23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, the Czech Republic, 15 – 18 May, 2017

THE CONTROL PROCESS OF A SCANNING AND TRACKING IR SEEKER USING INVERSE DYNAMICS

D. Gapiński[*], P. Szmidt[**]

Abstract: *The paper presents a control method of a designed detecting and tracking head for seeking short-range missiles. The problem of inverse dynamics in relation to different types of external interferences was used to control an optical axis of the seeker head. The research includes an analysis of impact of the mentioned interferences on accuracy of head axis control, shapes of its spatial displacements trajectories and values of generated control torques. Numerical simulations were performed using special software written in C++ and results of some research were presented graphically.*

Keywords: IR seeker, Dynamics, Homing, Control.

1. Introduction

The subject of the research is an optical detecting and tracking head (Gapiński, 2008) for seeking, anti-aircraft, homing missiles. The main task of the device is detecting and tracking air targets that emit infrared radiation (aircraft, helicopters, etc.). The paper presents control procedures for the abovementioned device by using, so-called, the inverse dynamics problem and, at the same time, considering the impact of interferences resulted from angular displacements of a missile launcher.

2. Interferences model

Despite of the fact that the interferences resulted from movements of a missile launcher are impossible to predict and have random character, there is a possibility of modelling this type of phenomenon to reflect natural phenomenon in a sufficient way (Stefański, 2012). The above research study presents one of the analysed types of interferences that impacts on the detecting and tracking head and comes from angular displacements of a missile launcher held by a shooter (an anti-aircraft shooter).

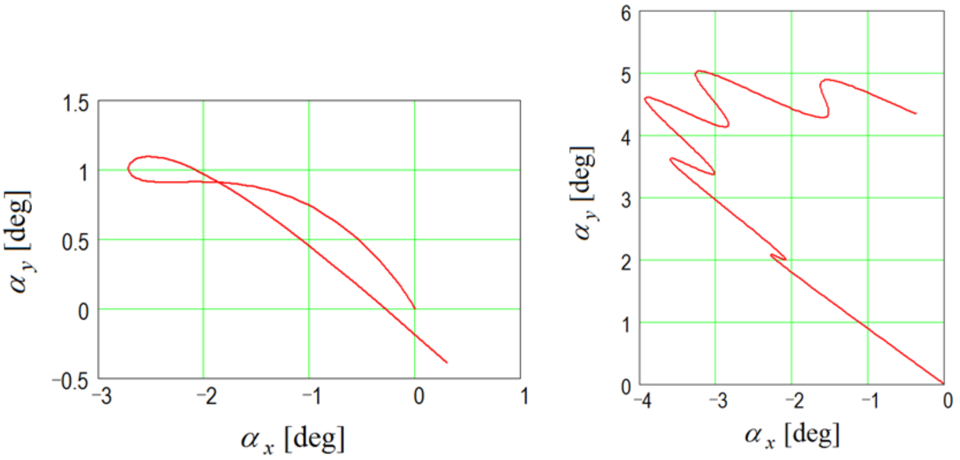

Fig. 1: Examples of axis angular movements simulations of a missile in a missile launcher.

---

[*] Research Assistant Daniel Gapiński, PhD. Eng.: Faculty of Mechatronics and Mechanical Engineering, Kielce University of Technology, al. 1000-lecia P.P. 7; 25-345, Kielce; PL, dgapinski@tu.kielce.pl

[**] PhD. student Piotr Szmidt, M.Sc. Eng.: Faculty of Mechatronics and Mechanical Engineering, Kielce University of Technology, al. 1000-lecia P.P. 7; 25-345, Kielce; PL, petersz@wp.pl

To prepare mathematical description of the interference phenomenon which consists of the abovementioned angular displacements of a missile launcher, the basic mathematical functions like sine or cosine were used in a way that allows for obtaining trajectories of missile launcher axis movements that correspond with real movements when shooting in a battlefield (Dziopa et al., 2015). The movement of a missile axis in a missile launcher was marked using angular displacements: α_x, α_y, represented in a plane perpendicular to a longitudinal axis of a missile (Koruba et al., 2013). Examples of numerical simulations of the above interferences are presented in Fig. 1. The total duration of the tracking air target before start the missile is on average 5 seconds (Gapiński et al., 2016).

3. Analysis of controlling possibilities of a head optical axis

In Fig. 2 there is 3D visualisation of the designed seeker head and a comparison of coordinate systems with equations of motion for its specified elements.

