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THE ANALYSIS OF VIBRATIONS OF CONTROL GYROSCOPE AS A DRIVE IN THE TARGET TRACKING UNIT OF HOMING MISSILE

SUMMARY

In the contemporary detection and target tracking units of rocket missile (RM), the control gyroscope remains an essential element being the device used for changing the position of the target line of sight (LOS). Target tracking accuracy of a rocket missile depends on the gyroscope work precision. Thus, it is necessary to examine the impact of the external actions and disturbances – rapid manoeuvres in the initial stage of RM flight, deck vibrations or strong wind blows – on the dynamics of the gyroscope. The paper discusses the research results of the dynamics of control gyroscope set on the RM deck while seeking, detecting and tracking a mobile target.

Keywords: *rocket missile, dynamics of control gyroscope, target tracking*

ANALIZA DRGAŃ STEROWANEGO ŻYROSKOPU
JAKO NAPĘDU W UKŁADZIE NAPROWADZANIA POCISKU RAKIETOWEGO

We współczesnych układach wykrywania i śledzenia celów w pociskach rakietowych (PR) istotnym elementem jest żyroskop sterowany, który stanowi urządzenie służące do zmiany położenia linii obserwacji celu. Od precyzji działania żyroskopu zależy dokładność naprowadzania PR na cel. Należy zatem zbadać wpływ oddziaływań i zakłóceń zewnętrznych – gwałtowne manewry w początkowej fazie lotu PR, wibracje pokładu czy też silne podmuchy wiatru – na dynamikę żyroskopu. W pracy przedstawione są wyniki badań dynamiki żyroskopu sterowanego na pokładzie PR podczas procesu poszukiwania, wykrywania i śledzenia celu ruchomego.

Słowa kluczowe: *pocisk rakietowy, dynamika sterowanego żyroskopu, śledzenie celu*

1. INTRODUCTION

The paper [3] describes the homing process of an anti-aircraft rocket missile onto a target with a particular emphasis on the working principle of the classical gyroscope suspended on Cardan joint and constituting the executive control system of the position of the target line of sight in the co-ordinator of the homing missile. The general view of the homing process of a rocket missile with a control gyroscope on deck is presented in Figure 1.

In the figure the symbols designate:

$O_o x_o y_o z_o$ – the coordinate system with the middle in the mass of the missile, and axes parallel to the inertial reference system;

$Oxyz$ – the coordinate system connected to the body of the rocket missile;

ϑ, ψ – angles which determine the position of the longitudinal axis of the missile in space (angle of inclination and deflection, respectively);

p, q, r – constituents of the vector angular velocity of the missile;

$\vec{V}_p$ – velocity of the rocket missile flight;

ε, σ – angles which determine the position of the target line of sight (LOS) in space (the angle of inclination and deflection LOS, respectively);

$Ox_1 y_1 z_1$ – the coordinate system whose axes are connected to the external frame of the gyroscope;

$Ox_2 y_2 z_2$ – the coordinate system whose axes are connected to the inner frame of the gyroscope;

$Ox_3 y_3 z_3$ – the movable coordinate system whose axes are connected to the rotor;

$\Phi_g, \vartheta_g, \psi_g$ – angles of the gyroscope axis self-rotation and of the rotation of the inner and external frames, respectively;

m_2 – the mass of the rotor and inner frame;

m_3 – the mass of the external frame;

g – Earth's acceleration;

l_g – distance between the mass centre of gyroscope and the centre of its rotation;

M_k, M_b, M_c – moments of friction forces affecting the rotor, the external frame and the inner frame, respectively;

M_{rk}, M_{rb}, M_{rc} – the reactions of the moments of friction forces affecting the rotor, the inner frame and the external frame, respectively.

Because of the fact that the optic system of target seeking and tracking head is set in the gyroscope axis, the accuracy of homing depends, to large extent, on the gyroscope correction system of which task remains to minimise the deviation of the actually performed motion from the pre-set motion, determined, in real time, by the image analysis system. The functional rule of a rocket missile guidance using gyroscope system is schematically presented in Figure 2 [2].

