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THE ANALYSIS OF SELECTION OPTIMAL PARAMETERS OF PID CONTROLLERS FOR A MODIFIED ARTILLERY-MISSILE SYSTEM

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Abstract: *The paper presents a numerical selection method for PID controller gains used for controlling cannons azimuth and elevation angles in the modified artillery and missile system named ''Wróbel II". The selection of parameters was carried out with a method of numerical optimisation and some of the research results were presented graphically.*

Keywords: Controlling, PID controller, Optimisation.

1. Introduction

Manual tracking of a manoeuvring air target may be inaccurate in some cases. Inaccuration may be caused by many factors including, among others, a complicated trajectory and high speeds of a target, stress caused by the aggressor's attack and bad weather conditions during military operations. Considering that fact, it is very favourable to replace human work with automatic control systems which, on the basis of signals from a head or seeker heads (Gapiński et al., 2016), render programmed angular positions over time. In these systems, control algorithms are very important – they are responsible for efficient use of electromechanical drive units (Koruba et al., 2013 and Grzyb et al., 2016).

2. The system model

3D system model designed in SolidWorks is presented in Fig. 1. Basing of used construction materials it is possible to calculate masses and inertia moments of specified elements. The scheme of the system model is presented in Fig. 2.

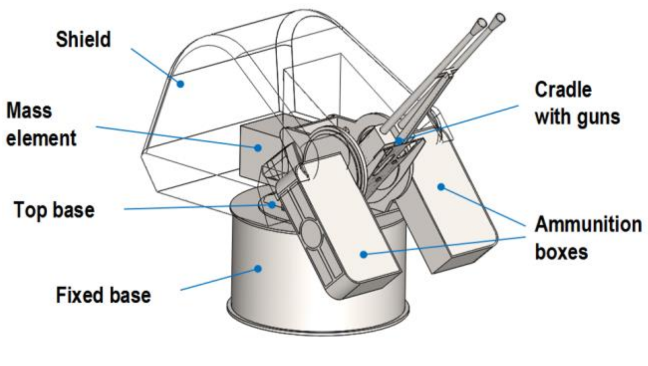

Fig. 1: 3D model of the presented artillery and missile system.

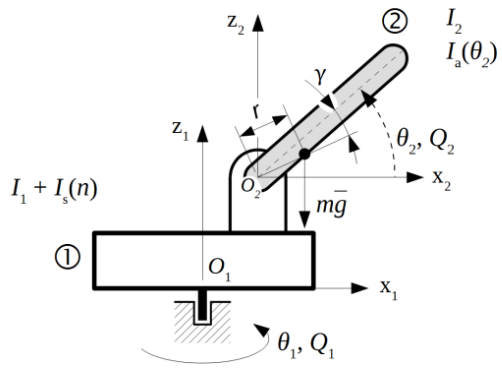

Fig. 2: The scheme of the system physical model.

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Designations presented in Fig. 2:

θ_1– azimuth angle (angle of system rotation),
θ_2– elevation angle (lifting),
$Q_i = M_i - T_i$ – generalised torque impacting on *i*-th element,
M_i – control torque (drive) impacting on *i*-th element,
T_i – friction torque impacting on *i*-th element,
I_1 – constant mass inertia moment of 1 element in relation to z_1 axis,
$I_s(n)$ – variable mass inertia moment of 1 element in relation to z_1 axis depending on a number of cartridges in *n* boxes,
I_2 – constant mass inertia moment of 2nd element in relation to y_2 axis,
$I_a(\theta_2)$ – variable mass inertia moment of 2nd element in relation to z_1 axis depending on elevation angle,
m – mass of 2nd element,
g – gravitational acceleration,
r – distance from the centre of gravity of 2nd element in relation to y_2 rotation axis,
γ – angular displacement of the centre of gravity of 2 nd element in relation to an axis of a gun barrel.

The Lagrange II equations were used to generate equations of the system motion. After calculating the Lagrangean and derivatives, (1) and (2) equations of generalised torques – Q_1 and Q_2 – were created.

$$\left(3a\theta_2^2 + 2b\theta_2 + c\right)\dot{\theta}_1\dot{\theta}_2 + \left(I_1 + pn + q + a\theta_2^3 + b\theta_2^2 + c\theta_2 + d\right)\ddot{\theta}_1 = Q_1 \quad (1)$$

$$I_2\ddot{\theta}_2 - \frac{1}{2}\left(3a\theta_2^2 + 2b\theta_2 + c\right)\dot{\theta}_1^2 + mgr\cos(\theta_2 + \gamma) = Q_2, \quad (2)$$

where: *a*, *b*, *c*, *d* – coefficients of polynomial describing the change of the inertia moment I_a in an angle function of θ_2; *p* – number of cartridges in boxes; *n* – coefficient depending on a cartridge mass.

