x}_1 - 26.67\hat{x}_2 - 12\hat{x}_3 - 7.87\hat{x}_4 + \vartheta_p + 21.548\vartheta. \end{cases}$$

The system of linear equations allows you to build a model in the Matlab application software package.

The model is shown in Fig. 12.

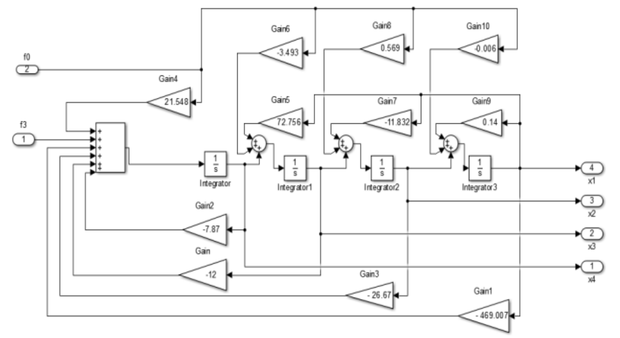


Fig. 12. System state observer model

According to the structural diagram (Fig. 6), we simulate the SSV open-loop orientation and stabilization system. The model is shown in Fig. 13.

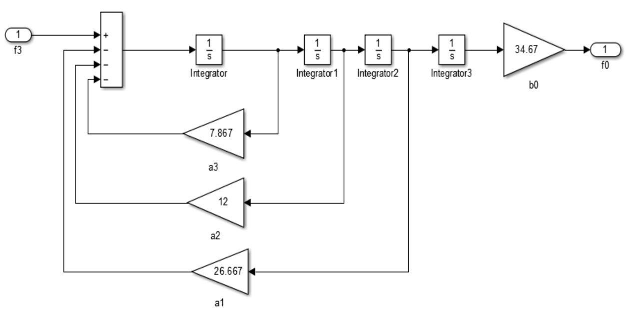


Fig. 13. Model of the SSV open-loop orientation and stabilization system

Based on the models (Figs 12 and 13), in accordance with the scheme (Fig. 2a) of placing the state observer in the system, taking into account the formation of the control law $u(t) = -\mathbf{K}\hat{\mathbf{x}}(t)$ and the values (3) of the matrix $\mathbf{K}$ components, we develop a complete model of an automated system of orientation and stabilization of a small space vehicle with a system state observer. The model is shown in Fig. 14. Here, the models of the open-loop orientation and stabilization system, as well as the system state observer, are reduced to the level of subsystems.

The developed models (Fig. 10 and Fig. 14) made it possible to carry out a comparative assessment of the orientation and stabilization systems of a small space vehicle with a system state observer and in the classical version.

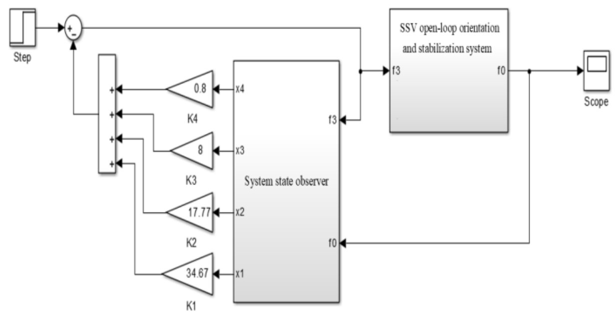


Fig. 14. ASOS SSV model with a system state observer

Criteria of stability of automatic systems, criteria of an estimation of quality in steady and transient operating modes, criteria of an estimation of quality at action of casual disturbing influences were used as criteria of comparison.

Figure 15 shows the fields of zeros and poles of the systems under study. The upper field corresponds to the ASOS with a system state observer, the lower one – to the classical one.