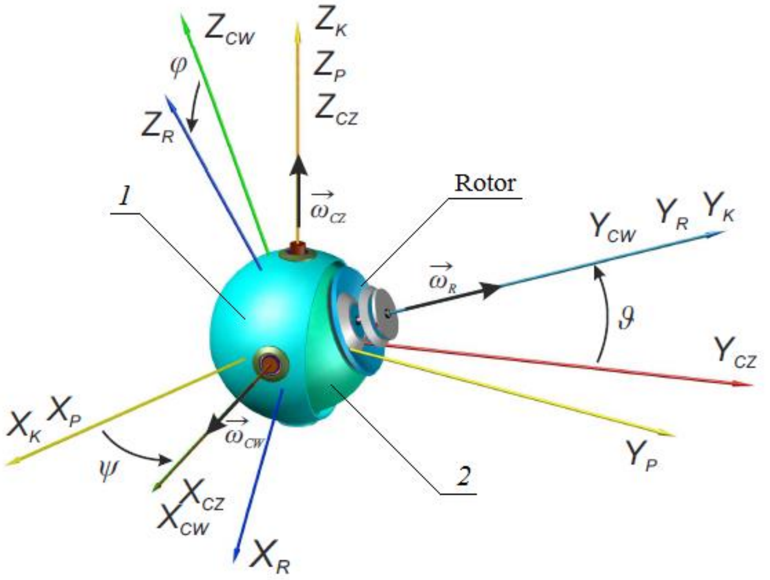

Fig. 2: 3D visualisation of the seeker head with chosen coordinate systems.

The following systems of coordinates were introduced:
$OX_K Y_K Z_K$ – system of coordinates connected with the set direction in space;
$OX_P Y_P Z_P$ – moving coordinate system connected with the missile;
$OX_{CZ} Y_{CZ} Z_{CZ}$ – moving coordinate system connected with the outer housing;
$OX_{CW} Y_{CW} Z_{CW}$ – moving coordinate system connected with the inner housing;
$OX_R Y_R Z_R$ – moving coordinate system connected with the rotor.

The following markings of angles of rotation and the order of measuring them were adopted:
ψ – angle of rotation $OX_{CZ} Y_{CZ} Z_{CZ}$ in relation to $OX_P Y_P Z_P$ around axis Z_{CZ},
ϑ – angle of rotation $OX_{CW} Y_{CW} Z_{CW}$ in relation to $OX_{CZ} Y_{CZ} Z_{CZ}$ around axis X_{CW},
φ – angle of rotation $OX_R Y_R Z_R$ in relation to $OX_{CW} Y_{CW} Z_{CW}$ around axis Y_R,
1, 2 – outer and inner housing made of reinforcement polymer composites (Chatys, 2013).

Controlling by using, so-called, the inverse dynamics problem consists of calculating control torques (Takosoglu, 2016) of specified seeker head caps that cause required axis movements determined by the angles: $\vartheta_z(t)$ and $\psi_z(t)$. So, the inverse dynamics problem allows for programming the changes in time of both angles of a seeker head axis deviation (Krzysztofik et al., 2014). M_Z and M_W control torques are calculated using the correlation:

$$\begin{aligned} M_Z = &\left[J_{z_{CZ}} + J_{z_{CW}} + J_{z_R} + \left(J_{y_{CW}} - J_{z_{CW}} - J_{z_R}\right)\sin^2\vartheta_z\right]\dot{\omega}_{z_{CZ}} + \\ &+\frac{1}{2}\left(J_{y_{CW}} - J_{z_{CW}} - J_{z_R}\right)\sin 2\vartheta_z\left(\omega_{z_{CZ}}\dot{\vartheta}_z + \dot{\omega}_{y_{CZ}}\right) + \\ &-\left[J_{z_{CW}} + J_{z_R} - \left(J_{y_{CW}} - J_{z_{CW}} - J_{z_R}\right)\sin^2\vartheta_z\right]\omega_{y_{CZ}}\dot{\vartheta}_z + \\ &-\left(J_{z_{CW}} + J_{z_R}\right)\omega_{z_{CW}}\omega_{x_{CW}}\sin\vartheta_z - J_{y_{CW}}\omega_{y_{CW}}\omega_{x_{CW}}\cos\vartheta_z + \\ &+ J_{y_R} n\omega_{x_{CW}}\cos\vartheta_z - \left(J_{x_{CZ}} - J_{y_{CZ}}\right)\omega_{x_{CZ}}\omega_{y_{CZ}} + \\ &-\left(J_{x_{CW}} + J_{x_R}\right)\omega_{x_{CW}}\omega_{y_{CZ}} + c_z\dot{\psi}_z \end{aligned} \tag{1}$$