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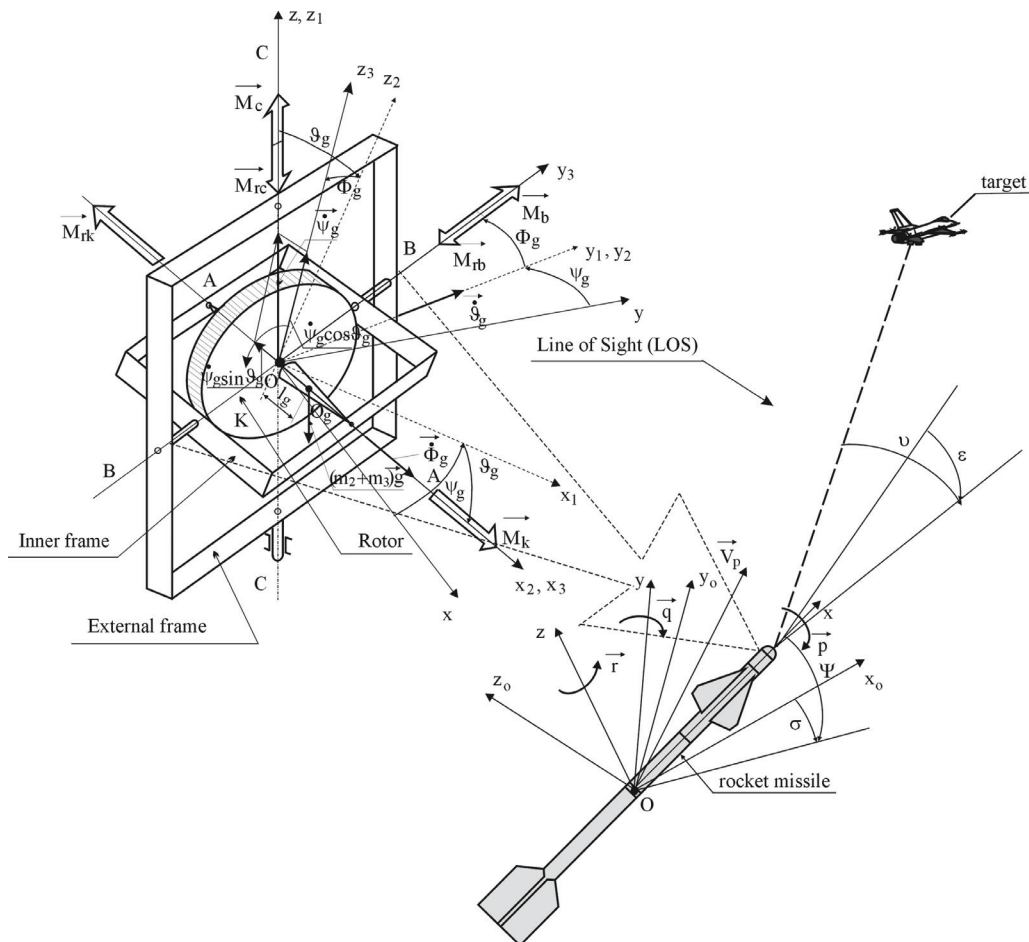
Fig. 1. General view of the homing process of a rocket missile with a control gyroscope on deck
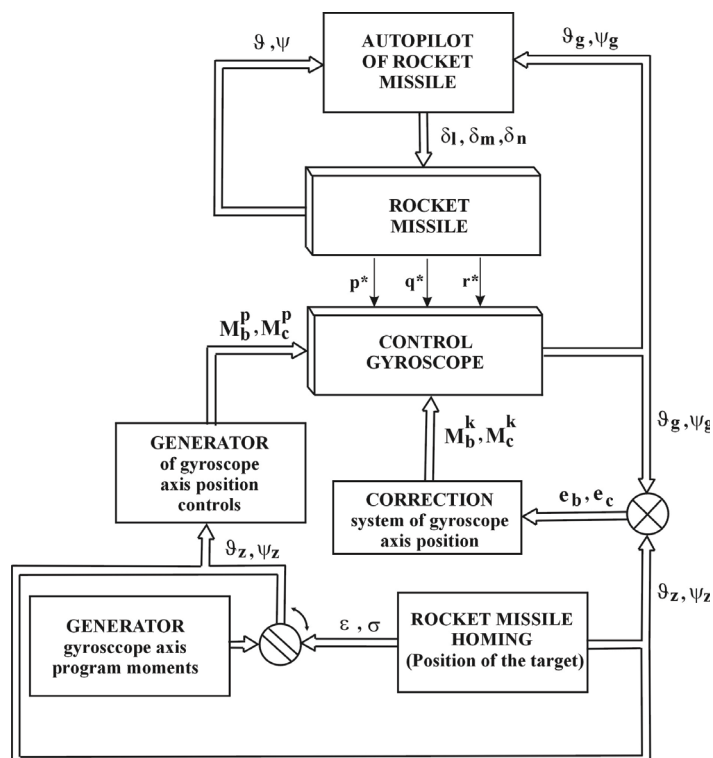

