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MATHEMATICAL MODELING OF ELECTRONIC DEVICES OF SERVO SYSTEM FOR INERTIALLY STABILIZED PLATFORMS

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Abstract**—***Features of mathematical and computer modeling of electronic devices servo systems assigned for inertially stabilized platforms mounted on the ground moving vehicles are considered. The basic equations of the model of the inertially stabilized platforms are represented. Features of the model are described in details. Modeling results are represented. Method of transition from continuous to discrete control units is proposed. The obtained results can be useful for platforms with observation equipment operated on moving vehicles of other types.*

Index Terms—electronic devices; inertially stabilized platform; servo system; stabilization; tracking.

I. INTRODUCTION

Control of electric drives on the basis of the direct current motor is important for many practical applications. Nowadays, sufficient interest is given to research of gyroscopic servo systems with the elastic mechanism. Such systems are widespread in area of control of inertially stabilized platforms. They can be used for stabilization and tracking of different equipment, for example, photo- and television cameras mounted on the moving vehicles. Another example is stabilization and tracking of an antenna of the radio-locator mounted in gimbals.

II. PROBLEM STATEMENT

The main goal of the research is to analyze possibilities of MatLab for modeling of electronic devices of servo system assigned for control of gyrostabilized gimballed platform motion. For this it is necessary to develop the mathematical model of the servo system including electronic devices.

Therefore research of possibilities to simulate electronic devices of servo systems taking into consideration development of modern computing facilities should be done. Furthermore, development of a way to convert continuous control units of servo system into the discrete ones is of the great interest for design of modern servo systems. On the one hand, such an approach allows us to apply useful results of previous developments. On the other hand, it is possible to create servo systems, which meet modern level of the computer engineering. At last, modeling of electronic devices is relevant for solving problem of the choice of discreteness of updating information. Since, the solution of this problem largely determines ways of development the system as a whole.

II. REVIEW OF PUBLICATIONS AND RESEARCHES

Methods of development of servo systems with direct current motors are quite fully represented in the textbook [1]. Problems of mathematical modeling are discussed also in [2] – [4]. It should be noted that many approaches to development of the mathematical models of the studied systems remain relevant to date. At the same time, approaches to modeling by means of a computer require the new research taking into consideration special software.

III. FEATURES OF MATHEMATICAL MODELING OF ELECTRONIC DEVICES OF SERVO SYSTEM

As an example, it is possible to research the servo system for the ground moving vehicle, which must provide stabilization and tracking of the observation equipment in the vertical and horizontal planes respectively. Models of electronic devices for the vertical and horizontal channels differ by some components and parameters only. Therefore, this article emphasizes on the mathematical description of the vertical channel of control of servo system.

In correspondence with [1], the servo system includes the electric motor, reducer and voltage amplifier connected in series. Control signals are formed in the pulse-width-modulator (PWM) on the basis of signals entering from the control unit of the servo system. Tracking and stabilization in the vertical plane is implemented based on signals of the gyroscopic tachometer, control console, and feedback signals by the current and voltage. Electronic devices of the vertical channel carry out functions of amplification, filtering, integrating, and control laws forming. Features of the model of the vertical channel are presence of limiting devices and switches. This can be explained in the following way. In some situations, a kind of the model of the electronic devices depends on the signal level. The control unit implements also reduction to the unique dimensionality of feedback signals by the current and voltage.

The output signal of a control unit's model enters to PWM model, which forms a sequence of impulses of the given voltage and duration U_{PWM} depending on the control signal. This sequence is input for the electric motor model. In its turn, a motor's model includes the relationship forming the current of the electric motor armature, aperiodic units taking into consideration the time constant of the armature and the electro-mechanical time constant of the motor. The current of motor armature is used for forming the moment of motor control and also feedback signals by the voltage and current. The voltage at the motor windings U_w defines a level of the current in windings of the motor armature [5]

$$U_w = U_{\text{PWM}} - c_{\text{emf}}\dot{\varphi}_m ,$$

where c_{emf} is the coefficient of electromotive force, φ_m is the angle of motor rotation.

