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TECHNOLOGICAL ASPECTS OF CONSTRUCTING A MISSILE'S CONTROL SYSTEM WITH COMPLEXING COORDINATORS IN THE PRESENCE OF FUNCTIONAL CONNECTION BETWEEN THEM AND MUTUAL CORRECTION

In the article the authors present the characteristic technological aspects of the construction of anti-aircraft (anti-ship) missile control systems with a control system that functions on the basis of the integration of various types of coordinators. It is shown that the presence of a functional connection between coordinators in a complex guidance system allows to expand the range of accuracy capabilities of the homing system in a certain way.

For this purpose, the structure of the command generation device, which ensures the operation of the integrated guidance system with two meters, should include such functionally necessary elements as: a switching device with a delay device; device for decoupling the circuit transfer coefficient from the current kinematic value of the speed.

It was also concluded that when an external disturbance is acting on the radio technical coordinator, which by its nature is equivalent to the action of an obstacle leading by speed, it is necessary to extrapolate the current values of the angular speed of the line of sight and the relative speed of approach in the control system.

Keywords: *integrated guidance system, command generation device, integration of radio technical and optical coordinators.*

The results of the authors' studies given in [1], along with the results of a large number of other publications [1, 4, 9, 10] confirm the high efficiency of combining coordinators of different physical nature in the control system of a homing missile.

However, the control system, in which the optical coordinator is introduced in the absence of a functional connection with the radio technical coordinator, has limited capabilities when exposed to interference from the radio and radiant ranges, as well as due to the peculiarities of constructing the optical coordinator (lack of information about the current kinematic value of the approach velocity $\dot{r}_l$). Such a coordinator does not provide the required dynamic properties of the system, as in this case does not stabilize the navigation constant (N), in addition, there is no possibility to extrapolate the current coordinate values, which is also a disadvantage. The task of increasing the dynamic accuracy of the system and expanding its capabilities can be solved by using a higher level: combining a radio technical coordinator with autonomous coordinators in the presence of a functional connection between them and mutual correction. In this case, it becomes possible to use extrapolators.

The scheme corresponding to this level of integration is shown in Fig. 1.

The block diagram of the control system includes the following main elements: a complex meter, a device for generating control commands, an «autopilot-missile» system, and a kinematic link. The purpose and role of the last two elements are known [2].

Let us consider the structure of the complex meter in more detail. In the general case, a complex meter has in its structure n coordinators of different physical nature, principles of construction and having their own advantages and disadvantages.

In each case, the structure of a complex meter can be a combination of coordinators of different types:

– radio engineering (active, semi-active);
– radio engineering (passive);
– optical;
– infrared;
– laser;
– television;
– inertial meters, etc.

In the general case, the functional connection between the coordinators in order to introduce initial conditions, implement mutual correction and transmit missing information is carried out through a computing device with a transfer function ($W_t(p)$).

The task of the complex meter circuit is to maximize the use of the positive properties of a particular meter. Each specific combination determines the task and circuit design of the computing device. In the general case, the mathematical description of a homing system with a complex meter can be represented as [3]

$$\Delta\varepsilon_l = f(r_l^*, \varepsilon_l^*, ...) - f(r_l, \varepsilon_l, ...). \quad (1)$$

Kinematic equations
$$\begin{cases} \dot{r}_l = V_t \cos(\theta_t - \varepsilon_l) - V_p \cos(\theta_p - \varepsilon_l) \\ r\dot{\varepsilon}_l = V_t \sin(\theta_t - \varepsilon_l) - V_p \sin(\theta_p - \varepsilon_l) \end{cases} \quad (2)$$

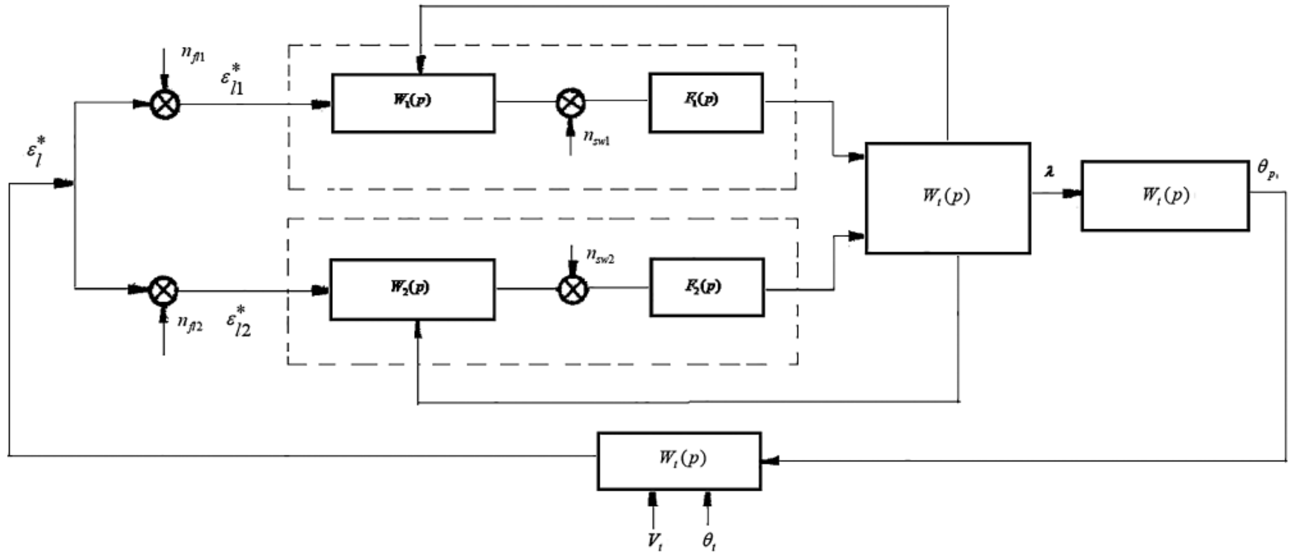

Fig. 2. Complex meter composed of a combination of two coordinators with transfer functions $W_1(p)$ and $W_2(p)$