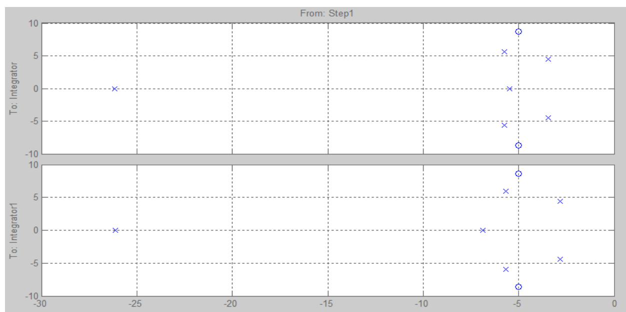


Fig. 15. Fields of zeros and poles

The analysis of the given material shows that the margin of stability of ASOS with the system state observer is 9% higher, than in classical. The dynamics of the systems is similar.

Since the tracking mode for ASOS is the main one when adjusting the angular orientation of the SSV according to the signals of the Flight Control Center, the estimation of tracking errors $\theta_{tr}(t)$ of the studied systems was performed. The laws of change in time of the control signal $\vartheta_p(t)$ and the output signals of the ASOS with the system state observer $\vartheta_{sso}(t)$ and the classical $\vartheta_{cl}(t)$ are given in Fig. 16.

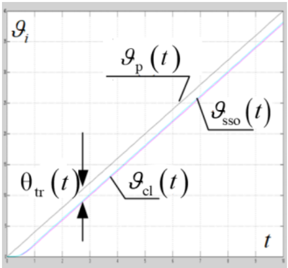


Fig. 16. Characteristics in the tracking mode

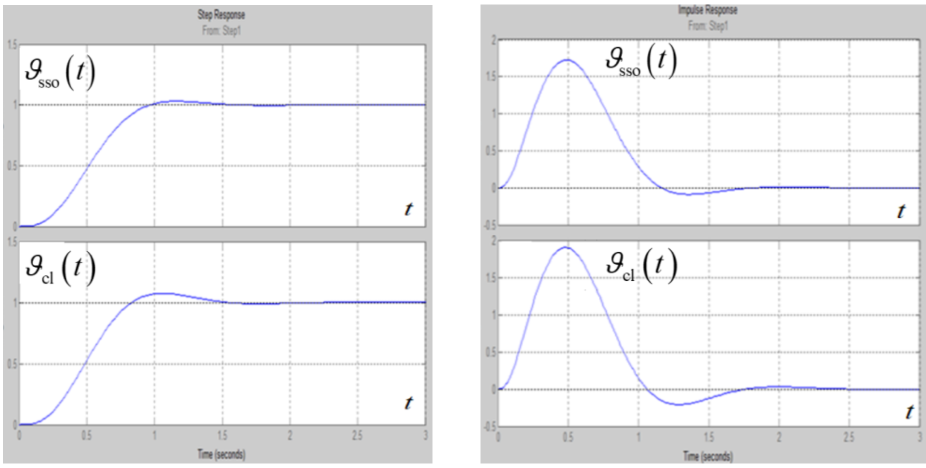
The discrepancy of tracking errors for the considered systems does not exceed 0,2%.

The dynamics of the systems is illustrated by the transient and impulse transient characteristics obtained during the experiment. The characteristics are shown in Fig. 17. They confirm the preliminary conclusion about the similarity of the dynamic processes of ASOS.

It has been established that the control signal response time in the ASOS SSV with the system state observer is slightly higher than the analogous indicator of the classical ASOS. On the other hand, the regulation time of the ASOS of the small space vehicle with the system state observer is less than in the classical one. The over-regulation in the ASOS with the system state observer is 5%, in the classical – 12%.

Since the authors did not have accurate information about random perturbations, an assumption was made about their unlimited power. In the theory of automatic control, the role of a random process with infinitely high energy is played by the so-called white noise. If for the selected worst operating conditions of the SSV as a result of research satisfactory results are obtained and the characteristics of the ASOS will remain within the norms of the technical conditions, we can assume that they will be no worse in other random perturbations.