$$\begin{aligned} M_W = &\left(J_{x_{CW}} + J_{x_R}\right)\ddot{\vartheta}_z + \left(J_{x_{CW}} + J_{x_R}\right)\dot{\omega}_{x_{CZ}} + \\ &-\left(J_{y_{CW}} - J_{z_{CW}} - J_{z_R}\right)\omega_{y_{CW}}\omega_{z_{CW}} - J_{y_R} n\omega_{z_{CW}} + c_w\dot{\vartheta}_z \end{aligned} \tag{2}$$

where:

$$\omega_{x_{CZ}} = \omega_{x_P}\cos\psi + \omega_{y_P}\sin\psi\ ,$$

$$\omega_{y_{CZ}} = -\omega_{x_P}\sin\psi + \omega_{y_P}\cos\psi\ ,$$

$$\omega_{z_{CZ}} = \dot{\psi} + \omega_{z_P}\ ,$$

$$\omega_{x_{CW}} = \omega_{x_{CZ}} + \dot{\vartheta}\ ,$$

$$\omega_{y_{CW}} = \omega_{y_{CZ}}\cos\vartheta + \omega_{z_{CZ}}\sin\vartheta\ ,$$

$$\omega_{z_{CW}} = -\omega_{y_{CZ}}\sin\vartheta + \omega_{z_{CZ}}\cos\vartheta\ .$$

As given quantities the following were adopted:
$J_{x_{CZ}}, J_{y_{CZ}}, J_{z_{CZ}}$ – moments of inertia of the complete outer housing;
$J_{x_{CW}}, J_{y_{CW}}, J_{z_{CW}}$ – moments of inertia of the complete inner housing;
$J_{x_R}, J_{y_R}, J_{z_R}$ – moments of inertia of the rotor;
$\vec{\omega}_P\left(\omega_{x_P}, \omega_{y_P}, \omega_{z_P}\right)$ – missile angular velocity;
M_Z – moment of missile forces interacting on the outer housing;
M_W – moment of forces of the outer housing interacting on the inner housing;
M_R – moment of forces of the inner housing interacting on the rotor;
M_{TR} – moment of friction forces in rotor bearings and aerodynamic resistance;
M_{TW}, M_{TZ} – moments of friction forces in the bearings of respectively: inner and outer housing, provided that $M_{TW} = c_w\dot{\vartheta},\ M_{TZ} = c_z\dot{\psi}$,

where:
c_w – friction coefficient in the bearing of the inner housing,
c_z – friction coefficient in the bearing of outer housing.

The law of scanning the air space by the optoelectronic system of the device was presented in (Gapiński, 2008) and we will write it in the following way:

$$\beta_x(t) = arctg(tg(\beta(t))\cdot\cos\left(\arcsin\left(\frac{z_{zp}(t)}{\sqrt{x_{zp}(t)^2 + z_{zp}(t)^2}}\right)\right) \tag{3}$$

$$\beta_z(t) = arctg(tg(\beta(t))\cdot\sin\left(\arcsin\left(\frac{z_{zp}(t)}{\sqrt{x_{zp}(t)^2 + z_{zp}(t)^2}}\right)\right) \tag{4}$$

where:
$\beta_X(t),\ \beta_Z(t)$ – angular coordinates of the detected target in relation to the scanning seeker axis,
$\beta(t)$ – the resultant angle of deflection of a light beam from the optical axis,
$x_{zp},\ z_{zp}$ – components of the location of a light beam on the surface of the primary mirror,

x_c, z_c – components of the location of a target on the surface of the scanning plane,
x_s, z_s – components of the location of a light beam on the surface of the scanning plane.

Controlling the seeker head axis was evaluated, among others, by programming it for searching the airspace, first on the cone plane, and, after scanning the whole chosen space, searching the airspace along a developing spiral. A computer simulation of airspace searching with chosen trajectories and tracking a manoeuvring air target (moving with the speed of 200 m/s) are presented in Fig. 3. The target trajectory is described by the equation described in (Koruba et al., 2010) Fig. 4.