Fig. 2. The functional diagram of the homing process for a rocket missile with control gyroscope

The following symbols have been introduced:

M_b^p, M_c^p – the gyroscope programming control;

M_b^k, M_c^k – the gyroscope correction control;

ϑ_z, ψ_z – the pre-set angles of the gyroscope axis position in the space;

$e_b = \vartheta_g - \vartheta_z, e_c = \psi_g - \psi_z$ – angular deviations;

$\delta_l, \delta_m, \delta_n$ – angles of rudders deflections in the channel of tilt, inclination, deflection respectively.

Gyroscope errors result primarily from the friction in suspension bearings and the rotor mass centre not coinciding with the point were the axes of suspension frames intersect [1, 5, 6]. That is why, the gyroscope reacts to the kinematic input of the base, on which it is located, namely, angular motion and changes in the linear velocity of the rocket missile. Apart from that, other assets detailed in the simplified diagram in Figure 3, wield significant impact.

Changes in the missile flight parameters are exceptionally marked at the homing process initial stage, i.e. after the missile is launched, finding the target by the scanning co-ordinator, when the start engine turns off and the missile control system switches on. The target line of sight, along with the rocket seeks the target, is then erroneously specified. If the gyroscope axis gets off the pre-set position too much, the target image can get lost in the field of view.

The correction system and the gyroscope parameters should therefore be selected very carefully so that the impact of the rocket board vibrations on the accuracy of the gyroscope axis position could be minimised. In the papers

[1] and [3], the authors relied on linear square optimisation LQR (linear quadratic regulator). In this paper the authors carry out the dynamics analysis for control gyroscope and its impact on the target tracking accuracy in the homing process.

2. DISCUSSION OF RESULTS

The numerical investigation covered a hypothetical close range ground-to-air rocket homing missile, with a control gyroscope located aboard, which functions as target co-ordinator drive.

Gyroscope parameters were assumed to have the following values:

$$J_{go} = 5.0 \cdot 10^{-4} \text{ kgm}^2, J_{gk} = 2.5 \cdot 10^{-4} \text{ kgm}^2, n_g = 600 \frac{\text{rad}}{\text{s}},$$

$$\eta_b = \eta_c = 0.01 \text{ Nms}, l_g = 0.001 \text{ m}, m_2 + m_3 = 0.24 \text{ kg}.$$

Gyroscope behaviour was investigated at the application of the following deflection controls:

$$M_b = -k_b e_b - h_g \dot{e}_b,$$

$$Mc = -k_c e_c - h_g \dot{e}_c,$$

as well as at the application of the optimum controls calculated with the LQR [1] method:

$$M_b = -k_b e_b + k_c e_c - h_g \dot{e}_b,$$

$$Mc = -k_c e_b - k_b e_c - h_g \dot{e}_c,$$

where:

k_b, k_c – coefficients of enforcement;

h_g – coefficient of damping.

The coefficients for the unoptimum controls were assumed to have following values: k_b = 2.15, k_c = 0.3, h_g = 15.75 and for the optimum controls: k_b = 15.7, k_c =15.7, h_g =15.75.

Switching on of the rocket missile control system happens in time t = 0.5 s, the start engine works for 2 s, the initial missile velocity is V_{po} = 50 m/s, and the final velocity is V_{pk} = 1000 m/s.

Figure 4 presents the set and real paths of rocket missile flight (here forming one path line) and the path flight of target in the homing process.
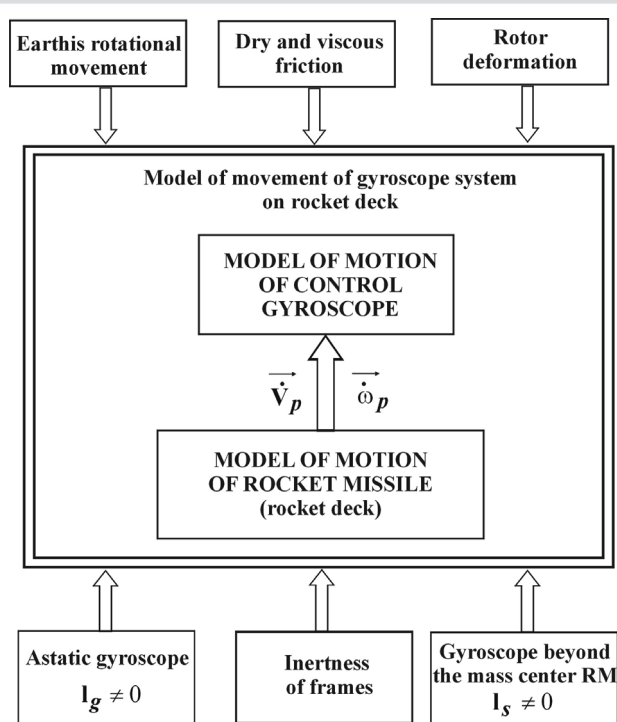

