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THE IMPACT OF ATMOSPHERE TURBULENCE ON GUIDANCE PARAMETERS IN THE TRACKING COORDINATOR

Reviewer: František RACEK

A b s t r a c t :

The turbulence of the atmosphere can to change the size and shape of the image target, to bring about fluctuation of the amplitude of radiation impact on modulator or photodetector, to bring about random change of position of the aim and hereby to cause random error in aiming of target and in measurement angle position of the target, possibly angular velocity, and to influence range of coordinator. The impact of the real atmosphere on output signal of optoelectronic tracking coordinator is analysed in this article.

1. Introduction

At homing rockets VSHORAD and SHORAD the optoelectronic (OE) tracking coordinators (TC) with one-gyroscope tracking actuating mechanism are use the most [1] that is movably place on the board of a homing racket. The position of the optic axis of coordinator is controlled to follow the target all the time. It is allow to get necessary parameters for realization of guidance method used (aiming angle and angular velocity of target). Function chart of the OE TC with gyroscope tracking actuating mechanism for the vertical plane is in the Figure 1.

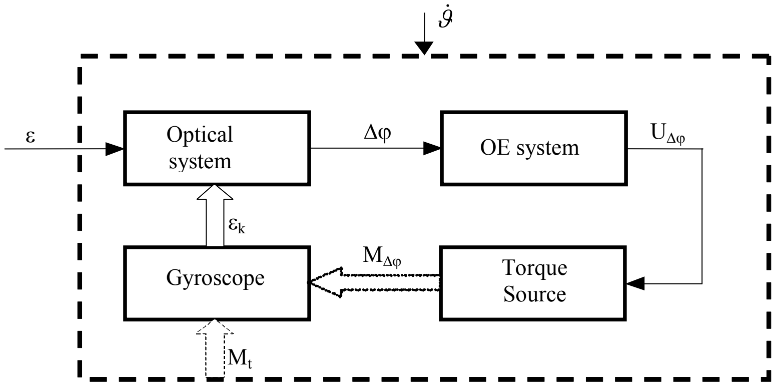

Figure 1 – Function chart of the OE TC with gyroscope for the vertical plane

The measurement of desired parameters is based on the detection optic radiation to propagate in the atmosphere from interest target to OE TC. The atmosphere has an unnegligible impact on propagated radiation (Figure 2). In ideal atmosphere conditions the effect of attenuation (absorption, scattering) and turbulence on quality of image does not assume. Tasks of range of the OE TCs are solved only according to geometrical formulas (Johnson criterion). The effect of attenuation and turbulence has to analyse when we research range and accuracy of the measurement of OE TCs in real atmosphere. But according to the need solve task, all three atmosphere optic phenomenon's do not need to solve.

The impact of attenuation and scattering of optic radiation on the resulting image created by optic or OE system expresses especially on intensity decreasing of optic radiation during the propagation in atmosphere and on decreasing of contrast target/background. It decreases range of OE apparatus on the given target. Neither absorption nor scattering causes an angular error of aiming. Besides we are able to compensate a scattering sufficiently during measurement of a distance.

