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FEATURES OF CONTROL OF TRACKING MODES

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Abstract—*The paper deals with research of systems for control by orientation of lines-of-sight of information and measuring devices on moving base. Automated control laws of researched systems in tracking modes are proposed. Control algorithm with the local feedback by the current of motor armature circuit is given. The integral assessment of the plant acceleration based on current of the motor armature circuit is obtained and the possibility of its usage in control laws is shown. The mathematical model of the system assigned for operation on the ground vehicles is represented. The simulation results are given and their analysis is carried out. The obtained control laws can be used in low cost systems with nonstabilized drive, and also in tracking modes of multi-mode systems of control by orientation of lines-of-sight of information and measuring devices operated on vehicles.*

Index Terms—Tracking modes; nonstabilized drive; ground vehicles; automated control; feedback.

I. INTRODUCTION

Creation of systems for control of observation devices line-of-sight orientation is issue of the day. This problem becomes complicated for devices operated on vehicles. Usually such a system functions in modes of tracking and stabilization [1]. Control laws in these modes differ from each other.

Moreover in some practical applications it is convenient to use nonstabilized drive. This approach leads to simplification of hardware configuration due to using of tracking mode only. Its advantage is decrease of cost of system design, manufacturing, and maintenance.

Automation of control processes by different plants is accompanied by wide using of servo drives. They are used in control systems of vehicles both for control of their motion and for control of their equipment movements.

Now creation of the new perspective systems for stabilization of observation devices becomes widespread in many areas of vehicle equipment design. The main requirements to such systems are the high speed of operation and smoothness of platform movements. The goal of proposed research is increase of tracking processes quality. This can be achieved by means of creation of new control laws for tracking modes.

II. PROBLEM STATEMENT

It is known that control features depend effectively on type of a plant and operation conditions. The paper considers the laws of control of systems assigned for operation on the ground vehicles.

Basic function of the researched system is tracking of moving reference point and elimination of an error between the direction to a reference point and line-of-sight axis of the observation device. In the general case control by the plant during tracking can be automatic, manual, and automated [2]. For the low cost system able to carry out sufficient quantity of functions and to provide necessary accuracy it is convenient to use the automated control.

The image of a reference point, which is formed in the indicator unit, is shown in Fig. 1.

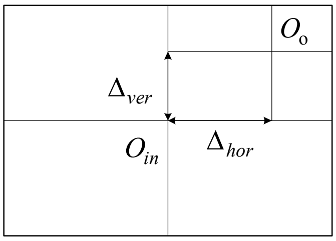


Fig. 1. Representation on the display of the indicator unit: O_{in} is the centre of the display; O_o is the reference point

The basic function of the optical and electronic system is conversion of electromagnetic waves in the optical range into electrical and light signals. The latter signals provide visualization of information. Coordinates of reference point present deviations of the electronic point from intersection lines on the indicator display.

The operator implements manipulations with control console handles to keep values of the horizontal and vertical deviations Δ_{hor}, Δ_{ver} close to zero [2].

The system plant includes the platform with a payload (observation equipment). In general case the researched system can include the plant, controller, measuring sensors, power amplifier, pulse-width-modulator, and geared drive including the direct current motor and reducer.

The structural scheme of the tracking system with the automated control is represented in Fig. 2.

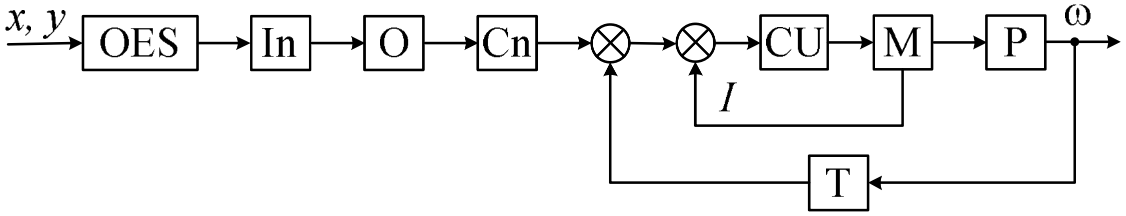


Fig. 2. The structural scheme of automated tracking system: OES is an optical and electronic system; In is an indicator; O is an operator; Cn is a console; CU is a computing unit; M is a motor, P is a platform; T is a tachometer; x, y are coordinates; ω is a platform angular rate; I is a motor armature current

In accordance with the scheme represented in Fig. 2 the output signal of the optical and electronic system enters to the indicator, where it is taken by the operator. He chooses rate of tracking based on visual observation by means of control console. At the same time the operator continues visual observation by the moving reference point. To increase accuracy of tracking processes two modes of tracking rates (high and low) and also the possibility to switch off tracking rate instantaneously are used. The latter situation arises during coincidence of line-of-sight with direction to reference point.

