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APPLICATION OF THE SLIDING CONTROLLER FOR THE GYROSCOPE SYSTEM OF THE ANTI-AIRCRAFT MISSILE

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Abstract: *Precision of anti-aircraft missile homing depends mainly on correct determination of the current angle between the axis of the gyroscope system and the line of sight. The system of automatic gyroscope control should ensure automatic minimization of that angle, and thus, constant directing of the gyroscope system axis towards the line of sight, i.e. tracking the target by the homing head. This paper presents a sliding controller applied to control the gyroscope system. Subsequently, the dynamics of that system during the process of anti-aircraft missile homing onto a moveable target was studied. Some chosen results of the simulation research were presented graphically.*

Keywords: Gyroscope system, Sliding controller, Missile.

1. Introduction

The process of homing a surface-to-air missile consists mainly in determining the line of sight (LOS) – a straight line positioned from the homing head to the target (Dziopa et al., 2015 and Grzyb, 2016). The gyroscope system (GS), i.e. a controlled gyroscope on the Cardan joint, is a drive element of the head. In the moment when the gyroscope system axis overlaps with the line of sight, it is assumed that the missile tracks and follows the target. The sensors measure the angle between the line of sight and the missile axis and transfer it to the autopilot. Regardless of the above, the autopilot measures with its own devices the angular position of the missile axis in relation to the Earth, and subsequently, determines control signals and transfers them to the executive control system. Precision of missile homing depends mainly on correct determination of the current angle between the gyroscope axis and the line of sight. The system of automatic gyroscope control should ensure automatic minimization of that angle, and thus, constant directing of the gyroscope system axis towards the line of sight, i.e. tracking the target by the head (Krzysztofik, 2014).

The errors of the gyroscope system are caused mainly by the friction to be found in the bearings and the fact that the rotor mass centre does not overlap with the intersection point of the suspension frame axis. That is why, the gyroscope system reacts to angular motions and changes of the linear velocity of the missile. Especially great changes of parameters are to be found at the initial stage of homing. The line of sight might be then determined incorrectly, on the basis of which the missile is directed to the target. With too excessive deviations of the line of sight from the set position, the sight of the target image might be lost (Gapinski, 2014a).

Therefore, in order to minimize the influence of all disruptions coming from the missile (basis of the gyroscope system) on the accuracy of the motion of the gyroscope system axis, the parameters of the control system should be selected carefully (Gapiński, 2014b and Koruba, 2013). The scope of research conducted should entail formulation of a proper physical and mathematical model as it was presented in (Blasiak et al., 2014; Koruba, 2010; Laski et al., 2015 and Takosoglu, 2016).

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This paper includes an analysis of the dynamics of the gyroscope system with the use of a sliding controller. A mathematical model of motion of non-linear gyroscope system described in a detailed way in (Koruba et al., 2010) was adopted for considerations. A PD controller with optimal parameters chosen with the use of a modified method of optimization by Gołubiencew was applied to control the gyroscope system in this paper.

2. Sliding control for the gyroscope system during missile homing onto a moveable target

For the gyroscope system in question, two sliding surfaces are defined (Utkin, 2008 and Wang, 2011):

$$s_{g1} = \dot{e}_{\vartheta} + \lambda_1 e_{\vartheta} \tag{1a}$$

$$s_{g2} = \dot{e}_{\psi} + \lambda_2 e_{\psi} \tag{1b}$$

where:

$e_{\vartheta} = \vartheta_g - \varepsilon$; $e_{\psi} = \psi_g - \sigma$ – control errors;

$\dot{e}_{\vartheta} = \dot{\vartheta}_g - \dot{\varepsilon}$; $\dot{e}_{\psi} = \dot{\psi}_g - \dot{\sigma}$ – change of errors;

λ_1, λ_2 – positive constant;

ϑ_g, ψ_g – angles determining the position of the gyroscope system axis in space;

ε, σ – angles determining the position of the line of sight in space.

Sliding controls are derived from the following equations:

$$M_b = -K_1 \operatorname{sgn}(s_{g1}) + M_{beq} \tag{2a}$$

$$M_c = -K_2 \operatorname{sgn}(s_{g2}) + M_{ceq} \tag{2b}$$

where:

M_{beq}, M_{ceq} – equivalent controls;

K_1, K_2 – sliding reinforcements.