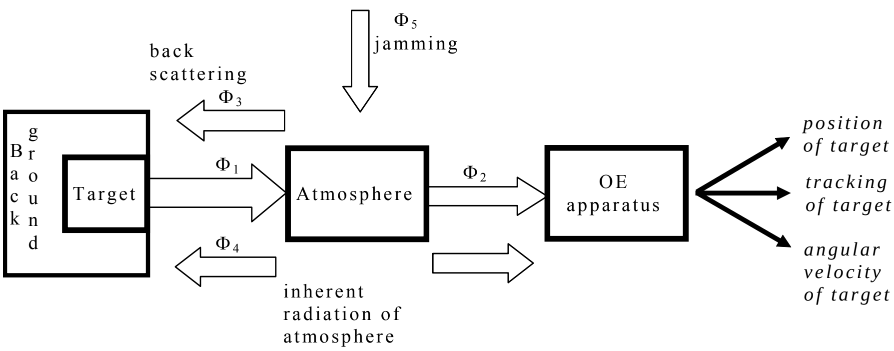

Figure 2 – Chart of radiation in system of target, atmosphere and OE apparatus

Turbulence of atmosphere – chaotic change of refraction index of air can change of dimension and shape of target image, to produced fluctuation of radiation amplitude impact to the modulator or photodetector, to produced random changes of position target image and to cause random error in aiming target and in measurement angular position target, possibly angular velocity, and in the end to influence of range of TC [2, 3].

2. The mathematical model of OE track coordinator

Function chart from Figure 1 is possible to transform into structural chart of OE TC with gyroscope tracking actuating mechanism, in the Figure 3.

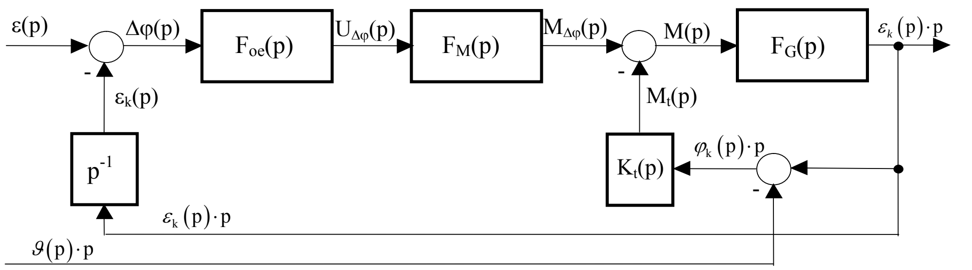

Figure 3 – Structural chart of OE TC with gyroscope for the vertical plane

In structural chart in the Figure 3 represent:

$$F_{oe}(p)=\frac{U_{\Delta\varphi}(p)}{\Delta\varphi(p)}=\frac{K_{oe}}{1+p\cdot T_e}$$ standard transfer function of OE system includes an objective; (1)

$$F_M(p)=\frac{M_{\Delta\varphi}(p)}{U_{\Delta\varphi}(p)}=\frac{K_M}{1+p\cdot T_e}$$ standard transfer function of torque source; (2)

$$F_G(p)=\frac{\varepsilon_k(p)}{M(p)}=\frac{1}{p\cdot L}=\frac{K_G}{p}$$ standard transfer function of free gyroscope; (3)

K_t friction coefficient in bearings of gyroscope.

Input information of TC about angular position (eventually angular velocity) of tracked target is represented by value of position angle ε (eventually angular velocity of change of the aiming line of target $\dot{\varepsilon}$). Goal of control is the optic axis of TC to aim to the target all the time. This situation is possible to describe by term $\varepsilon_k=\varepsilon$, and control deviation $\Delta\varphi = 0\,\text{rad}$ too. Longitudinal vibrations of rocket $\dot{\vartheta}$ are next input quantity ("harmful"), that influence must be eliminated. According to theory of automatic control and too [1], when it is true a condition $K_t \to 0$, for the control deviation of TC (Figure 3) to valid formula

$$\Delta\varphi(p) \doteq \frac{p^2 T_e T_M + p(T_e + T_M) + 1}{p^3 T_e T_M + p^2 (T_e + T_M) + p + K_o} \dot{\varepsilon}(p) = F_{\Delta\varphi,\dot{\varepsilon}}(p) \cdot \dot{\varepsilon}(p), \qquad (4)$$

where: $K_o = K_{oe} \cdot K_M \cdot K_G$ is whole amplification given as product amplification of OE system, source of torque and inverse value of a moment of momentum of the gyroscope; $F_{\Delta\varphi,\dot{\varepsilon}}(p)$ is a transfer function of a control deviation; T_e a T_M are time constants of filter cells of the electronic block and source of torque.