The spectral densities of the SSV ASOS reactions to white noise are shown in Fig. 18.



a) *b*)

Fig. 17. Dynamic characteristics of ASOS SSV: (*a*) is the transient; (*b*) are pulse transients

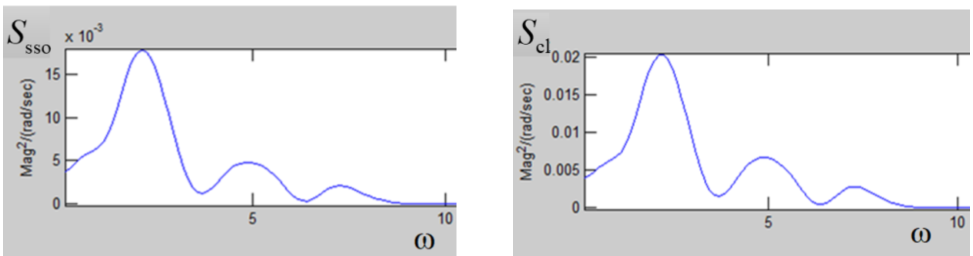


Fig. 18. Spectral densities of output signals

It was found that the frequency spectra of the ASOS with the систем state observer and the classical one coincide. At the same time, the root-mean-square value of the error of the system with an observer is only 0.8% higher than that of the classical ASOS.

IV CONCLUSIONS

The use of small space vehicles (SSV) makes it possible to implement low-cost projects - monitoring, data collection, observation of the terrain, etc., which is quite accessible to a wide range of states and individual consumers.

A promising direction in the development of SSV can be the creation of automated orientation and stabilization systems (ASOS) with the use of system state observers.

The developed mathematical models of ASOS allowed to carry out a comparative assessment of the system of classical construction with the system, which includes a system state observer.

According to the research results, it has been established that the use of a system state observer in the orientation and stabilization systems of small space vehicles will allow not only to reduce the weight and overall dimensions of the small space vehicle, increase their reliability and reduce the cost of components, but also provide practically the same control quality indicators as in the classical version. ASOS.

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О. К. Аблесімов, А. О. Цьоба. Орієнтація та стабілізація малих космічних апаратів

Розглянуто можливість застосування у складі систем орієнтації та стабілізації малих космічних апаратів спостерігачів стану. Виконано порівняльну оцінку систем із спостерігачем стану та класичного виконання. Для порівняння використовувалися критерії стійкості автоматичних систем, критерії оцінки якості в встановлених та перехідних режимах роботи, критерії оцінки якості при дії випадкових впливів, що обурюють. Як метод дослідження використовується метод математичного моделювання. Для його реалізації розроблено математичні моделі систем та їх компонентів. Моделювання виконано в змінних станах. Синтез ґрунтується на апараті сучасної теорії управління. Встановлено, що застосування спостерігача стану в системах орієнтації та стабілізації малих космічних апаратів дозволить не лише знизити їх масо габаритні показники, підвищити їхню надійність та знизити вартість комплектуючих, а й забезпечити практично ті ж показники якості керування, що й при класичному виконанні.

Ключові слова: малий космічний апарат; орієнтація; стабілізація; вектор стану; спостерігач стану системи; матриця; передатна функція; характеристичне рівняння; модель; поліном; закон керування; підсистема; структурна схема; гіродин.

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А. К. Аблесимов, А. А. Цьоба. Ориентация и стабилизация малых космических аппаратов
Рассмотрена возможность применения в составе систем ориентации и стабилизации малых космических аппаратов наблюдателей состояния. Выполнена сравнительная оценка систем с наблюдателем состояния и классического исполнения. Для сравнения использовались критерии устойчивости автоматических систем, критерии оценки качества в установившихся и переходных режимах работы, критерии оценки качества при действии случайных возмущающих воздействий. В качестве метода исследования используется метод математического моделирования. Для его реализации разработаны математические модели систем и их компонентов. Моделирование выполнено в переменных состояния. Синтез основан на аппарате современной теории управления. Установлено, что применение наблюдателя состояния в системах ориентации и стабилизации малых космических аппаратов позволит не только снизить их массогабаритные показатели, повысить их надежность и снизить стоимость комплектующих, но и обеспечить практически те же показатели качества управления, что и при классическом исполнении.
Ключевые слова: малый космический аппарат; ориентация; стабилизация; вектор состояния; наблюдатель состояния системы; матрица; передаточная функция; характеристическое уравнение; модель; полином; закон управления; подсистема; структурная схема; гиродин.

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