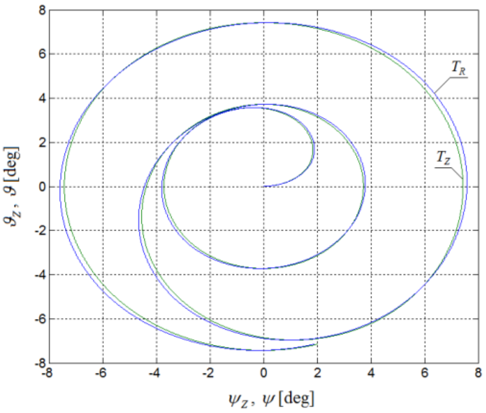

Fig. 3: The trajectory of T_Z set and actual T_R movement of the seeker head axis.

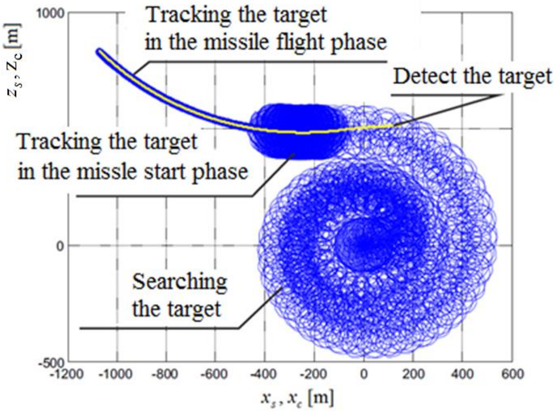

Fig. 4: Target searching, detecting and tracking.

4. Conclusions

The results of the computer simulations presented in the paper show that, despite of the impact of different external interferences, the tested seeker head can track detected targets very precisely. Controlling the seeker head axis by using the inverse dynamics is performed with precision appropriate for homing. The non-linearity of equations (1, 2) of the mathematical model should be considered because it is caused, among others, by unspecified parameters of external forces. Considering the non-linearity of the system, all calculations should be performed in, so-called, real-time in relation to current measurements from all sensors – obviously, it will force using additional numeric processors for calculating.

References

Chatys, R. (2013) Investigation of the Effect of Distribution of the Static Strength on the Fatigue Failure of a Layered Composite by Using the Markov Chains Theory. Mechanics of Composite Materials, 48, 6, pp. 629-638.

Dziopa, Z., Buda, P., Nyckowski, M. and Pawlikowski, R. (2015) Dynamics of an unguided missiles launcher. Journal of Theoretical and Applied Mechanics. No. 1, Vol. 53, pp. 69-80.

Gapiński, D. and Koruba, Z. (2016) Analysis of reachability areas of a manoeuvring air target by a modified maritime missile-artillery system ZU-23-2MRE. Dynamical Systems: Theoretical and Experimental Analysis, Springer Proceedings in Mathematics & Statistics, Vol. 182, pp. 125-144.

Gapiński, D, (2008) Optical scanning seeker, Patent PL 199721 B1 (in Polish).

Koruba, Z. and Krzysztofik, I. (2013) An algorithm for selecting optimal controls to determine the estimators of the coefficients of a mathematical model for the dynamics of a self-propelled anti-aircraft missile system. Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics, 227, 1, pp. 12-16.

Koruba, Z. and Ładyżyńska-Kozdraś, E. (2010) The dynamic model of a combat target homing system of an unmanned aerial vehicle. Journal of Theoretical and Applied Mechanics, 48, 3, pp. 551-566.

Krzysztofik, I. and Koruba, Z. (2014) Mathematical Model of Movement of the Observation and Tracking Head of an Unmanned Aerial Vehicle Performing Ground Target Search and Tracking. Journal of Applied Mathematics, 2014, Article ID 934250, 11 p.

Stefanski, K. and Koruba, Z. (2012) Analysis of the guiding of bombs on ground targets using a gyroscope system. Journal of Theoretical and Applied Mechanics, 50, 4, pp. 967-973.

Takosoglu, J.E. (2016) Control system of delta manipulator with pneumatic artificial muscles, in: Proc. 22th Int. Conf. Eng. Mech. 2016 (eds. Zolotarev, I. and Radolf, V.), Svratka, Czech Republic, pp. 546-549.