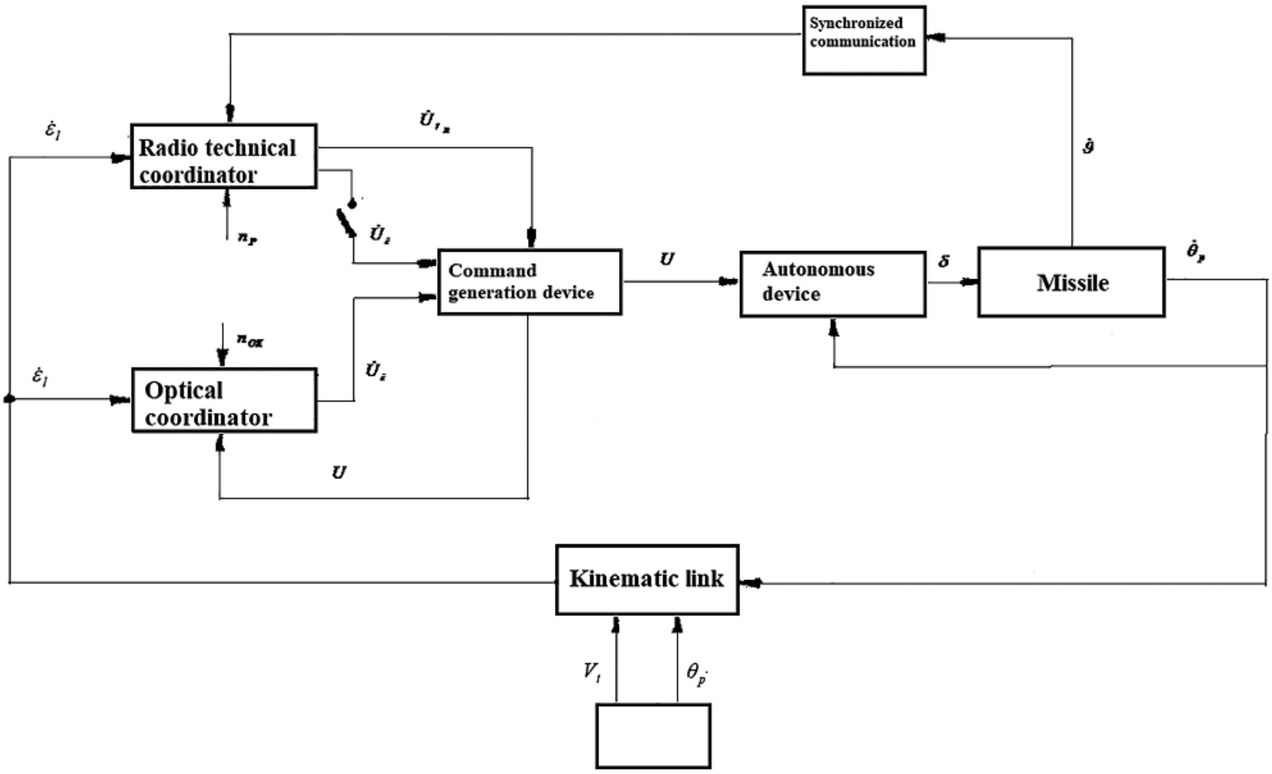

Fig. 3. Functional diagram of a homing system with a complex meter

In the same way, the orientation of the radio technical coordinator according to the signals of the optical coordinator can be carried out. The layout of the homing circuit with coordinators operating in complex mode and interlinked with each other is shown in Fig. 4.

Analysis of the quality of control of the complexing system of guidance with a radio technical coordinator and an optical coordinator in the presence of a functional connection between them

On the basis of the obtained structure, a scheme of the electronic model with a radio coordinator and an optical coordinator in the presence of a functional connection between them was built. In the process of modeling, at the stage of operation of the optical coordinator, the information for formation of the control command λ came from two meters in a complex way: from the optical coordinator $\dot{\varepsilon}_l$ and from $\dot{r}_l$ the radio coordinator.

Thus, continuous stabilization of the gain of the circuit (*N*) was carried out. The study of the quality of control of the integrated guidance system was conducted on a computer in the following sequence.

At the first stage, the behavior of the system during pointing to a non-maneuvering target was investigated qualitatively for the conditions: km, $\varepsilon_{l_0} = 15^0, \theta_0 = 25^0$. The coordinators were switched at a range to the target in the range of $r_{l_{tr}} = 14 \div 2$ km in succession over two kilometers.