Generalised torque Q_i impacting on *i*-th element consists of the driving torque M_i reduced by the friction torque T_i generated by movements in the element.

$$Q_i = M_i - T_i \quad (3)$$

The friction torque includes T_{i0} component which depends on velocity and T_{i1} component depending on load and impacting only during element movements (Ioannides and Guillermo, 2012).

$$T_i = T_{i0} + T_{i1} \quad (4)$$

$$T_{i0} = f_0 \cdot 10^{-7} \cdot (v \cdot n)^{2/3} d_i^3 \quad (5)$$

$$T_{i1} = u_1 \cdot f_1 \cdot P_{i0} \cdot \frac{d_i}{2}, \quad (6)$$

where: f_0, f_1, u_1 – coefficients depending on bearings types; v – lubricant viscosity, mm^2/s; *n* – rotational speed, rot/min; d_i – bearing pitch diameter, mm; P_{i0} – loading force, N

3. The control system structure

The adopted control system structure of angular positions of the system elements is presented in Fig. 3. The structures of the azimuth control system and the elevation control system are identical, so, as the example, the azimuth control system will be explained. The central element of the system is PID controller in a parallel, so-called, independent form.

$$u(t) = K_P e(t) + K_I \int e(t)dt + K_D \frac{d\,e(t)}{dt}, \quad (7)$$

where: K_P, K_I, K_D – continuous gain coefficients of proportional, integral and derivative terms, *e*(*t*) – position error; *u*(*t*) – control signal (an output of a controller) (Dębowski, 2008).

The control error *e*(*t*) is the difference between the desired signal of an angular position – $\theta_{1\,zad}$ and position θ_1 detected by a displacement sensor (Stefański et al., 2014). On the basis of the error, the controller creates the control signal $u(t)$ which is sent to the driver of the azimuth control system. The model of the drive system consists of *Rate limiter* block that is responsible for limiting torque acceleration to real values (100 N.m/s were considered), then the saturation block (maximal torque ±20 N.m for the considered motors) and a mechanical transmission designed for increasing torque on the motor shaft. Then signal gets into *Backlash* block causing the non-linearity in a form of backlash (0.05 °). The driving torque M_1 drives the first element of the system responsible for azimuth rotation (Dziopa et al., 2012). In *The system model* block the previously presented system model was implemented. The output of the model is an angular position θ_1. Next, the measurement is distorted with a white noise with an amplitude of ±0.01 ° (i.e. quantisation noise from sensor).

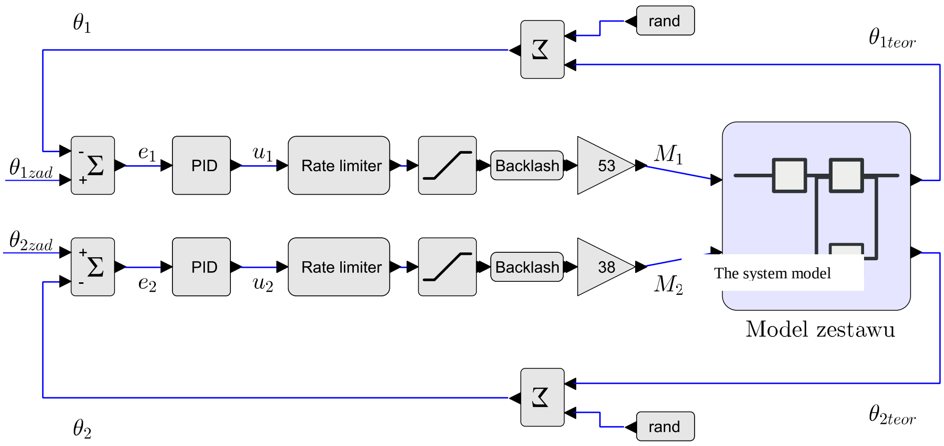

Fig. 3: General structure of the control system.

4. Controller optimal parameters selection

Considering optimal adjustment some criterion was adopted. The integral of absolute error (IAE) was chosen because this index does not decrease small errors like, e.g. the integral of the squared error (ISE), which would not be favourable in accurately controlling. The procedure of optimal parameters selection used Nelder-Mead algorithm (Stachurski, 2009) in iterative simulation of the controlling system impacted by forces by using. The minimised objective function was a performance index and decision variables were PID controller gains (parameters): K_P, K_I, K_D (Takosoglu, 2016). Optimisation was performed subsequently for the controller of element 1 and next, for the controller of element 2. Values of the performance indexes in subsequent iterations of optimisation are presented in Fig. 4.