Fig. 3. The functional diagram of the vibrations affecting control gyroscope located on board of a homing missile
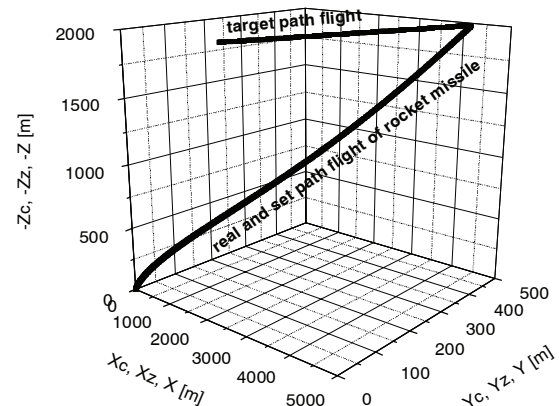

Fig. 4. Rocket missile and its target trajectories of flight

Figures 5–11 present the result of the computer simulations for the unoptimum gyroscope controls without the influence (Fig. 5 and 6) and with the influence of disturbances on it (Fig. 7–11). Then, the Figures 12–18 present the same, however, for the gyroscope optimum controls. It is not difficult to notice the considerable improvement in the gyroscope work accuracy in the second case – it is clearly noticeable when comparing Figures 10 and 11 with Figures 17 and 18.
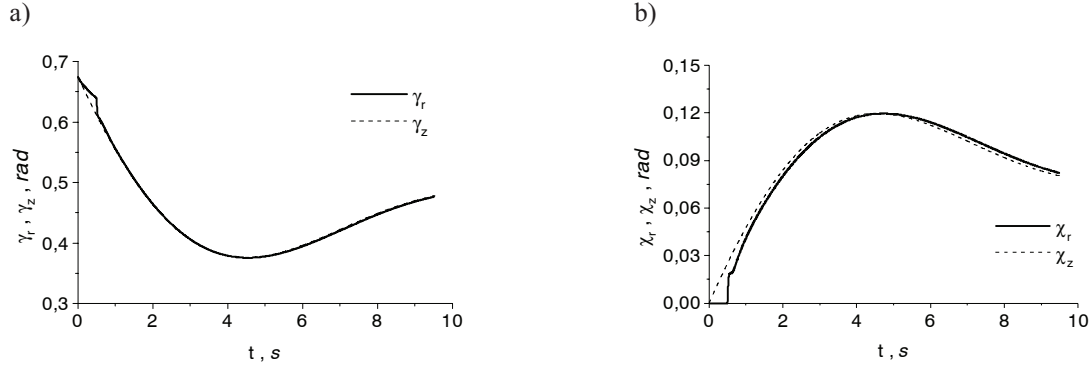

Fig. 5. Changes in time of the actually performed and the desired angles: a) inclinations γ_r, γ_z; b) deflections χ_r, χ_z of vector of missile flight velocity (unoptimum control)

Fig. 6. Changes in time of angles: (a) ϑ_g and ε as well as (b) ψ_g and σ defining the position LOS and gyroscope axis in space without external disturbance (unoptimum control)
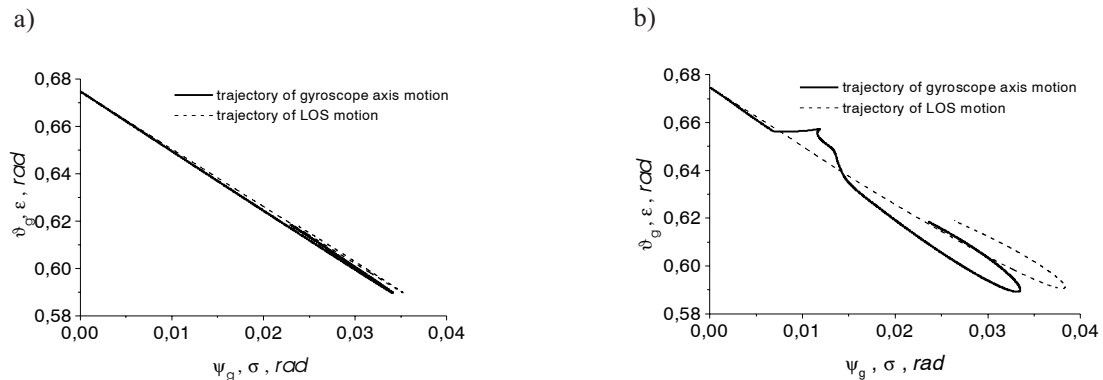