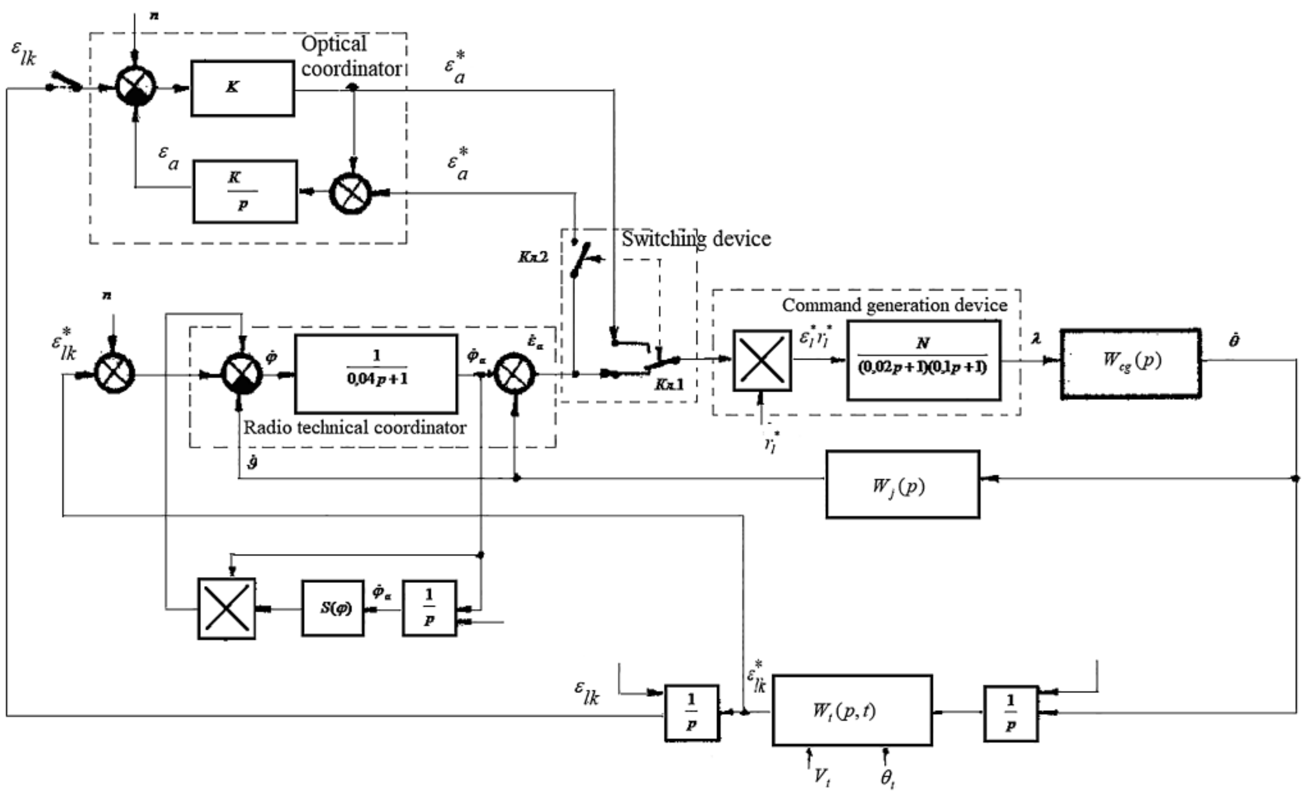

Fig. 4. A structural diagram of a homing circuit with radio and optical coordinators operating in a complex mode and united by a functional link

Oscillograms of deterministic transients are shown in Fig. 5.

The dependences of changes in the angular velocity of the line of sight $\dot{\varepsilon}_l$, the normal acceleration of the missile W_p and the control command λ on the range of gauge switching were taken. When the coordinators were switched, an additional transient process occurred in the system (a spike on the oscillogram of changes in the control command value).

Analysis of deterministic processes showed that the presence of this transient process affects the magnitude of the miss, depending on the switching range. At a distance of

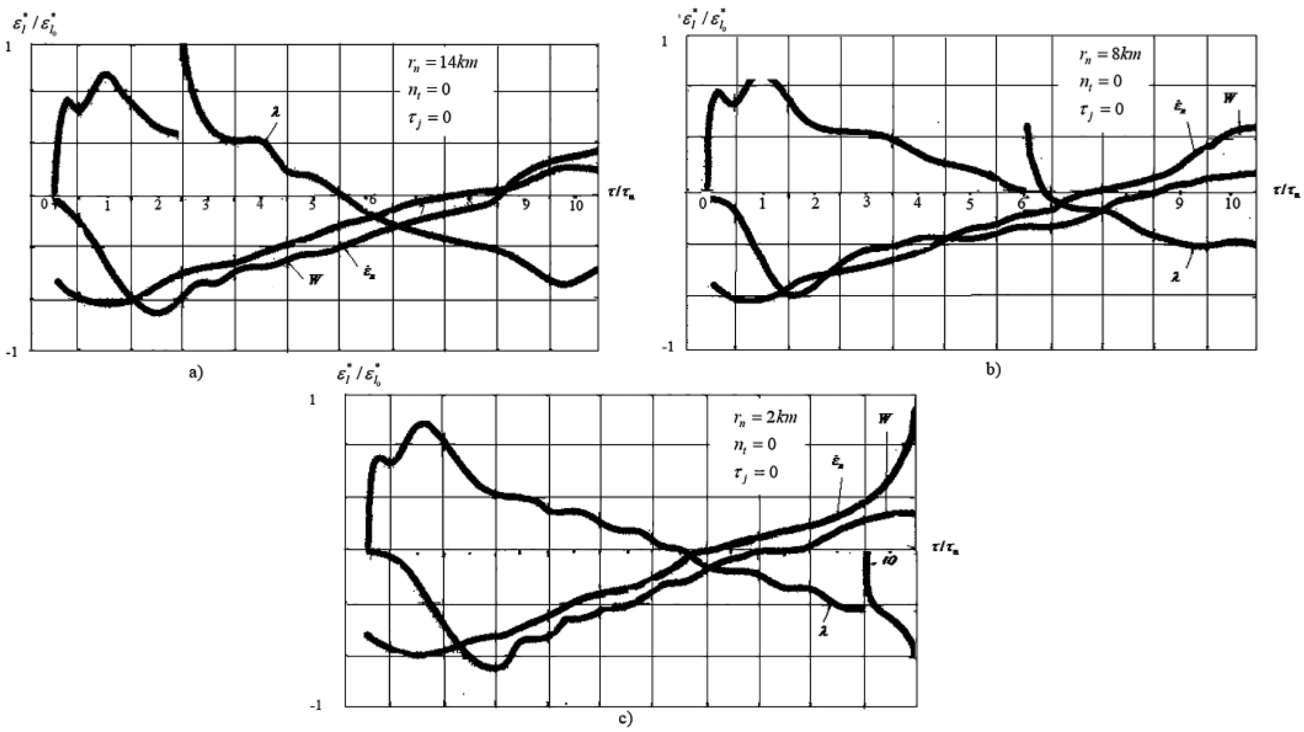

Fig. 5. Oscillograms of deterministic transients

Table 1. **System simulation results for the case of a maneuvering target**

№	V_p (m/s)	V_t (knot)	t_M(s)	η^0	$r_{l\,tr}=14$ km		12 km		10 km		8 km		6 km		4 km		2 km	
					P	$h[m]$	P	$h[m]$	P	$h[m]$	P	$h[m]$	P	$h[m]$	P	$h[m]$	P	$h[m]$
1	720	20	3	35	0,99	13,2	0,99	13,5	0,95	14	0,90	19,5	0,88	20	0,85	22,5	0,80	25
2	680	20	5	75	0,99	8,0	0,99	8,0	0,99	8,5	0,98	14,5	0,95	15	0,94	15,5	0,92	17
3	660	20	7	95	1,0	7,5	1,0	8,0	1,0	9	0,99	14	0,98	14,5	0,96	15	0,95	16
4	670	20	11	130	1,0	7,5	1,0	10,0	1,0	13	1,0	15	0,99	16	0,99	17,5	0,98	18
5	720	35	3	25	0,97	14	0,90	16	0,87	17	0,75	20	0,68	25	0,63	30	0,58	35
6	680	35	5	30	0,98	12,5	0,97	14	0,93	15	0,90	19	0,88	21	0,86	23	0,84	25
7	660	35	7	35	1,0	11,5	1,0	13	0,99	14,5	0,98	15	0,97	17	0,95	19	0,92	20
8	720	35	11	40	1,0	9,0	1,0	11	1,0	12	0,99	13,5	0,98	14,5	0,97	15	0,95	17

$r_{ltr}=14\div10$ km, switching did not have a significant effect on the pointing accuracy, however, starting from $r_{ltr}=10\div8$ km, a deterioration in the accuracy of the system was observed, increasing with a decrease in r_l.