Now control laws in stabilization modes are well known. Manual control in tracking modes is sufficiently known too. The new approach to problem is creation of control laws in tracking modes with nonstabilized drive using automated control and computing unit respectively. The created laws must provide the high speed of operation, sufficient accuracy, and simplification of hardware implementation.

III. REVIEW

General principles of control by drives in servo and tracking systems are represented in [3], [4]. The approaches to creation of the researched systems operated on the ground vehicles are given in [5]. The paper [1] researches modes of stabilization and stabilized tracking for the system of the considered type. The general approach to implementation of control in tracking systems with nonstabilized drive is represented in [6]. Earlier known engineering solutions have been provided manual control by means of the console. Using computing unit in these modes it is possible to increase accuracy of observation processes due to feedbacks.

IV. GENERAL FEATURES OF AUTOMATED CONTROL

It should be noted that in the general case systems of the researched type can operate using the automated control, when the stabilization mode is carried out automatically and the tracking mode includes control of the operator.

Considered control contour includes the operator as a block of the control system. Quality of tracking processes depends on operator physiological characteristics and level of its training. The operator and tracking system are interconnected components of the man-machine control system. Nowadays there are many different types of models representing behaviour of the operator from the mathematical point of view. As stated above stabilization processes in the researched systems are implemented without participation of the operator. One of the widespread models can be represented as the transfer function [2]

$$W_0(s) = \frac{k(T_1 s + 1)}{(T_2 s + 1)(T_3 s + 1)} e^{-\tau s}, \tag{1}$$

where k (40…100) is an operator transfer constant; τ (0.13…0.2 s) is time of an operator reaction on a signal of the trajectory control (0.25…2.5 s) ; T_1 is a constant of forestalling, which defines ability of an operator to compensate delay of reaction; T_2 (0.1 s) is the nervous and muscle time constant; T_3 (0.6…2 s) is the filtration constant.

Input of (1) represents signal of the trajectory control (forestalling signal) and output – the control signal created by the operator.

Dependence of the control parameter (error) Δx on cross motion of the reference point and platform with observation equipment during tracking processes can be represented by the error equation or equation of the trajectory control.

Any tracking method is characterized by the specific error equation. The equation $\Delta x = 0$ corresponds to the ideal navigation [2].

The most widespread tracking methods based on the automated control are the method of direct tracking, method of tracking with forestalling, and method of proportional tracking or proportional navigation [2], [9].

Advantages of the method of the proportional navigation are its simplicity and usability [9]. Furthermore the method of proportional navigation is suitable for operation in changed conditions. This method is the most preferable for the short and middle range applications [9].

In accordance with the method of the proportional navigation the tracking angular rate $\dot{\gamma}$ is directly proportional to the line-of-sight rate $\dot{\lambda}$ [9], [10]

$$\dot{\gamma} = N\dot{\lambda}. \tag{2}$$

The equation (2) is the most suitable for implementation of tracking processes in systems of the researched type. The navigation constant N in (2) depends on manoeuvres of the observable reference point and errors of tracking systems. Usually it changes from 3 to 5, and for non-movable reference point it can be equal to 1 [10].

V. CONTROL LAWS

There are some approaches to creation of control laws for tracking modes. The developed laws are represented in ordering of complication.

A. *Control by Means of Console*

In the simplest case control can be provided by means of a signal given from the console U_{con} [3]

$$U_c = U_{con}. \tag{3}$$

B. *Control by Means of Console and Feedback by Tachometer and Motor Armature Current*

Basic feedback in tracking systems of the researched type can be implemented by means of devices, which sense angular rate or acceleration of the plant or motor shaft. Such rate sensors as tachometers mounted on the motor shaft and rate gyros mounted on the plant are widely used for the considered application. Signals proportional to voltage of the motor armature circuit can be used for this purpose too [3].

Additional feedback in the researched systems can be implemented based on signals proportional to a moment created by the motor.