Fig. 7. Tracks of LOS and gyroscope axis: (a) without external disturbance and (b) with kinematic impact of the rocket missile on the gyroscope (unoptimum control)
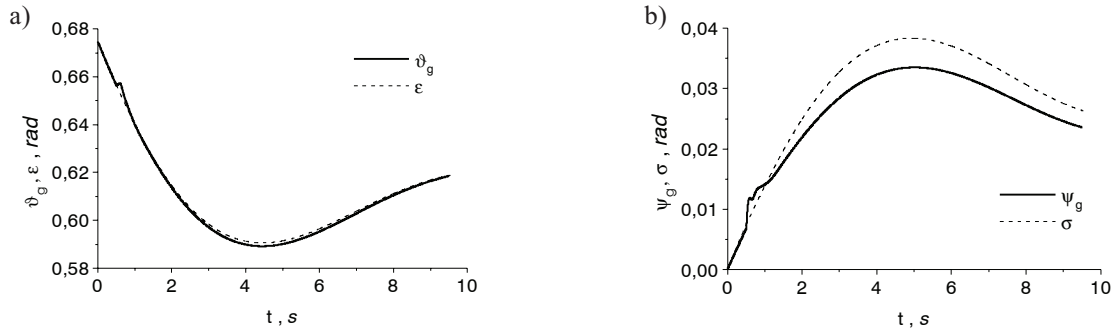
a)

b)

Fig. 8. Changes in time of angles (a) ϑ_g and ε as well as (b) ψ_g and σ defining the position LOS and gyroscope axis in space with the kinematic impact of the rocket missile (unoptimum control)
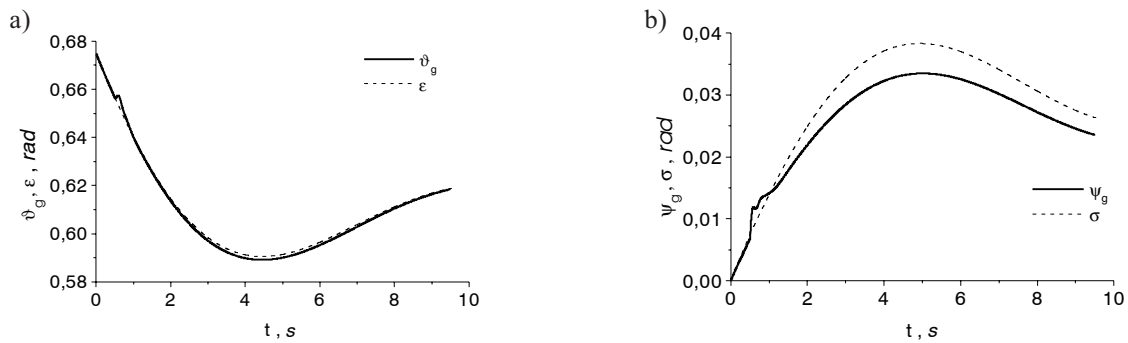
a)

b)

Fig. 9. Changes in time of angles (a) ϑ_g and ε as well as (b) ψ_g and σ defining the position LOS and gyroscope axis in space with the kinematic impact of the rocket missile and taking into account the inertia of gyroscope frames (unoptimum control)
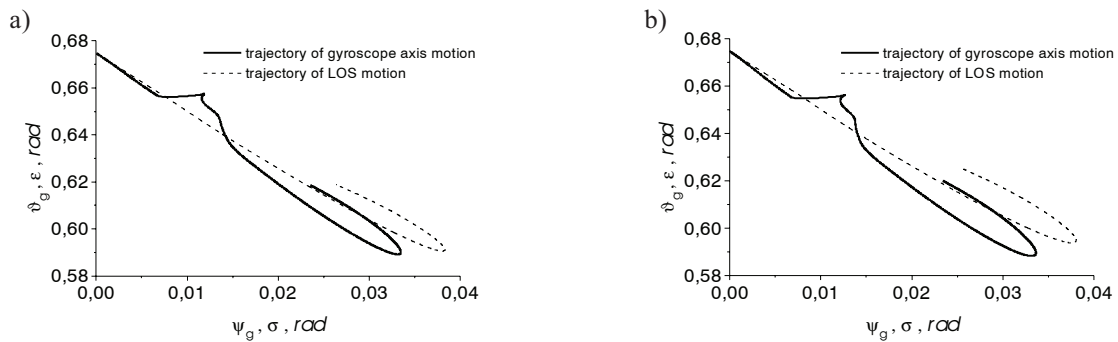
a)