Then for the stabilized value of control deviation is valid

$$\Delta\varphi_{ust} = \lim_{t\to\infty} \Delta\varphi(t) = \lim_{p\to 0}\left[p \cdot \Delta\varphi(p)\right] = \lim_{p\to 0}\left[p \cdot F_{\Delta\varphi,\dot{\varepsilon}}(p) \cdot \frac{\dot{\varepsilon}_o}{p}\right] = \frac{1}{K_o}\dot{\varepsilon}_o \qquad (5)$$

where: $\dot{\varepsilon}_o$ is magnitude of angular velocity jump of a change direction of target aiming line.

From carried out analysis and from terminal formula (5) follow that

- **stabilized value of control deviation $\Delta\varphi$ is proportional to angular velocity of the change of direction of the target aiming line $\dot{\varepsilon}(t)$**;
- TC with a partial transfer functions (1 to 3) behaves as a system with first astatism, i.e. the system has a zero stabilized deviation of position and constant deviation of velocity;
- the using of gyroscope tracking actuating mechanism leads in effective suppression of rocket longitudinal vibrations on operation of TC.

Followed conclusions are convenient for the method of proportional guidance and their modifications that used at homing rocket VSHORAD and SHORAD the most.

3. The simulation function of the OE TC

The conclusions from analysis of TC at chapter 2 are possible to check and enlarge with the help of the simulation model (*SledKoord1.mdl*) in interface Matlab (Figure 4).

For the simulation of function the OE TC of homing rockets VSHORAD and SHORAD have to determine as soon as the following parameters (here for the OE TC system Strela-2M):

- The optic and OE system introduced by transfer function $F_{oe}(p)$;

- gain of optic system K_o. It can be up to 5000. For the simulation we choose $K_o = 100$.
- gain of electronic system K_e. For the simulation we choose $K_e = 100$.
- time constant of electronic system (filter) T_e. The values can move at wide range from hundredth milliseconds up to tenth seconds. We start with formula $T_e = f_r^{-1} = 100^{-1}\ \mathrm{s} = 10\ \mathrm{ms}$.

- The source of torque (i.e. induction coil);

- gain of source of torque $K_M = 0{,}001$.
- time constant of the source of torque T_M. The values of time constant are orders microseconds. We choose value $T_m = 0{,}1\ \mathrm{ms}$.

- The actuating mechanism (one-gyroscope tracking actuating mechanism);

- gain (a moment of momentum) of gyroscope $K_G = L^{-1} = \left(0{,}12\ \mathrm{kg}\cdot\mathrm{m^2 s^{-1}}\right)^{-1} \approx 8{,}33\ \mathrm{kg^{-1} m^{-2} s}$;
- friction coefficient in bearings of gyroscope $K_t = 1\cdot 10^{-3}$.

- The target;

- angular velocity of target. The maximum angular velocity of tracking is $12^\circ \mathrm{s^{-1}} \approx 0{,}2\ \mathrm{rad}\cdot\mathrm{s^{-1}}$. We choose for software model $\dot{\varepsilon}(t) = 0{,}2\ \mathrm{rad}\cdot\mathrm{s^{-1}}$.

- The longitudinal vibrations of rocket;

- frequency range $(600 \div 1200)\ \mathrm{min^{-1}}$, we choose $f_r = 900\ \mathrm{min^{-1}} = 15\ \mathrm{s^{-1}}$, i.e. $\omega_r = 94{,}5\ \mathrm{s^{-1}}$,
- amplitude of vibrations range $0{,}01\ \mathrm{rad} \div 0{,}2\ \mathrm{rad}$.