Equivalent controls are determined by comparing the derivative of the control surface to zero, i.e. $\dot{s}_{g1} = 0$ and $\dot{s}_{g2} = 0$.

Signum function is defined in the following way:

$$\operatorname{sgn}(s_{g1,2}) = \begin{cases} -1 & \text{for } s_{g1,2} < 0 \\ 0 & \text{for } s_{g1,2} = 0 \\ +1 & \text{for } s_{g1,2} > 0 \end{cases} \tag{3}$$

In order to reduce the phenomenon of the so called *chattering*, instead of *signum* function, *saturation* is applied (Lee, 2007 and Shtessel et al., 2013):

$$M_b = -K_1 \operatorname{sat}(s_{g1} / \phi) + M_{beq} \tag{4a}$$

$$M_c = -K_2 \operatorname{sat}(s_{g2} / \phi) + M_{ceq} \tag{4b}$$

where :

ϕ – thickness of the border layer.

3. Simulation research

Simulation research of the dynamics of the gyroscope system during missile homing onto a moveable target was conducted in Matlab/Simulink environment.

The real and set flight path of the missile and the target was shown in Fig. 1. Figs. 2 - 6 present the results of the simulation of the missile and GS dynamics during homing onto a moveable target.

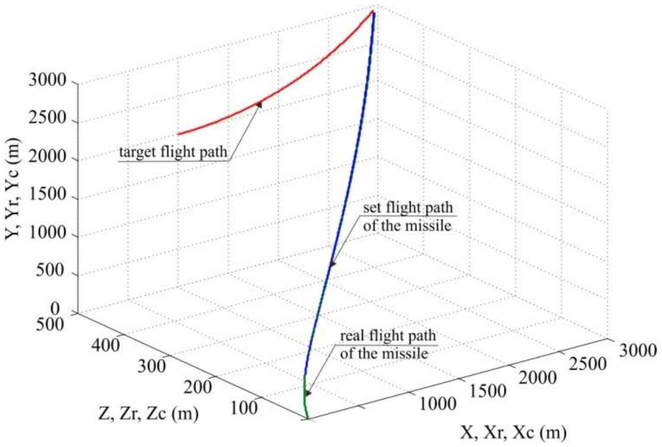

Fig. 1: The real and set flight path of the missile and the target.

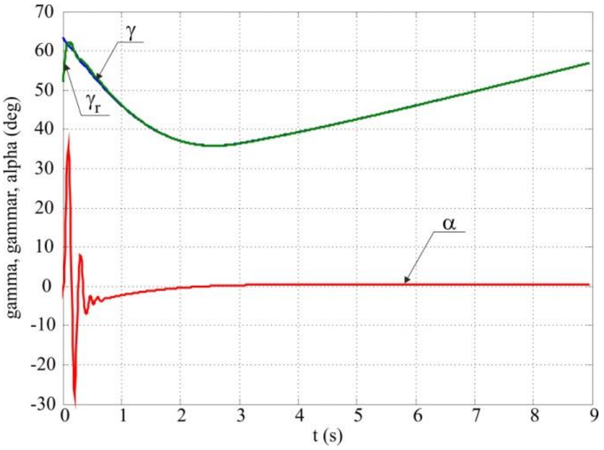

Fig. 2: The real γ_r and set γ flight angles of missile and angle of attack α.

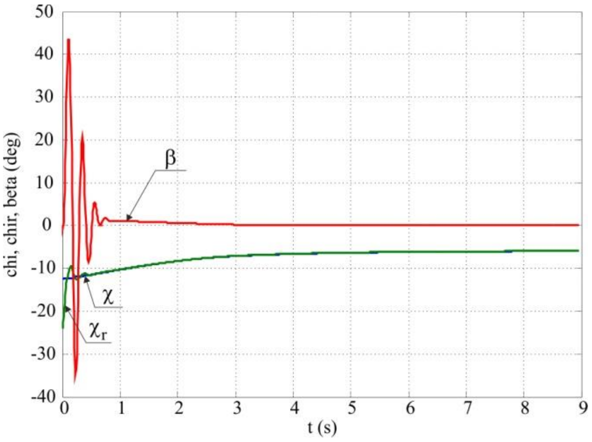

Fig. 3: The real χ_r and set χ flight angles of missile and sideslip angle β.