b)

Fig. 10. Tracks of LOS and gyroscope axis (a) only with the kinematic impact of the rocket missile and (b) with the kinematic impact of the rocket missile on the gyroscope and taking into account the inertia of the frames (unoptimum control)
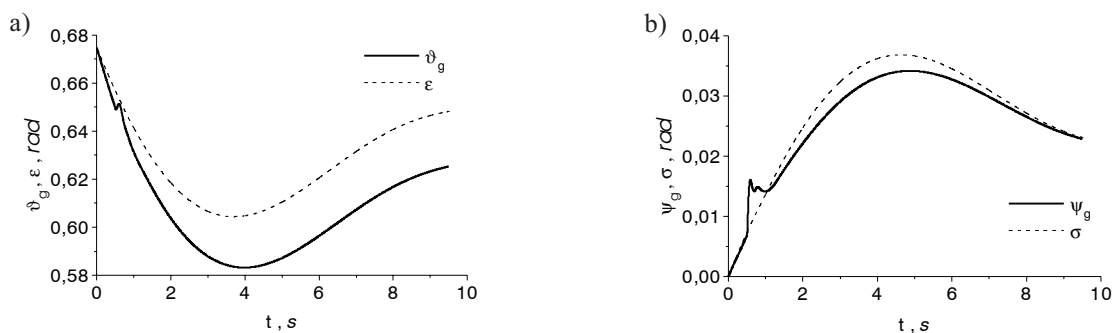
a)

b)

Fig. 11. Changes in time of angles (a) ϑ_g and ε as well as (b) ψ_g and σ defining the position LOS and gyroscope axis in space taking into account all the disturbances (the kinematic impact of the missile, taking account the inertia of the frames and the unbalanced gyroscope – unoptimum control)
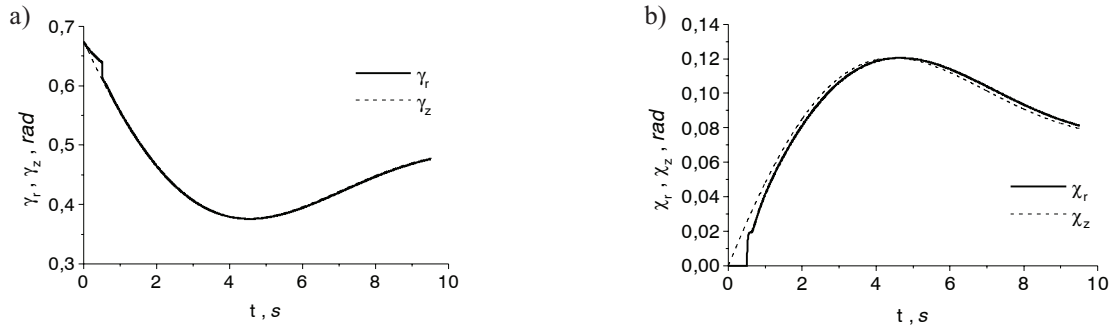
Fig. 12. Changes in time of the actually performed and the desired angles (a) inclinations γ_r, γ_z and (b) deflections χ_r, χ_z of vector of missile flight velocity (optimum control)