The time constant of the motor armature is taken into consideration by means of the aperiodic unit with the single gain

$$T_a p U_{cor} + U_{cor} = U_w ,$$

where T_a is the time constant of motor armature; U_{cor} is corrected output signal of the aperiodic unit, p is the Laplace operator. The signal U_{cor} enters to the contour of voltage feedback, further trough the unit $\frac{1}{R_w}$ in the contour of current feedback (I_{cor}), and further trough the time constant of the loading moment on the motor shaft c_m. So, the moment of motor control M_m is formed by means of the relationship

$$M_m = c_m I_{cor} .$$

The mathematical model of the mechanical part of the motor can be represented by the differential equation in the following form [5]

$$J_m\ddot{\varphi}_m + M_r \operatorname{sign}\dot{\varphi}_m = M_m - c_r \frac{\varphi_h - \varphi_e n_r}{n_r^2} ,$$

where M_m is the moment of motor control; M_{r} is the moment of resistance to rotation; c_r is rigidity of the reducer; n_r is the ratio of the reducer; J_m is the moment of inertia of the motor rotor; φ_m is the angle of the turn of the motor rotor; φ_h is the angle of turn of the motor rotor taking into consideration nonlinearity of the hysteresis caused by the motor gap; φ_e is the angle of turn of observation equipment.

The mathematical model of the motor has following features.

1) The nonlinearity of the hysteresis is taken into consideration. For this, the angle of motor rotation φ_m (the output signal of the mathematical model of the motor) enters to the nonlinear unit.

2) Interconnection of the mechanical part of the motor and the platform with observation equipment is implemented by means of the reducer. From a mathematical point of view, this interconnection is provided by introducing an angle of the platform with observation equipment rotation in the mathematical model of the motor. In this case, the motor and platform with the observation equipment are believed to be a single unit of control signal reproduction.

3) To provide adequacy of a model to functioning real motor, nulling of the acceleration of motor rotation for definite relationships between moments acting on the motor is used. These conditions look like

$$\left| M_m - c_r \frac{\varphi_h - \varphi_e n_r}{n_r^2} \right| \le | M_r |; \quad \dot{\varphi}_m = 0 .$$

Relation between the platform with observation equipment and motor can be described by the following equation

$$J_e\ddot{\varphi}_e + M_{fr}\operatorname{sign}\dot{\varphi}_e - M_{unb}\sin\varphi_e + \\ k_s\varphi_e + c_r\varphi_e = k_s A + c_r\varphi_h / n_r - M_{unb},$$

where M_{fr} is the moment of friction; M_{unb} is the unbalanced moment; k_s is the spring rigidity; A is the angle of resetting balanced spring; J_e is the moment of inertia of the platform with observation equipment; φ_e is the angle of rotation of observation equipment.

IV. Features of Computer Modeling Electronic Devices of Servo Systems

The mathematical model of the servo drive can be represented as a set of differential equations as such a representation of the complex dynamic system is obvious and convenient for application. The program implementation of the model can be realized by means of Simulink (Toolbox of MatLab). The representation is created on the basis of transfer functions of the control unit. Nonlinear units are used to make a model close to real apparatus realization. As example, Simulink models of the motor and PWM are shown in Figs 1 and 2.