The dependence of the accuracy on the switching range was most pronounced when noise was fed to the control system input and during target maneuvering. The results of system simulation for a maneuvering target with $n_{t\max}=3g$, V_t = 20 knots; 35 knots for switching ranges of r_{ltr} = 14, 12, 10, 8, 6, 4, 2 km, respectively, are shown in Table 1.

Graphs of the change in the value of the dynamic component of the miss and the integral laws of the distribution of misses depending on the switching distance of the coordinators are shown in Fig. 6.

At a distance of 8 km or less significant errors also began to have errors due to the fairing of the radio technical coordinator.

During the study, the system was subjected to the influence of an external disturbing effect equivalent to continuous noise radio interference (the noise level at the input of the radio technical coordinator increased by 2.5 ... 3 times). The influence of the impact stopped when the coordinators were switched and the optical coordinator quite confidently captured the target.

Only when switching to a range of $r_{l\,tr}=6\div2$ km did the effect of interference begin to have a serious impact (the dynamic component of the miss increased by 1.3 ... 1.5 times).

It follows from the results obtained that, in general, the dynamic accuracy of the system was higher than in the previous cases.

An additional transient process has a rather serious effect on the dynamic accuracy of the complex system. In this connection, it is advisable to switch coordinators at a range of $r_{l\,tr}=6\div2$ km from the target. This task should be solved by the command generation device.

Development of a command issuing device structure to ensure the operation of complex homing systems with two sensors