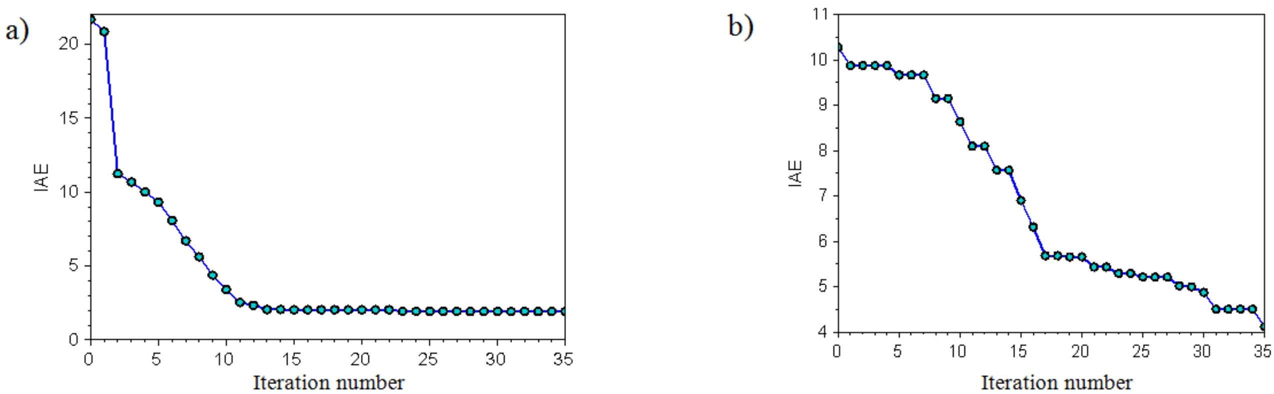

Fig. 4: Values changes of a quality index during optimisation process a) for the controller of 1 element position (azimuth), b) for the controller of 2 element position (elevation).

5. The simulation of the system movement by using optimal parameters

The obtained gain coefficients for the controller of element 1 were: K_{P1} = 9.81; K_{I1} = 0; K_{D1} = 3.31 and for the controller of element 2 were: K_{P2} = 9.23; K_{I2} = 4.16; K_{D2} = 1.31. Simulations of the system movements were compared to the desired signals in Fig. 5. The desired signals kept limits provided for the real system, i.e. for both elements the maximal angular acceleration did not exceed 1.05 rad/s^2 (60 deg/s^2) and maximal speed was not higher than 1.31 rad/s (75 deg/s) for azimuth rotation and 1.05 rad/s (60 deg/s) for an elevation movement. Driving torques for specified elements are presented in Fig. 6.

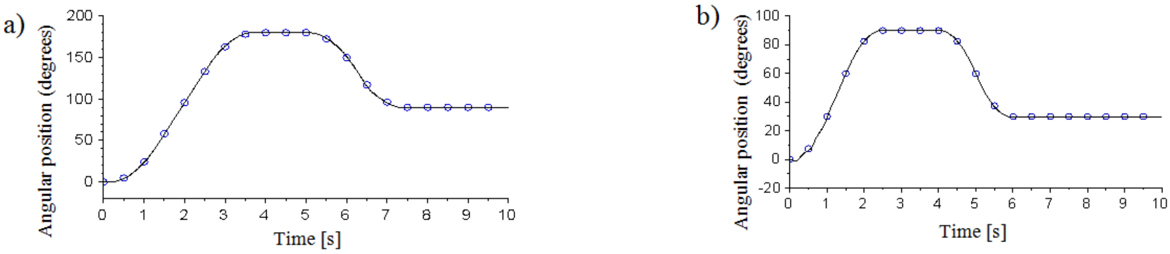

Fig. 5: Comparison of changes in desired processes ○ and processes performed ▬ by a) element 1 (azimuth), b) element 2 (elevation).

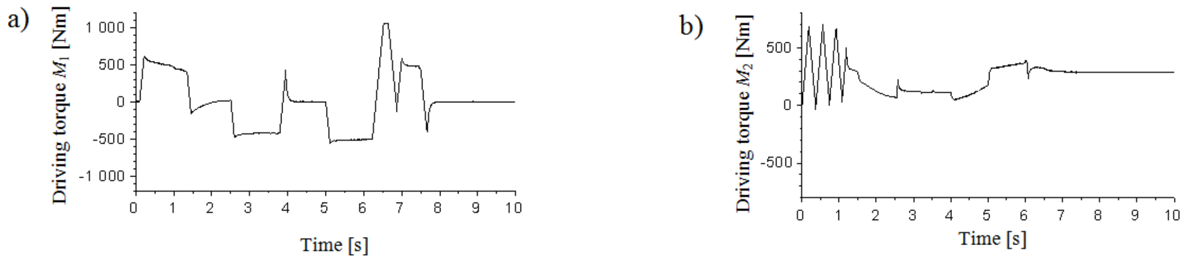

Fig. 6: Changes of driving torques of programmed movements for a) element 1, b) element 2.

6. Conclusions

It was ascertained that after adopting the quality and optimization criterion for controllers gain coefficients, the determined numerical parameters of controllers will allow for correct and efficient controlling both azimuth and elevation positions. The steady-state error for azimuth did not exceed 0.02 °. For elevation the steady-state error was 0.07 °. At the same time, it should be considered that there were backlash and noise modelled in the system. It can be stated, that tracking for desired angles is satisfactory. A further step in the work will be examination of the stability of the system for a variety of desired signals and control system robustness to change system parameters, including the variable weight of the ammunition boxes or growth moments of friction.

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