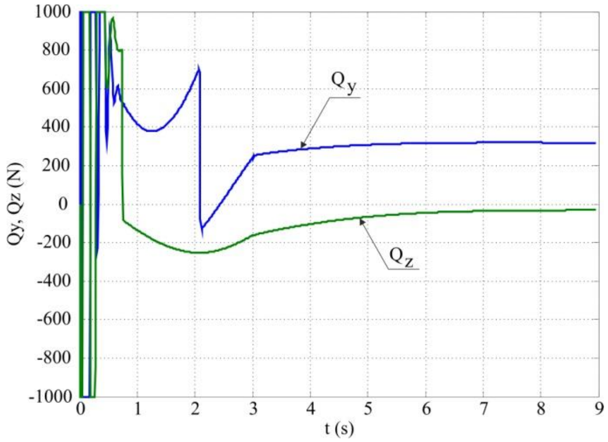

Fig. 4: Forces controlling the missile flight.

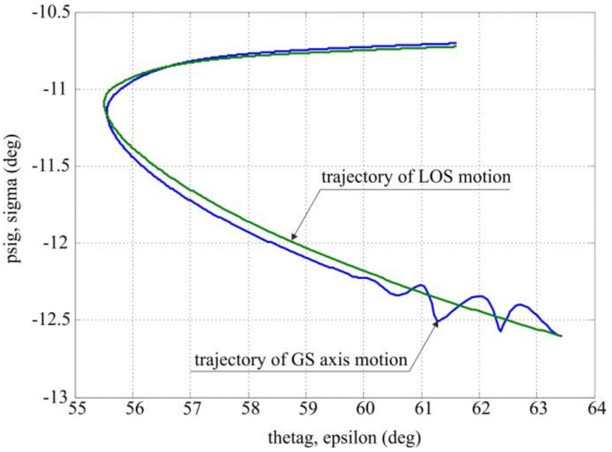

Fig. 5: The trajectories of motion of GS axis and LOS with the use of a PD controller.

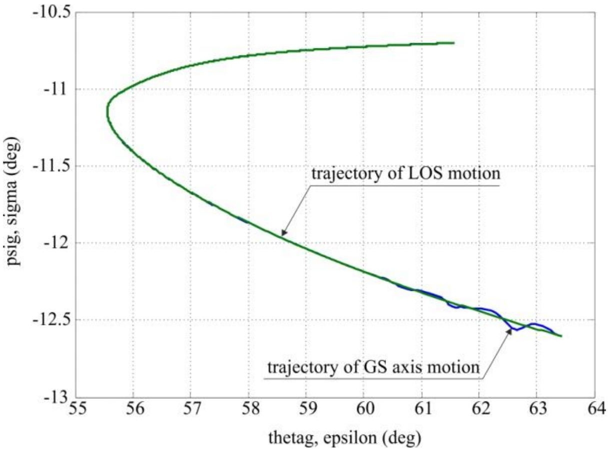

Fig. 6: The trajectories of motion of GS axis and LOS with the use of a sliding controller.

The missile flight was controlled with the use of a PID controller, however, to control the gyroscope system – a PD controller described in a detailed way in (Koruba et al., 2010) and a designed sliding controller were applied. The parameters of the motion of the missile, target and gyroscope system were the same as in the case of papers. As a result of simulation research conducted, the following parameters of a sliding controller were selected: $\lambda_1 = 75$, $K_1 = 15$, $\lambda_2 = 150$, $K_2 = 15$, $\phi = 1$. The studies were conducted with an integration step amounting to $dt = 0.00001$ (Baranowski, 2013).

4. Conclusions

The results of the numerical studies showed great efficiency of the sliding control for the gyroscope system of the anti-aircraft missile. A significant improvement of the operation accuracy of the gyroscope system operation might be easily noticed in the case of application of the sliding controller (Figs. 5 and 6).

The selected sliding controller allows stable and continuous maintenance of the target in the field of sight vision of the homing head. It minimizes the deviation of the gyroscope system axis as a result of the kinematic influence of the missile onto the suspension of the gyroscope system.

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