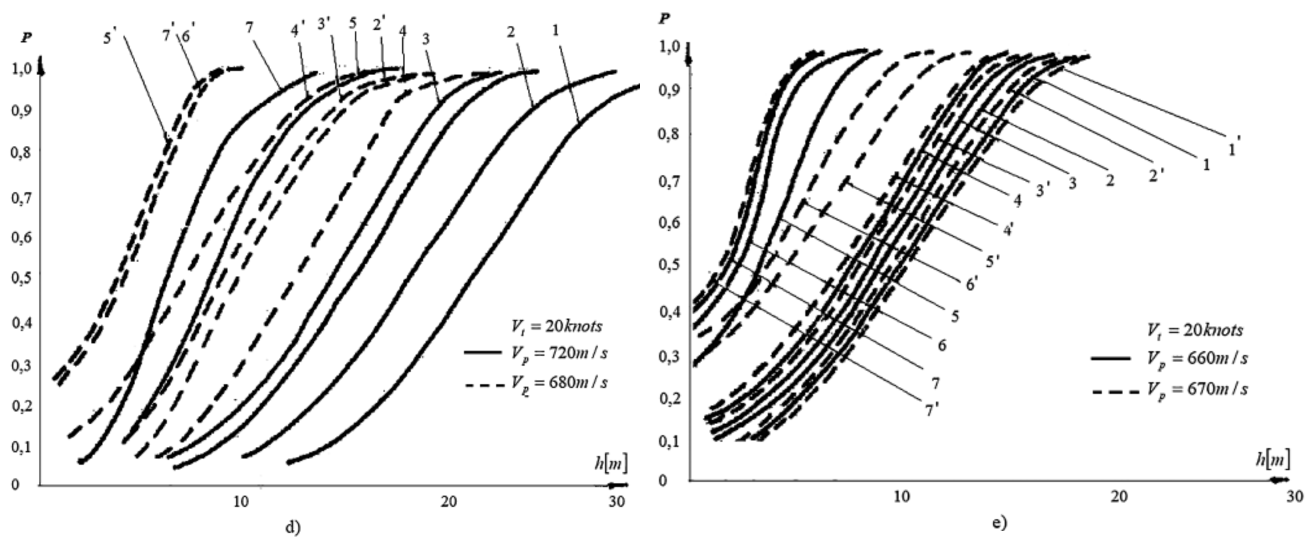

Fig. 6. Graphs of changes in the value of the dynamic component of the miss *h*

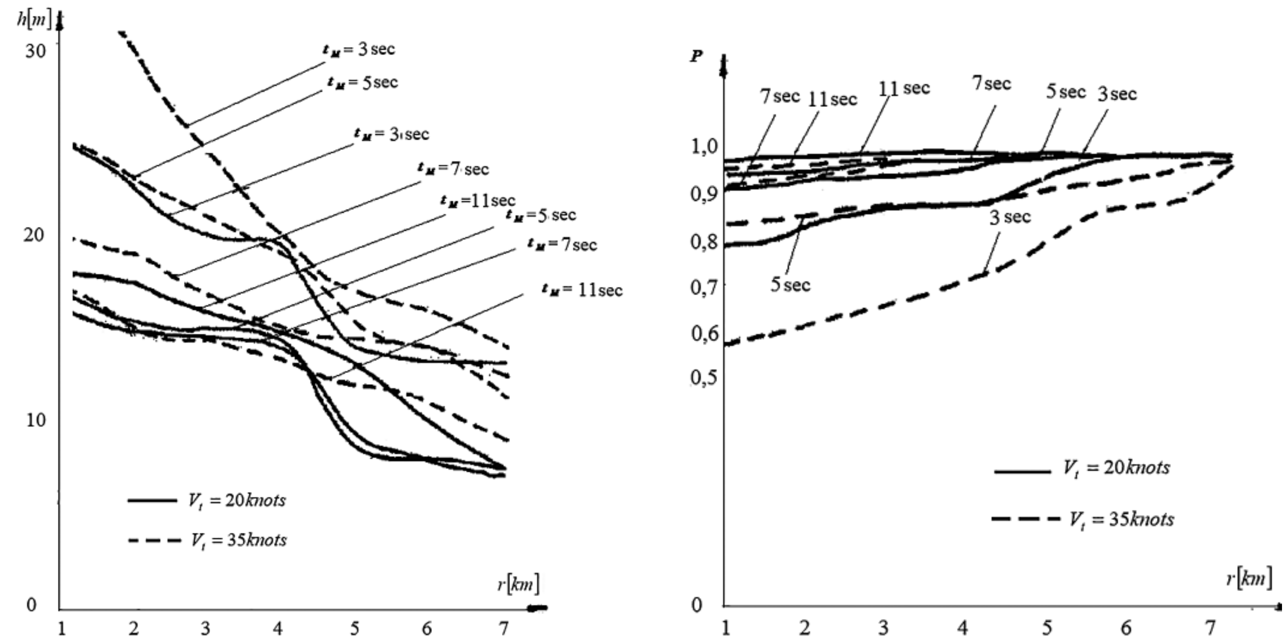

Fig. 7. Graphs of the integral laws of the distribution of misses depending on the switching distance of the coordinators

Command issuing device for a complex homing system with two sensors (radio and optical coordinators) if there is a functional link between them shall ensure:

– switching of coordinators depending on homing conditions;

– decoupling of the loop gain (navigation constant) from the relative velocity of the missile approaching the target

– formation of a control command according to the guidance method and control method.

In general, the structure of such a command generation device looks like (Fig. 8) and consists of three main elements:

– a switching device;

– a device that performs decoupling of the transmission coefficient;

– a device for filtering the signal.

The presence of additional auxiliary devices is also possible.

The influence of the last two elements is known [2]. The formation of the command in them is carried out by the general laws. It is of interest to select the type of a switching device, which provides guidance of the missile during the work of two gauges with functional linkage. The choice of the switching device structure was performed based on modeling of the proposed system.

When analyzing the control quality of the complex guidance system with a radio-technical coordinator and an optical coordinator in the previous paragraph, we pointed out the presence of an additional transient process (outlier) that occurs when the coordinators are switched. This outlier had an impact on the dynamics of the complex guidance system, especially from the switching range $r_{ltr} = 10 \div 8$ km.

From the obtained results we can see that in order to ensure the normal transient process in the system it is necessary to implement a delay in switching. The structure of the switching device in this case will have the form shown in Fig. 9.

By the method of mathematical modeling, a study of the complex induction system for different switching modes was carried out (Fig. 10). The moment of coordinator switching was carried out with some time delay τ_3.

First, the behavior of the system was studied qualitatively in terms of the nature of deterministic transient processes. When noise was applied to the inputs of the meters, the assessment of the accuracy characteristics of missile guidance to the target was carried out by determining the statistical distribution of the miss over forty model implementations at the optimal $r_{ltr} = 10$ km.

The delay value was initially chosen sequentially from 1 s to 0.01 s. However, a quantitative study of the complexation

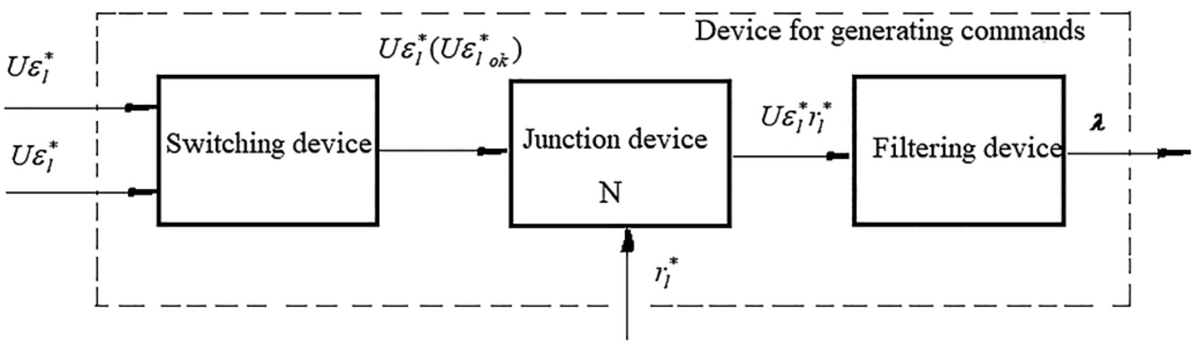

Fig. 8: General view of the structure of the control command generator

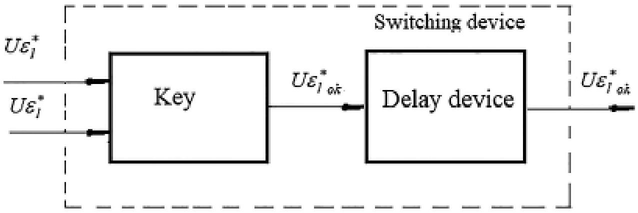

Fig. 9. Structure of the switching device

of the guidance system was carried out in the range $\tau_3 = 0 \div 0,5$ s, because above this range, the introduction of a delay led to a sharp deterioration in the accuracy characteristics (oscillograms in Fig. 11).

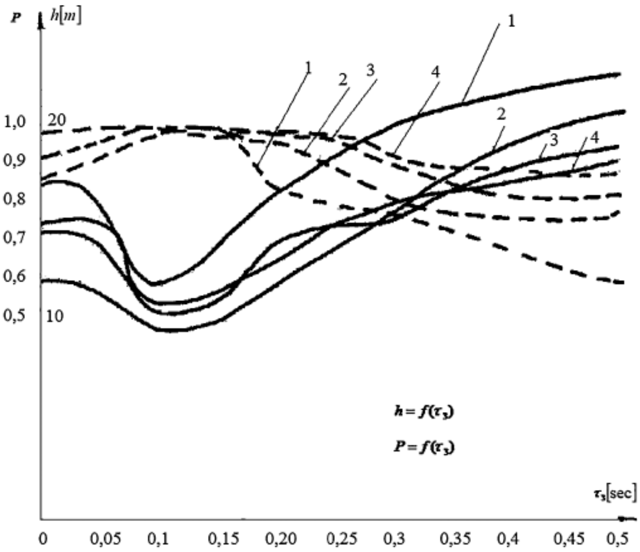

Fig. 10. Study of the complexation of the guidance system for various switching modes

The simulation results are given in Table. 2. In Fig. 12, 13 are graphs of the dependence of the change in the probability of defeat and the dynamic component of a miss on the value of the time delay τ_3 (curve designations according to Table 2).