It is known that there is some physical quantity in direct current motors, which corresponds to a moment developed by the motor [3]. This quantity can be measured and used for forming correctional signal. If mechanical deformations will be not taken in consideration, the moment developed by the motor can be represented in the following form [3]

$$M_{dr} = n\left(J_m + \frac{J}{n^2}\right)\dot{\omega} + \frac{1}{n}M_{dist}, \tag{4}$$

where M_{dr} is a moment developed by the drive; n is the reduction ratio; J is the moment of motor inertia; J is the moment of plant inertia; ω is the motor angular rate; M_{dist} is the disturbance moment.

Analysis of this expression shows that the moment developed by the engine consists of two components.

The first component in (4) is proportional to acceleration of the plant.

The second component in (4) is proportional to the disturbance moment.

The correctional signal proportional to the first component can be used for the drive control correction. The correctional signal proportional to the disturbance moment influences on accuracy of tracking processes [3].

One of proposed control laws lies in usage of the console control signal, basic feedback by tachometer signal, and additional feedback by current of the motor armature circuit [6]. The control signal can be described by the expression

$$U_c = U_{con} + U_{tax} + U_{cur}, \tag{5}$$

where $U_{con}, U_{tax}, U_{cur}$ are signals proportional to console output, tachometer output, and current of the motor armature circuit.

Elimination of the tachometer signal in (5) leads to oscillations of the low frequency. This fact is approved by experimental tests.

Feedback by the motor armature current can be the most efficient if to switch on this feedback at an instant of time when the console signal decreases.

Then the control law (5) will keep the total control signal at the same level by compensation of the console signal decrease by means of feedback signal increase.

Practical implementation of this control algorithm can be implemnted by the logical unit. Results of the algorithm execution are given in Fig. 3, and the logical unit structural scheme is represented in Fig. 4.

Efficiency of this algorithm functioning has been proved by experimental tests [6].

C. *Control by Means of Console and Feedback by Plant Acceleration Assessment and Motor Armature Current*

Elimination of the tachometer signal can be done using estimation of the plant acceleration due to drive action. The moment created by the drive looks like

$$M_{dr} = \eta n c_m I, \tag{6}$$

where η is the coefficient of efficiency; n is the reduction ratio; c_m is a constant of motor loading moment; I is the current of the motor armature circuit.