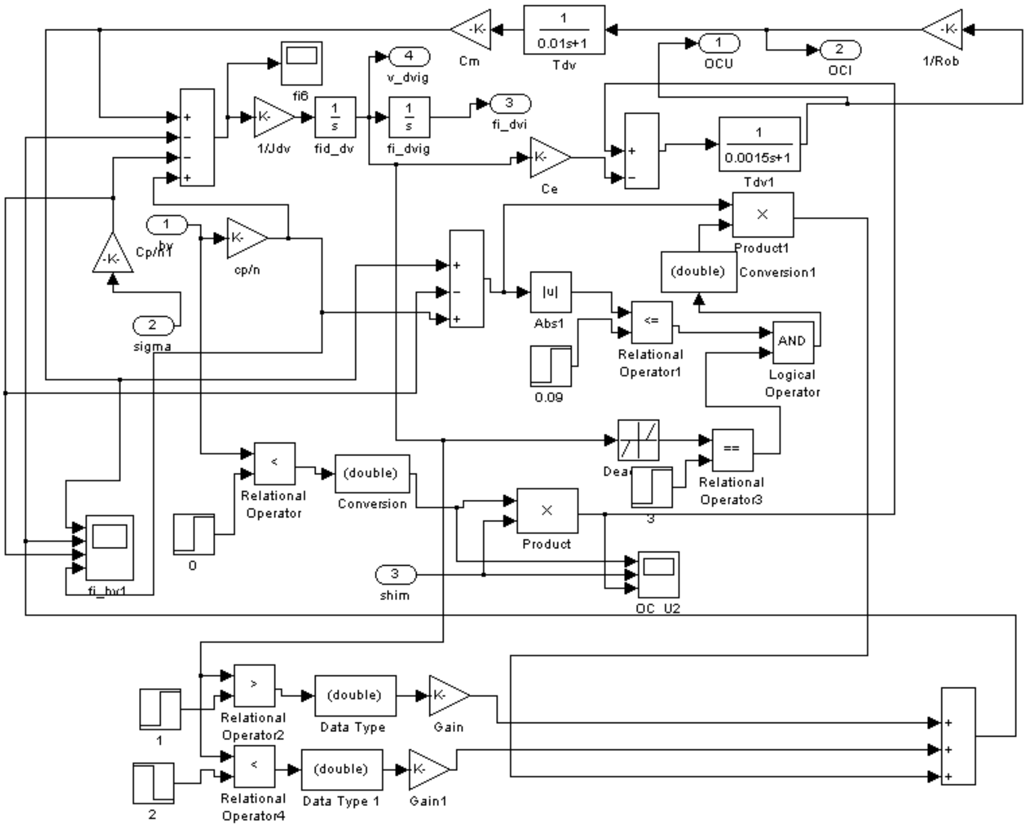


Fig. 1. Simulink model of the motor of the servo drive

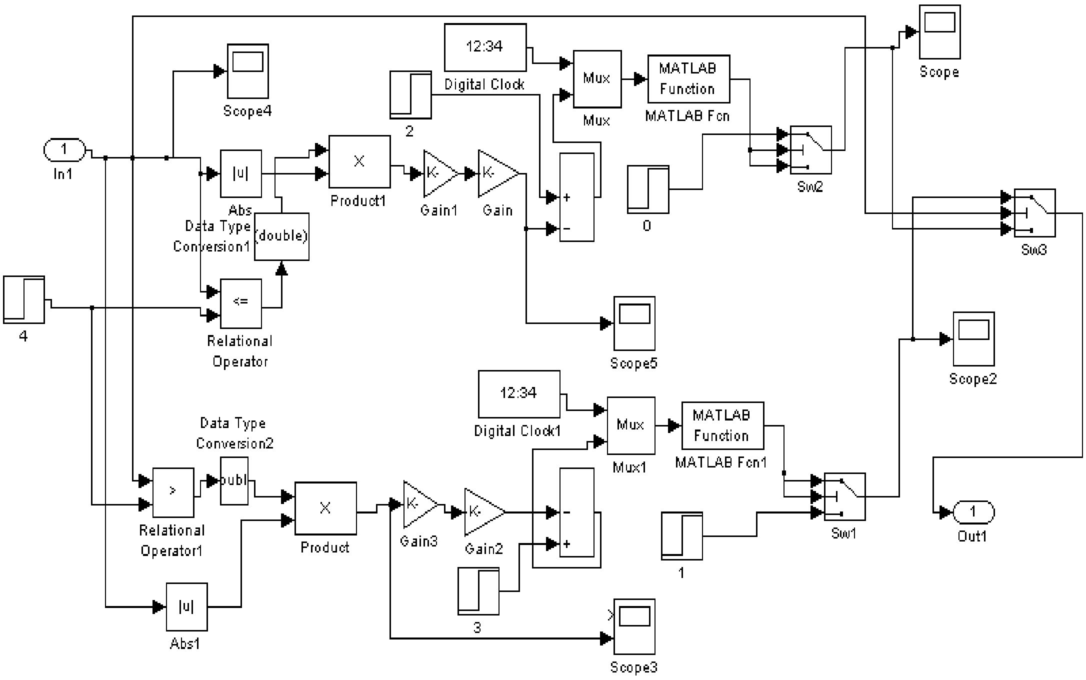
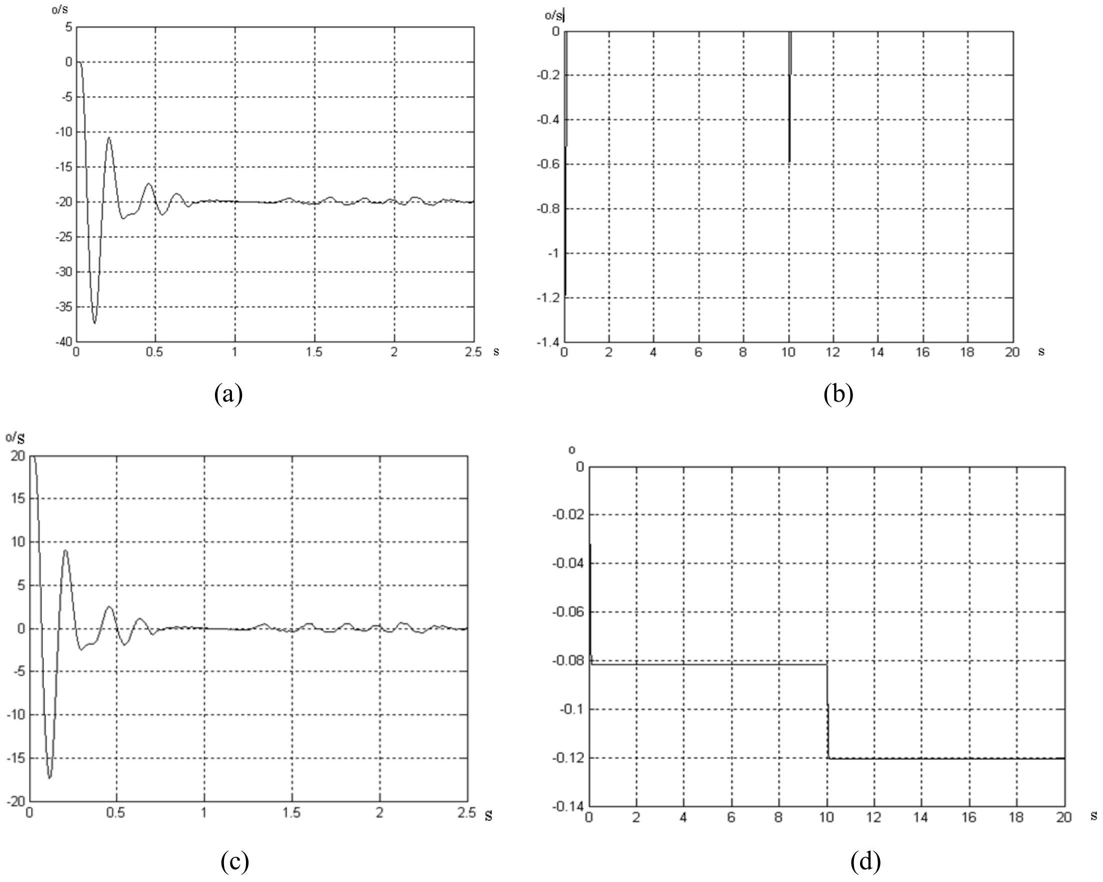