Fig. 13. Changes in time of angles (a) ϑ_g and ε as well as (b) ψ_g and σ defining the position LOS and gyroscope axis in space without external disturbance (optimum control)
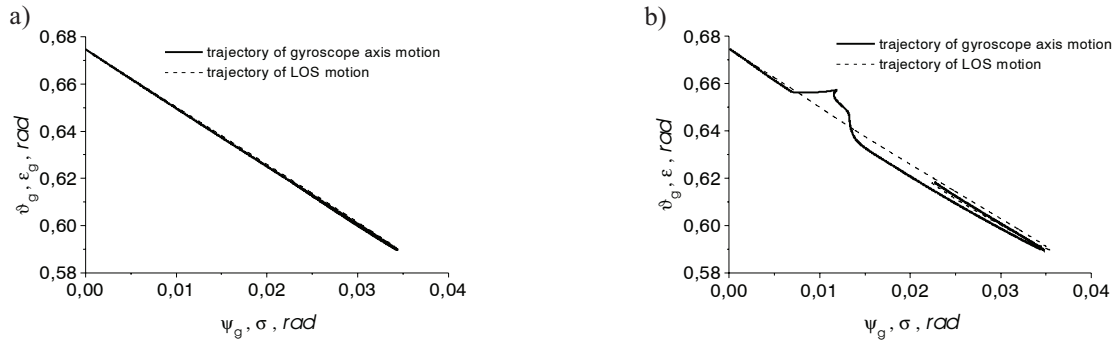

Fig. 14. Tracks of LOS and gyroscope axis (a) without external disturbance and (b) with kinematic impact of the rocket missile on the gyroscope (optimum control)
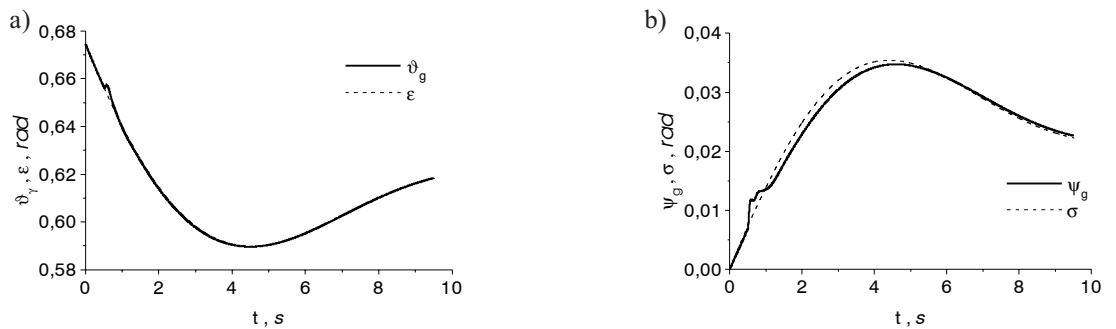

Fig. 15. Changes in time of angles (a) ϑ_g and ε as well as (b) ψ_g and σ defining the position LOS and gyroscope axis in space with the kinematic impact of the rocket missile (optimum control)
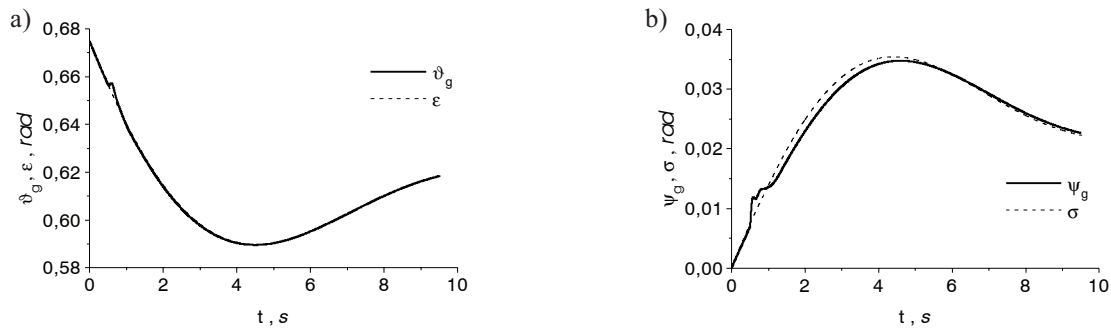
Fig. 16. Changes in time of angles (a) ϑ_g and ε as well as (b) ψ_g and σ defining the position LOS and gyroscope axis in space with the kinematic impact of the rocket missile and taking into account the inertia of gyroscope frames (optimum control)
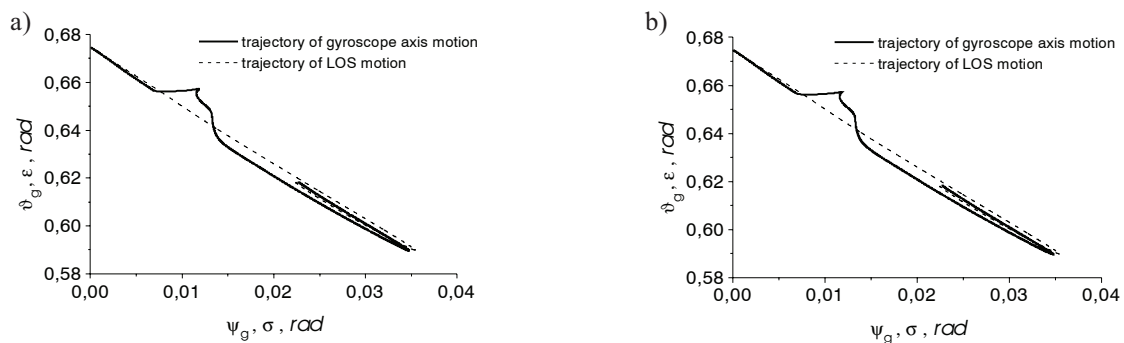