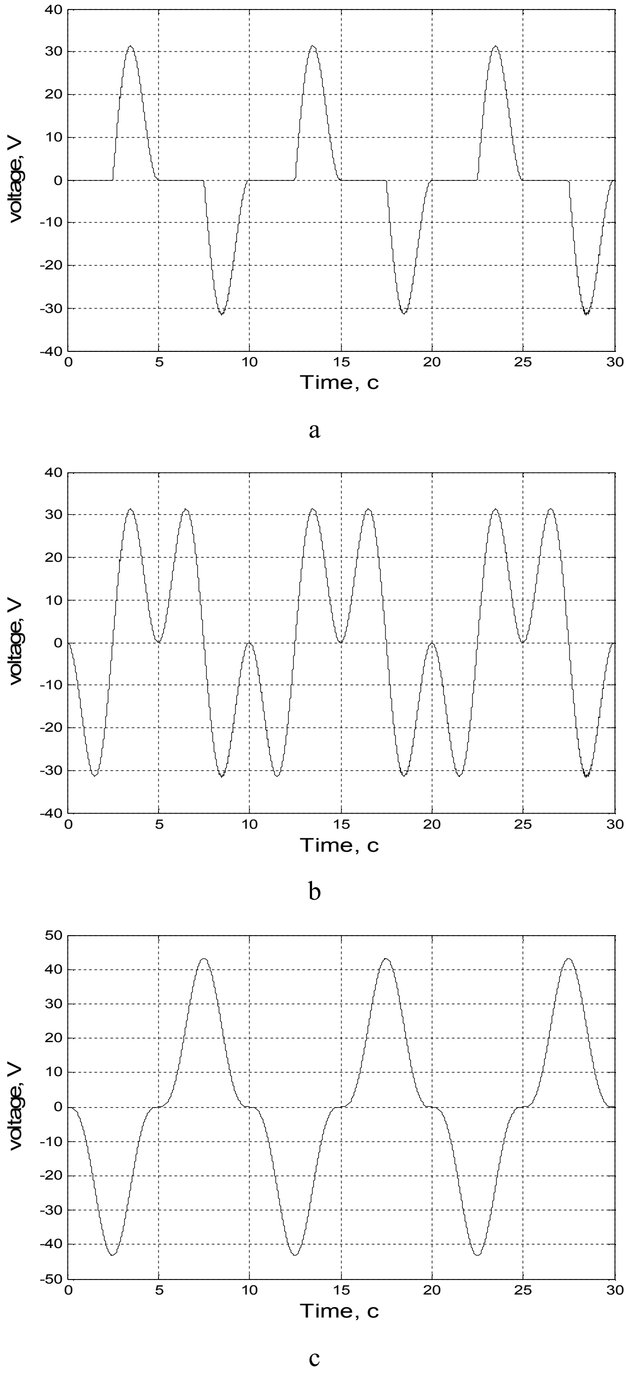


Fig. 3. Results of logic unit functioning: (a) is the output signal; (b) is the console signal; (c) is the derivative signal

The relationship (6) gives the possibility to determine an assessment of the plant acceleration arising under action of the moment created by the motor

$$\dot{\omega} = \frac{M_{dr}}{J} = \frac{\eta n c_m}{J} I , \qquad (7)$$

where J is the moment of the plant inertia.

To make control by the nonstabilized drive more efficient, the integral of the assessment (7) can be used

$$U_\omega = k_\omega \int_0^t I dt , \qquad (8)$$

where $k_\omega = \frac{\eta n c}{J}$. The signal of feedback by the motor armature circuit current during hardware implementation, as a rule, is formed by means of the Hall sensor. Therefore the equation (8) can be finally represented in the following form

$$U_\omega = k_h k_\omega \int_0^t I dt , \qquad (9)$$

where k_h is the transfer constant of the Hall sensor.

So, the control law taking into consideration the signal proportional to console output, feedback by signal proportional to assessment of plant acceleration, and signal proportional to current of the motor armature circuit becomes

$$U_c = U_{con} + k_h k_\omega \int_0^t I dt + U_{cur} . \qquad (10)$$

It should be noted that the second component in (7) is similar to tachometer signal used in the control law described by (5).

It is known that the important characteristic of the researched systems is the tracking rate [7]. Speed of operation in tracking mode is defined by sum of signals

$$\nu = U_{con} + U_{tax} . \qquad (11)$$

The value ν in (11) becomes equal to zero when the plant rate will achieve a value given from the console. Taking (9) into consideration the following condition can be satisfied

$$U_{con} = -k_h k_\omega \int_0^t I dt . \qquad (12)$$

It follows from (12) that the component U_{tax} will not change for constant U_{con}. So, to provide the higher tracking rate in this case it is necessary to add some complementary term δ in (12).

Based on theoretical grounds and experimental researches such a term it is convenient to represent in the form of the integral of the total signal of console and signal, which corresponds to the assessment of the plant acceleration

$$\delta = \int_0^\tau (U_{con} + k_h k_\omega \int_0^t I dt) \tau . \qquad (12)$$

Finally the control law taking into consideration the console signal, the plant acceleration assessment determined by (3), and feedback by the current of the motor armature circuit becomes

$$U_c = U_{con} + k_h k_\omega \int_0^t I dt + \int_0^\tau (U_{con} + k_h k_\omega \int_0^t I dt)\tau + U_{cur}. \quad (12)$$

Control laws (3), (5), and (12) can be applied for tracking modes of low-cost systems with nonstabilized drive and in tracking modes of the researched systems with the full set of the modes.

VI. CASE OF STUDY

Calculating scheme of the mathematical model is given in Fig. 5. Simulation results are given in Fig. 6.