It can be seen from the obtained results that in order to ensure a normal transient process in the circuit, it is necessary to delay the switching of coordinators in the range $\tau_3 = 0,08 \div 0,15$ s, which is optimal from the point of view of obtaining the greatest gain in dynamic pointing accuracy.

In this case, the structure of the command generation device that provides missile guidance to the target has the

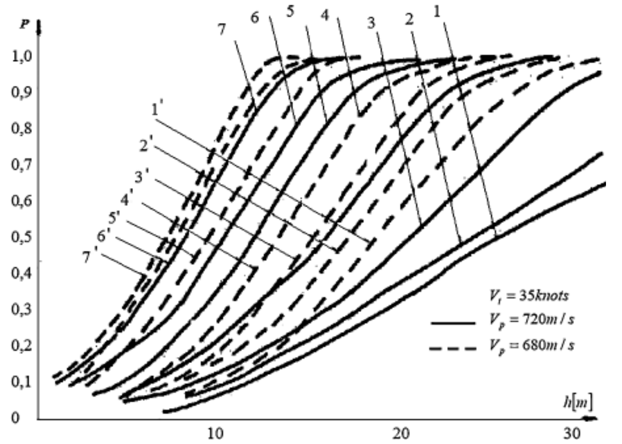

Fig. 11. Oscillograms of a quantitative study of the complexation of the guidance system in the range $\tau_3 = 0,5s$

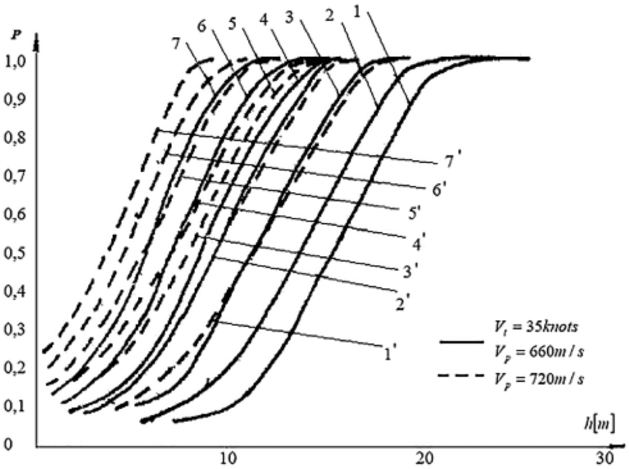

Fig. 12. Graphs of the dependence of the change in the probability of defeat and the dynamic component of a miss on the value of the time delay (designation of the curves according to Table 2)

form (Fig. 13). This scheme of the command generation device has one significant drawback.

To decouple the transmission coefficient of the complexing guidance system, information is needed about $\dot{r}_{lk}$, which in such a homing system can be obtained from the radio technical coordinator.

Under the action of an external disturbance on the radio coordinator, equivalent in its influence to the action of a

Table 2. **Results of quantitative modeling of the complexation of the guidance system**

№	V_p (m/s)	V_t (knot)	t_M(s)	η^0	$\tau_3 = 0$		$\tau_3 = 0,05s$		$\tau_3 = 0,1s$		$\tau_3 = 0,2s$		$\tau_3 = 0,25s$		$\tau_3 = 0,3s$		$\tau_3 = 0,5s$	
					P	$h[m]$	P	$h[m]$	P	$h[m]$	P	$h[m]$	P	$h[m]$	P	$h[m]$	P	$h[m]$
1	720	35	3	25	0,87	17	0,93	16	0,99	12	0,85	17	0,8	18,5	0,75	20	0,6	22,5
2	680	35	5	80	0,93	15	0,97	14,5	1,0	11	0,96	13	0,9	15	0,82	16	0,78	20,5
3	660	35	7	35	0,99	14,5	1,0	14,0	1,0	10,5	0,98	14	0,95	14,5	0,9	16	0,83	19
4	720	35	11	40	1,0	12	1,0	11,5	1,0	9,5	0,99	12	0,97	13,5	0,93	15	0,89	18,5

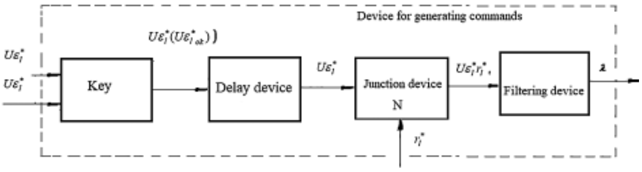

Fig. 13. The structure of the command generation device that provides missile guidance to the target

speed-stealing interference, the circuit does not meet the guidance requirements, since information about the relative approach velocity and the angular velocity of the line of sight is largely distorted.

To ensure the required conditions for missile guidance in this case, it is necessary to extrapolate the values $\dot r_{lk}$, $\dot\varepsilon_{lk}$ which can be achieved through the use of an extrapolator (computing corrective device) on board (Fig. 14).

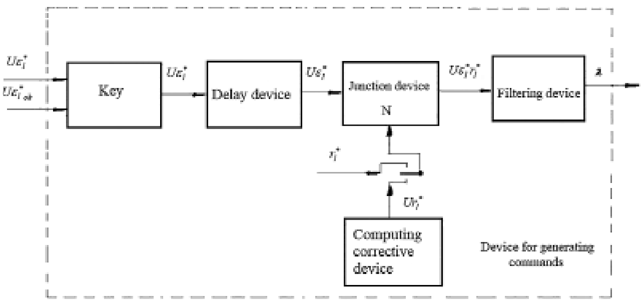

Fig. 14. Structural diagram with the use of an extrapolator (computing corrective device) on board

Development of a block diagram of a missile control system with a computational corrective device

In the general case, the task of the computational corrective device is to solve the equations of the relative motion of the missile and the target in order to obtain the current values of the angular velocity of the line of sight and the relative velocity of approach.