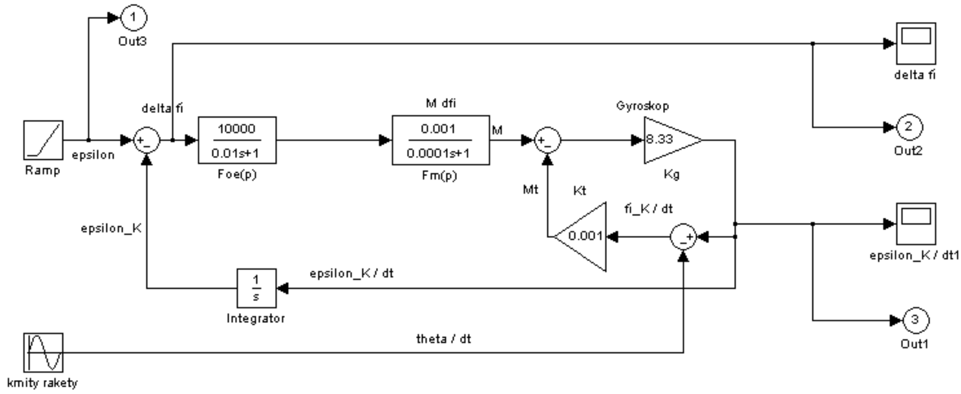

Figure 4 – Chart of simulation model OE TC with gyroscope at interface MATLAB – Simulink (*SledKoord1.mdl*)

The results of simulation of function the OE TC, i.e. courses of signals into model *SledKoord1.mdl* (Figure 4), are showed for time range $(0 \div 1)$ s and above mentioned parameters and for two characteristic cases (idealized and real situation) in diagrams in the Figure 5a and 5b.

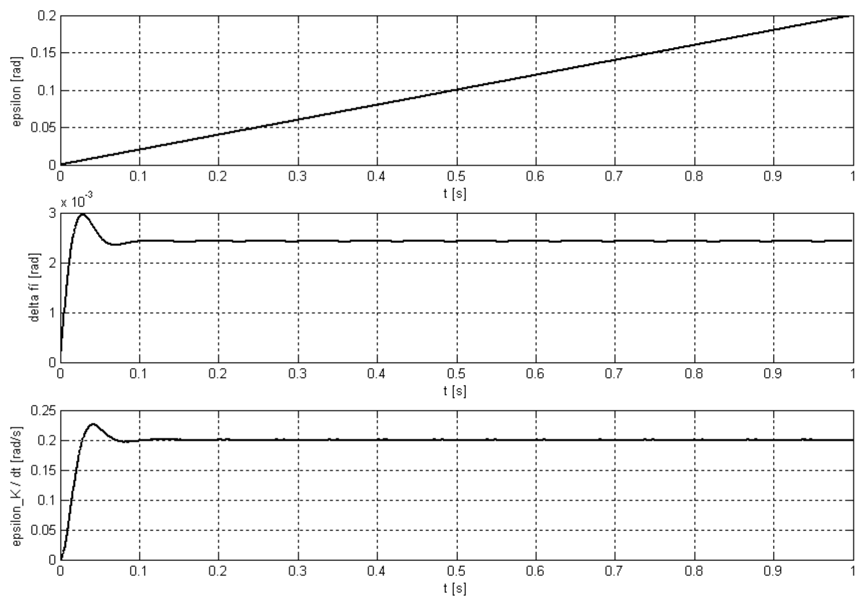

Figure 5a – Signals for the amplitude vibrations $A(\dot{\vartheta}) << 0{,}1$ rad and $K_t \to 0$