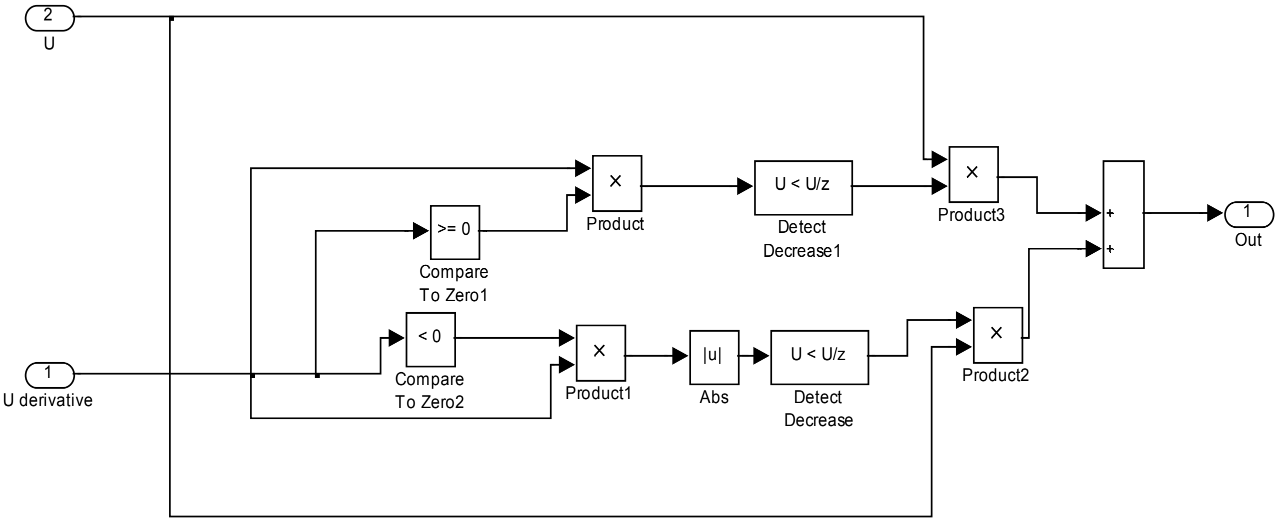


Fig. 4. The structural scheme of the logic unit

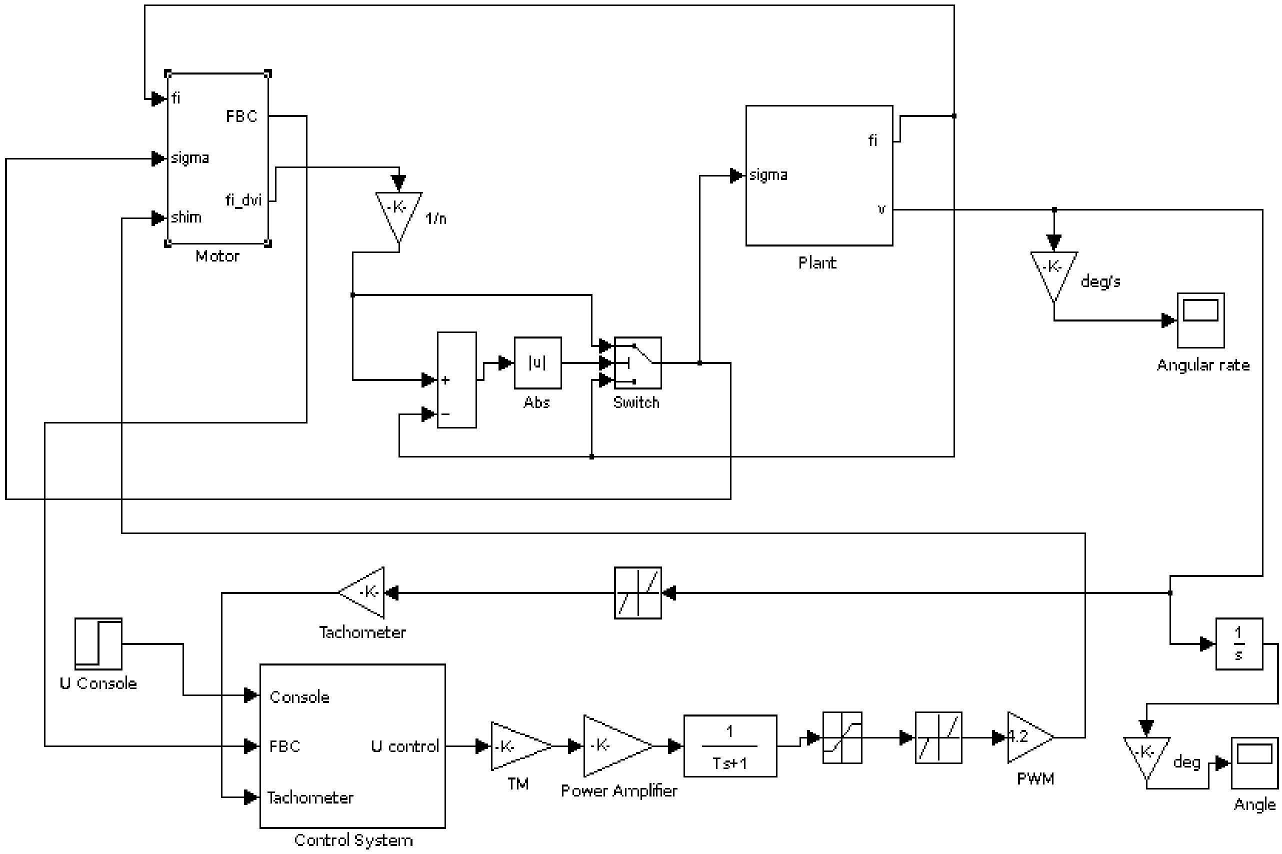
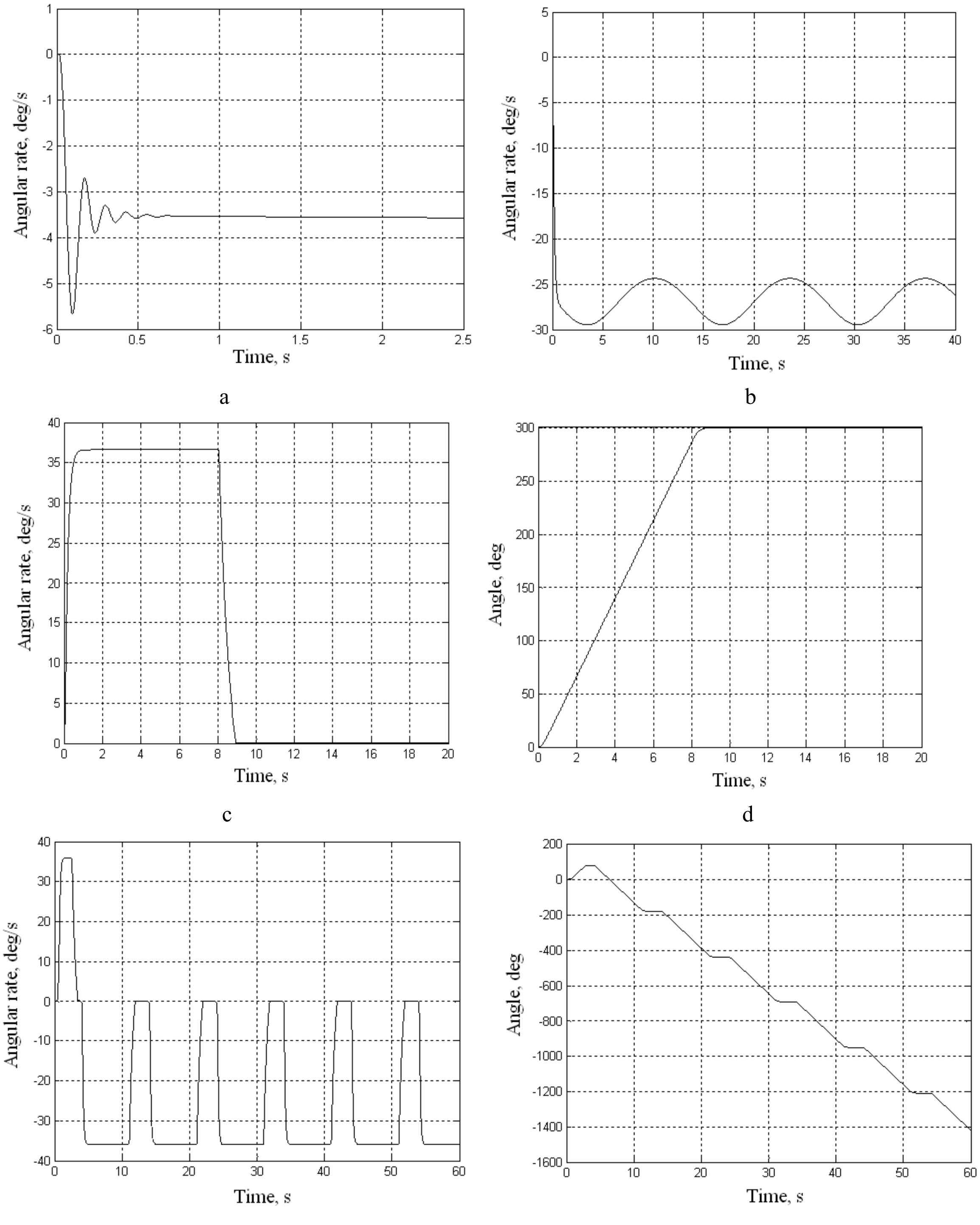


Fig. 5. Calculating scheme of the tracking system mathematical model



a b

c d

e f

Fig. 6. Results of tracking system simulation: (a), (b) are results of simulation using the control law (5), here (b) corresponds to elimination of the tachometer signal; (c), (d) is reaction on the step signal for the control law (13); (e), (f) is reaction on the sinusoidal signal for the control law (13).