The equation for the relative motion of the missile and the target has the form

$$\ddot\varepsilon_{lk} = -\frac{2\dot r_{lk}}{r_{lk}}\dot\varepsilon_{lk} + \frac{1}{r_{lk}}(W_t - W_p). \qquad (7)$$

When exposed to a radio coordinator of an external disturbance, which is equivalent in nature to a noise that leads away in speed, information about the kinematic value of the angular velocity of the line of sight is greatly distorted.

According to certain signs, indicating the effect of a disturbance, the radio coordinator must be turned off, and the missile must be controlled according to the information issued by the computing corrective device when it solves the equation

$$\ddot\varepsilon_{lp} = -\frac{2\dot r_{lp}}{r_{lp}}\dot\varepsilon_{lp} + \frac{1}{r_{lp}}(W_{t_n} - W_{p\,acl}), \qquad (8)$$

where $\ddot\varepsilon_{lp}$, r_{lp}, W_{t_n} – instrumental values of angular velocity of line of sight, relative approach velocity, and target normal acceleration, respectively; $W_{p\,acl}$ − measured value of missile normal acceleration.

The structure of the computational correction device corresponding to equation (8) is presented on Fig. 15.

The operation of this device with such a structure is as follows

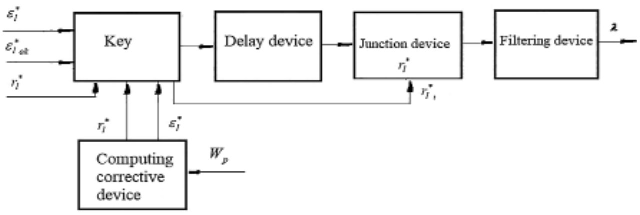

Fig. 15. The structure of the computing corrective device

At the moment of launch, the initial value of the range and the angle of inclination of the line of sight $\varepsilon_{l\,0_3}$ is fixed on the memory device of the computing corrective device. In the process of pointing, the current range $\dot r_{l\,T}$ is calculated from the value of the relative approach speed $\dot r_{l_k}$ given by the radio technical coordinator. In the absence of information from the radio technical coordinator, the current range is calculated by the value of $r_{l\,0_3}$. The scheme for the formation of the instrumental range has the form (Fig. 16).

Prior to the beginning of an external disturbance, the correction of the value $\dot r_{l\,n}$ by the antenna value $\dot\varepsilon_{la}$ must be ensured. The correction stops when the disturbance (interference) starts.

At this moment, information about the intended value of the normal acceleration of the missile $W_{p\,acl}$ (measured by a separate meter) should be sent to the computing corrective device [7, 8]. The instrumental value of angular velocity $\dot r_{l\,n}$ from the computational correcting device is fed to the command generating device to form the control command λ.

When calculating the structure, matching of the computational correcting device with the real kinematics is ensured by choosing the appropriate coefficient (matching coefficient). The current range $\dot r_{l\,T}$ in the computational correcting device is calculated by the following formula

$$r_{l_T} = r_{l_0} + \int_0^t \dot r_l\, dt. \qquad (9)$$

Since the current velocity value is calculated with an error or is taken from its initial value r_{l_0}, in order to ensure the performance of the computing correction device, it is necessary to introduce a range integration factor into dependence (9). In this case, the instrumental realization of dependence (9) will look like

$$r_{l\,T} = r_{l\,0} + K_r\int_0^{t_1}\dot r_l\, dt + K_r\int_{t_1}^{t}\dot r_{l\,n}\, dt, \qquad (10)$$

where $K_r \le 1$ − range integration coefficient; r_l − current kinematic value of approaching speed; $\dot r_{l\,n}$ − instrumental value of approaching speed.

Taking into account the features associated with extrapolation of current coordinate values, the structural diagram of the complex pointing system with integrated radiotechnical coordinator, optical coordinator and computing correction device in the presence of a functional connection between them is shown in Fig. 17.