Fig. 17. Tracks of LOS and gyroscope axis (a) only with the kinematic impact of the rocket missile and (b) with the kinematic impact of the rocket missile on the gyroscope and taking into account the inertia of the frames (optimum control)
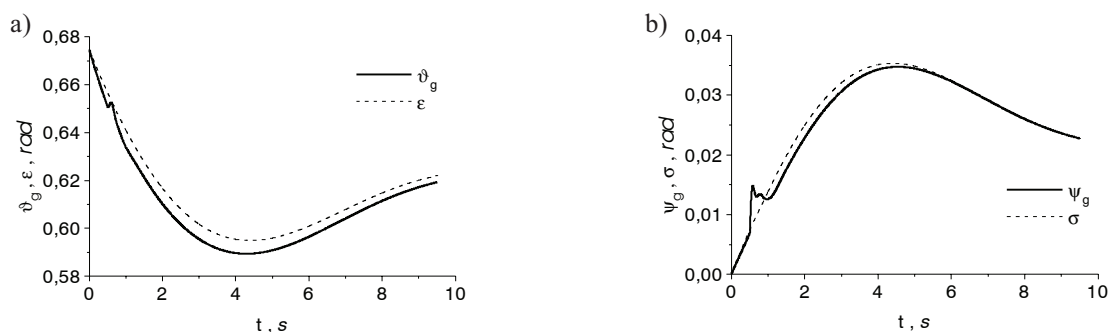

Fig. 18. Changes in time of angles (a) ϑ_g and ε as well as (b) ψ_g and σ defining the position LOS and gyroscope axis in space taking into account all the disturbances (the kinematic impact of the missile, taking account the inertia of the frames and the unbalanced gyroscope – optimum control)

3. CONCLUSIONS

The following assets have an impact on the accuracy of realization of the demanded motion of the control gyroscope axis, set on a homing rocket missile deck:

1) Values of friction forces coefficients in gyroscope frames bearings. Too small values of the coefficients, in the time of external disturbance or kinematic base forcing, result in the dynamic effects and thus lessen the accuracy of the pre-set motion realization. Whereas, their great values result in gyroscope axis getting off the pre-set position in space. Hence, it is necessary to minimise the coefficients of friction in gyroscope suspension bearings and simultaneously, additionally to apply optimally chosen dampers.

2) Impact of unlinear character of gyroscope motion model appearing especially at big angular deflections of gyroscope axis.

3) Additional gyroscope gettings off – which regardless to the numerous technological enterprises always appear, in bigger or smaller scope, in the exploitation process – and which should be minimised via gyroscope automatic correction system. The proper position of gyroscope axis in space is sustained by the automatic correction system, on the basic of the real position obtained from a measurement and the demanded gyroscope axis position worked out by a digital machine.

4) Imbalance of gyroscope used in homing missile target co-ordinator – should be as small as possible ($l_g \rightarrow 0$).

Gyroscope is firmly unlinear system. Due to fact, there are errors of the pre-set motion in relation to the real one. Hence, it is necessary to apply an additional optimum correction system when controlling the program gyroscope in unlinear range of its work and conditions of disturbances affecting the unit. Optimum parameters of gyroscope system allow for stable and continual keeping a target in the field of vision of a tracking head. It may have a particular importance in case when a target is delected at a considerable angular deflection of the longitudinal missile axis referring to the target line of sight. Optimum gyroscope correction system minimizes gyroscope axis going off being a result of kinematic interference of the missile board on the gyroscope suspension. An important issue to solve remains the problem of the time-minimal passing of the missile from the position corresponding to the target detection moment, to the kinematic path calculated from algorithm of homing method. Furthermore, it is necessary to conduct different research on the choice of an optimum structure of a complete control system considering the deformity of missile control executive bodies.

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