Fig. 2. Simulink model of PWM

Results of modeling are shown in Fig. 3.

Modern systems of control of servo drive foresee usage of computer engineering. Therefore development of the technique of converting continuous control unit into digital one is of great interest. For this, it is proposed to develop a model of the continuous control contour by means of transfer functions, for example, using known analytical dependences. This process is sufficiently difficult. Propriety of the analytical representation should be checked by means of experimental tests using a special tested bench. It is convenient to use systems of modeling electronic devices such as WorkBench or MultiSIM, which allow us to determine logarithmic amplitude-frequency characteristics of separate transfer functions. It is necessary to compare these characteristics with similar characteristics of the analytical transfer functions, for example, by means of MatLab. It should be noted that WorkBench has not the possibility of direct determining of transfer function analytical representation by the model of the electronic device. Such a possibility takes place in MatLab for applications assigned for simulation of power energetic circuits that leads to definite difficulties during simulation of electronic devices. After representation of the continuous control unit in the form of a model on the basis of transfer functions, transition to discrete unit by means of *z*-transformation of the appropriate transfer functions by the program way can be implemented. For this, it is possible to use Control SystemToolbox of MatLab system. The choice of discretization method is caused by the necessary accuracy of transformation, which can be estimated by the degree of coincidence of logarithmic amplitude-frequency characteristics of digital transfer functions with similar characteristics of transfer functions of continuous units. It should be noted that the most sensible to the method of discretization is the transfer function of the digital integrator. In this case, it is convenient to use the bilinear transformation.