The mathematical model of system for control of orientation of observation devises lines-of-sight includes models of the drive based on the direct current motor, plant, power amplifier, pulse-width modulator and control unit [11], [12]. It should be noted that the pulse-width modulation is the most widespread for control of the direct current motor. To simplify the mathematical model, the linearized model of the pulse-width modulator is used [13].

The studied system is assigned for operation on the ground vehicles.

Results of tracking processes simulation using control law (5) are shown in Fig. 6a. Further simulation was carried out for control based on signals of the console and feedback by the current only. In accordance with Fig. 6b elimination of the tachometer signal from the control law (5) leads to oscillations of the low frequency. Figures 6c–f show results of reaction of tracking system with control law (13) on step and sinusoidal signals.

VII. CONCLUSIONS

The control laws for tracking system with the nonstabilized drive are developed. The comparative analysis of the developed laws is represented. The results of simulation are given. Features of the proposed control laws implementation are analyzed.

The obtained results can be applied for automated systems. Proposed control laws can be useful for modes of nonstabilized tracking of the systems with the full set of modes such as stabilization, nonstabilized tracking and stabilized tracking. Developed relationships provide smooth tracking rate and increase speed of the reference point tracking.

Represented simulation results prove efficiency of developed control laws. It should be noted that the model, which was used for simulation, takes into consideration nonlinearities inherent to real systems including gap of the geared drive, and elastic connection between the drive and the platform with payload.

In the general case the researched system can operate in some modes such as stabilization, tracking and stabilized tracking. In such situation usage of the control law (14) in the tracking mode is the most preferable. Such approach allows increasing accuracy of tracking processes.

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О. А. Сущенко. Особливості керування в режимах стеження

Досліджено систему керування орієнтації осей візування інформаційно-вимірювальних пристроїв на рухомій основі. Запропоновано закони автоматизованого керування систем досліджуваного типу у режимах стеження. Запропоновано алгоритм керування з локальним місцевим зв’язком за струмом ланцюгу якоря двигуна. Отримано інтегральну оцінку прискорення об’єкта на підставі струму ланцюга якоря двигуна та показано можливість її використання в законах керування. Представлено математичну модель системи, призначеної для експлуатації на наземних рухомих об’єктах. Наведено результати моделювання та виконано аналіз його результатів. Отримані закони управління можуть бути використанні в недорогих системах з нестабілізованим приводом, а також в режимах стеження багаторежимних систем керування орієнтацією ліній візування інформаційно-вимірювальних пристроїв, що експлуатуються на рухомих об’єктах.

Ключові слова: режими стеження; нестабілізований привід; наземні рухомі об’єкти; автоматизований контроль; зворотний зв’язок.

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Напрям наукової діяльності: системи стабілізації інформаційно-вимірювальних пристроїв, експлуатованих на рухомих об’єктах широкого класу.

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О. А. Сущенко. Особенности управления в режимах слежения

Исследована система управления ориентации осей визирования информационно-измерительных устройств на подвижном основании. Предложены законы автоматизированного управления систем исследуемого типа в режимах слежения. Предложен алгоритм управления с локальной обратной связью по току цепи якоря двигателя. Получена интегральная оценка ускорения объекта на основании тока цепи якоря двигателя и показана возможность ее использования в законах управления. Представлена математическая модель системы, предназначенной для эксплуатации на наземных подвижных объектах. Приведены результаты моделирования и выполнен анализ его результатов. Полученные законы управления могут быть использованы в недорогих системах с нестабилизированным приводом, а также в режимах слежения многорежимных систем управления ориентацией линий визирования информационно-измерительных устройств, эксплуатируемых на подвижных объектах.

Ключевые слова: режимы слежения; нестабилизированный привод; наземные подвижные объекты; автоматизированный контроль; обратная связь.

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