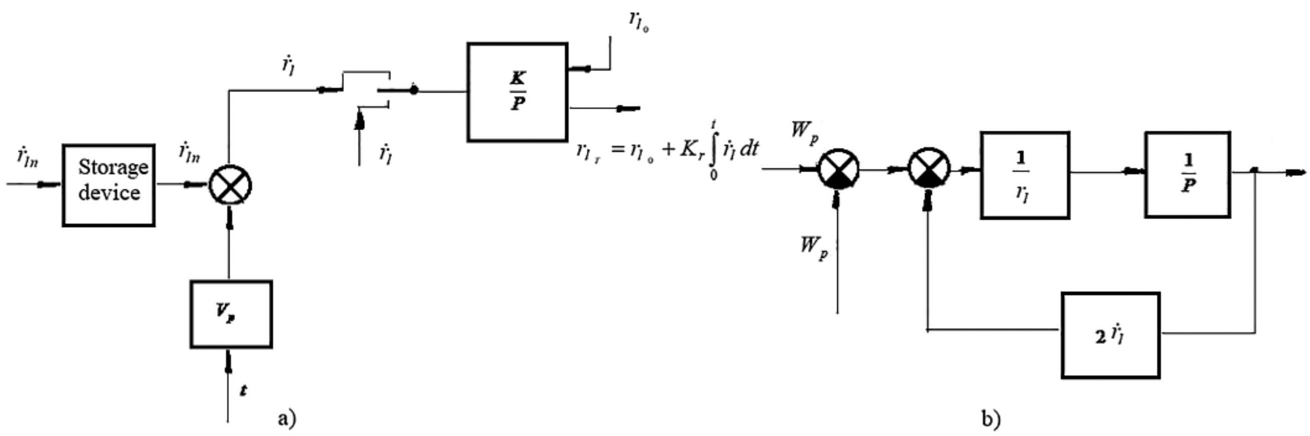

Fig. 16. Scheme of the formation of the instrumental range

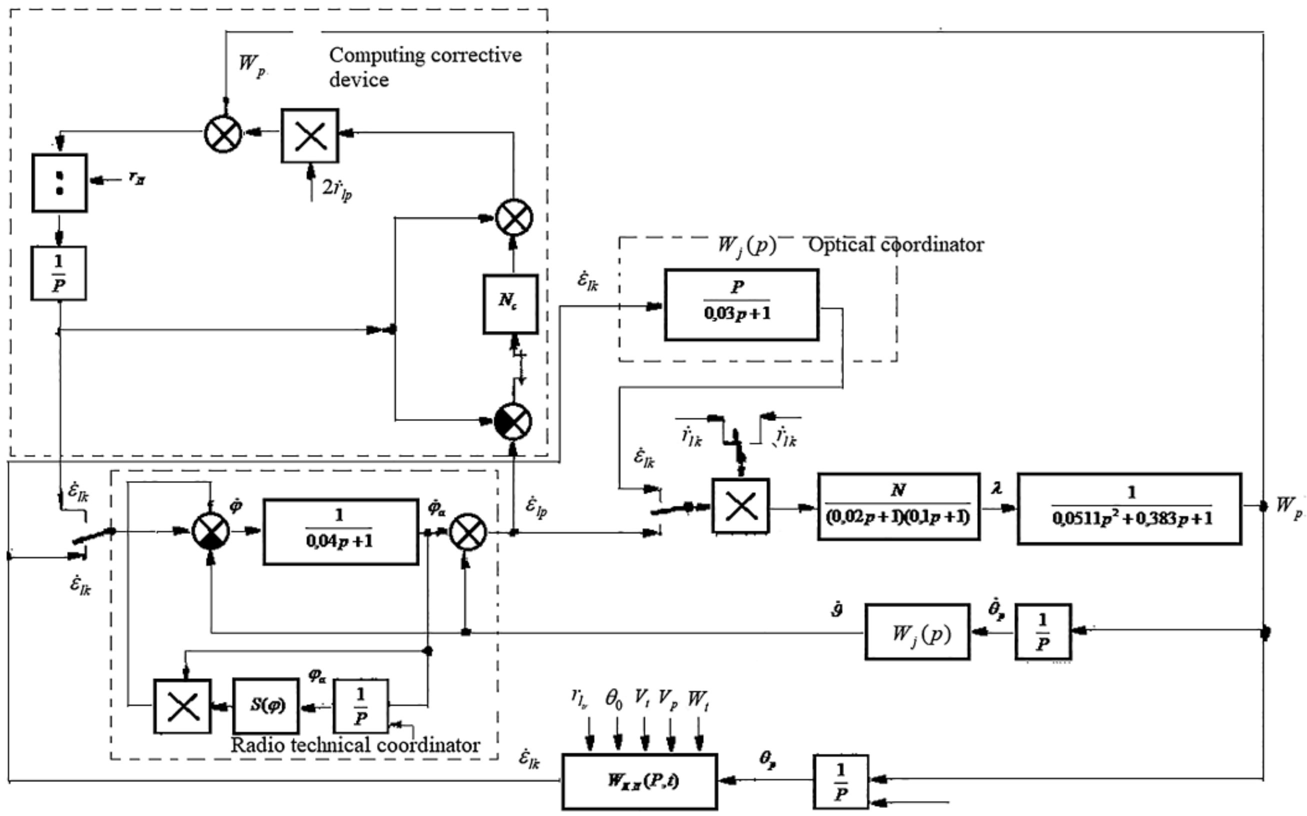

Fig. 17. Block diagram of the complex pointing system with integrated radio-technical coordinator, optical coordinator and computational correction device in the presence of functional connection between them

CONCLUSIONS

1. The presence of a functional link between the coordinators in the complex guidance system allows a certain expansion of the range of precision capabilities of the homing system. A computer analysis of the control quality of the complex homing system with a radio-technical coordinator and an optical coordinator in the presence of a functional link between them confirms this assumption.

2. The negative effect on the loop dynamics has an additional transient process that occurs when switching coordinators. In this regard, switching coordinators should be carried out at a range no closer than 8 km to the meeting point.

3. Time delay introduced at the moment of coordinators switching in order to eliminate the influence of the transient process should have the value $\tau_3 = 0,08 \div 0,15$ s.

4. The structure of the command issuing device, providing the operation of the complex pointing system with two meters, must include such functionally necessary elements as:

– a switching device with a delay device;

– a decoupling device of the loop transmission coefficient from the current kinematic value of the approaching velocity.

5. When the radio-technical coordinator is affected by an external perturbation, equivalent in its nature to the action of a velocity-evading noise, the control system must extrapolate the current values of the angular velocity of the line of sight and the relative velocity of convergence.

6. Extrapolation of the values of $\dot{\varepsilon}_l$ and $\dot{r}_l$ must be carried out with the help of a computational corrective device introduced into the structure of the complex guidance system.

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ТЕХНОЛОГІЧНІ АСПЕКТИ ПОБУДОВИ СИСТЕМИ УПРАВЛІННЯ РАКЕТИ З КОМПЛЕКСУВАННЯМ КООРДИНАТОРІВ ПРИ НАЯВНОСТІ ФУНКЦІОНАЛЬНОГО ЗВ'ЯЗКУ МІЖ НИМИ ТА ВЗАЄМНОЇ КОРЕКЦІЇ

В статті авторами представлено характерні технологічні аспекти побудови систем управління протиповітряних (протикорабельних) ракет з системою управління, що функціонує на базі комплексування координаторів різного типу. Показано, що наявність функціонального зв'язку між координаторами в комплексованій системі наведення дозволяє певним чином розширити діапазон точностних можливостей системи самонаведення. З цієї метою структура пристрою вироблення команд, який забезпечує роботу комплексованої системи наведення з двома вимірювачами, повинна включати в себе такі функціонально необхідні елементи, як: перемикаючий пристрій із пристроєм затримки; пристрій розв'язки коефіцієнта передачі контуру від поточного кінематичного значення швидкості.

Також зроблено висновок, що при дії на радіотехнічний координатор зовнішнього збурення, за своїм характером еквівалентного дії перешкоди, що веде за швидкістю, в системі управління необхідно здійснювати екстраполяцію поточних значень кутової швидкості лінії візування і відносної швидкості зближення.

Ключові слова: *комплексована система наведення, пристрій вироблення команд, комплексування радіотехнічних та оптичних координаторів.*

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