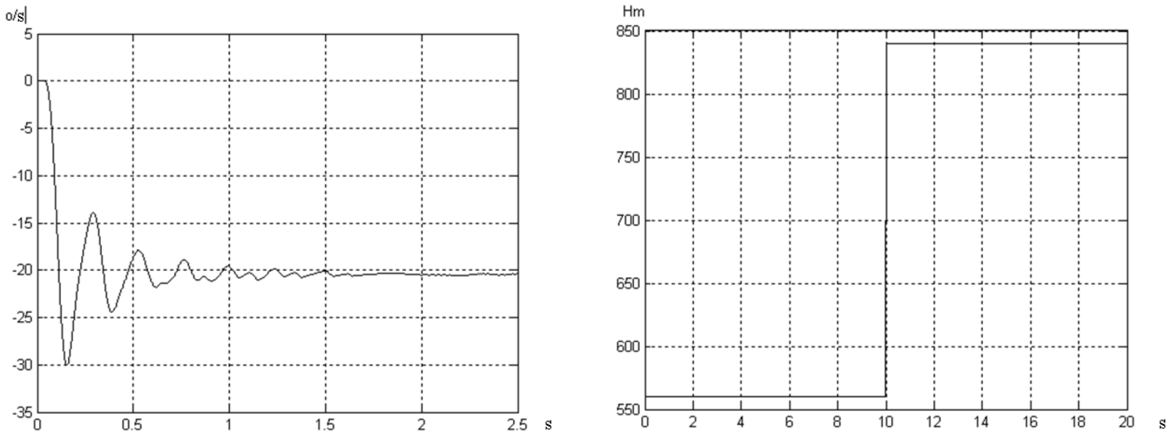
Advantages of the proposed approach to modeling of electronic devices of the servo drive are the possibility to research the possible value of sampling for information processing, the possibility of introducing adjustable coefficients and using PWM model. The choice of sampling interval provides search of compromise between the desired accuracy and convenience of practical implementation of the control unit.



(a) (b)

(c) (d)

Fig. 3. Results of modeling of transient processes and rigidity determination:
(a) is the transient process of relative rate; (b) is influence of zero rate under disturbance action;
(c) is the transient process of absolute rate; (d) is the absolute angle under disturbance action;
(e) is the transient process of the reference rate; *f* is the given reference



(e) (f)

Fig. 3. Ending. (See also p. 83)

Adjustable coefficients can be used for improving quality of control processes by results of modeling and tests. Such quality indices as time of the transient processes, the number of overheads, and the required rigidity of the system are also taken into consideration. The model of PWM can be implemented by means of Simulink. The proposed model provides the possibility of choice of sampling for processes of analog-digital conversion, as allows us to analyze frequency characteristics of output signals of separate units.

Figures 3a and 3c represent the transient processes of relative and absolute rates for the vertical discrete control contour. Simulation of platform motion in the vertical plane has been given by means of the translation rate. As follows from modeling results, motion of the platform with the rate 20 deg/s leads to deviation of the absolute rate from the zero level, which does not exceed a permissible level. Figure 3e shows the transient process for the rate given from the console. Figure 3b shows the reaction of the system on the disturbance for the zero angular rate of the platform. Figures 3d and 3f prove the required rigidity of the platform. For this, absolute angles of rotation of observation equipment are analyzed after application of moments 560 Nm and 840 Nm respectively.

VII. CONCLUSIONS

Features of mathematical description of the servo system for the platform mounted on the ground moving vehicle taking into consideration electronic devices are considered. Simulink model of the system of the considered type is developed.

The technique of transition from the continuous control contour of the servo system to discrete representation is proposed.

Computer modeling of the servo system has been carried out. The obtained results prove efficiency of the proposed approach.

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О. А. Сущенко, С. Г. Єгоров. Математичне та комп'ютерне моделювання електронних пристроїв слідкувальної системи для інерціальних стабілізованих платформ

Розглянуто особливості математичного та комп'ютерного моделювання електронних пристроїв слідкувальної системи, призначеної для інерціальних стабілізованих платформ, що встановлюються на наземних рухомих об'єктах. Представлено основні рівняння моделі інерціальної стабілізованої платформи. Детально описано особливості моделі. Представлено результати моделювання. Запропоновано метод переходу від неперервного представлення блока управління до дискретного. Отримані результати можуть бути корисними для платформ з обладнанням спостереження, що експлуатуються на рухомих об'єктах іншого типу.

Ключові слова: електронні пристрої; інерціальна стабілізована платформа; слідкувальна система; стабілізація; стеження.

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О. А. Сущенко, С. Г. Егоров. Моделирование электронных устройств следящей системы для инерциальных стабилизированных платформ

Рассмотрены особенности математического и компьютерного моделирования электронных устройств следящей системы, предназначенной для инерциальных стабилизированных платформ, которые устанавливаются на наземных подвижных объектах. Представлены основные уравнения модели инерциальной стабилизированной платформы. Подробно описаны особенности модели. Представлены результаты моделирования. Предложен метод перехода от непрерывного представления блока управления к дискретному. Полученные результаты могут быть полезными для платформ с оборудованием наблюдения, эксплуатируемых на подвижных объектах другого типа.

Ключевые слова: электронные устройства; инерциальная стабилизированная платформа; следящая система; стабилизация; слежение.

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