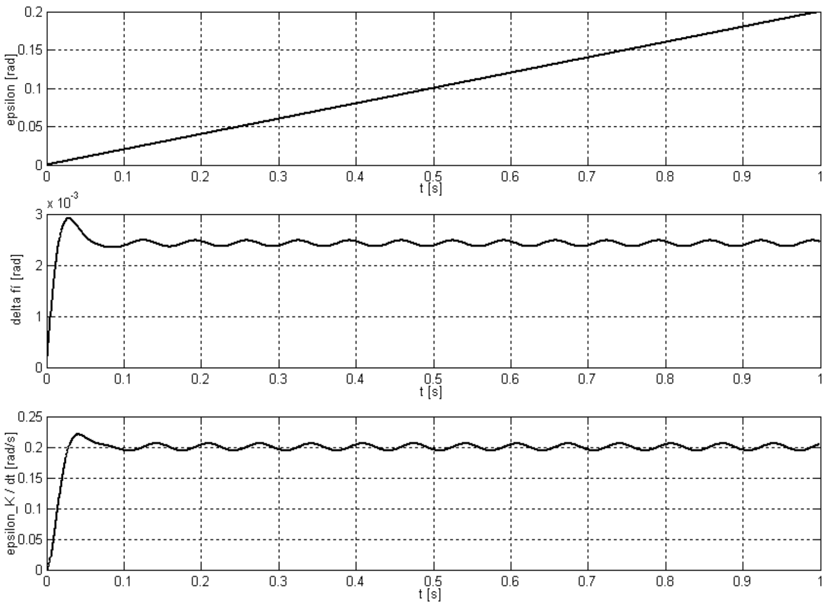

Figure 5b – Signals for the amplitude vibrations $A\left(\dot{\vartheta}\right) \geq 0{,}1\ \mathrm{rad}$ and $K_t \to 0$

From diagrams in the Fig. 5a follow, if the target moves constant angular velocity $\dot{\varepsilon}\left(t\right) = konst$ (i.e. $\varepsilon\left(t\right) = k \cdot t$) at vertical plane and if friction coefficient in bearings is minimal ($K_t \to 0$), and at the same time amplitude of the longitudinal vibrations $A\left(\dot{\vartheta}\right) << 0{,}1 rad$, so courses of signals correspond to theoretical assumptions. From the last diagram in the Fig. 5a can read value $\dot{\varepsilon}_k\left(t > 0{,}1\ \mathrm{s}\right) \approx 0{,}2\ \mathrm{rad} \cdot \mathrm{s}^{-1} = \mathrm{konst.}$, that correspond chosen input value $\dot{\varepsilon}\left(t\right) = 0{,}2\ \mathrm{rad} \cdot \mathrm{s}^{-1}$.

So that to be valid $\dot{\varepsilon}_k\left(t > 0{,}1\ \mathrm{s}\right) = \dot{\varepsilon}\left(t\right)$. Next to see, $\dot{\varepsilon}_k\left(t\right) = \Delta\varphi\left(t\right) \cdot k$, and thus control deviation $\Delta\varphi\left(t > 0{,}1\ \mathrm{s}\right)$ is possible to use for measurement of value $\dot{\varepsilon}\left(t\right)$, or to be valid $\dot{\varepsilon}\left(t > 0{,}1\ \mathrm{s}\right) = \Delta\varphi\left(t\right) \cdot k$.

If conditions are fulfilled from point 1, except value of amplitude of the longitudinal vibrations of rocket, that is $A\left(\dot{\vartheta}\right) \geq 0{,}1\ \mathrm{rad}$, then courses of signals are showed on the Fig. 5b. It knows that $\dot{\varepsilon}_k\left(t > 0{,}1\ \mathrm{s}\right) \neq \mathrm{konst.}$, but values vary. Course of $\dot{\varepsilon}_k\left(t > 0{,}1\ \mathrm{s}\right)$ can approximately express by formula

$$\dot{\varepsilon}_k\left(t > 0{,}1\ \mathrm{s}\right) = \dot{\varepsilon}_{k\_konst} + \dot{\varepsilon}_{k\_prom}\left(A_{\dot{\vartheta}}\right) \cdot \sin\left(2\pi f_r \cdot t\right),$$

where $\dot{\varepsilon}_{k\_prom}\left(A_{\dot{\vartheta}}\right)$ is error amplitude of measurement of angular velocity of TC optic line, that value is function of amplitude $A\left(\dot{\vartheta}\right)$. By simulation it is possible to show that a amplitude periodical variation $\dot{\varepsilon}_{k\_prom}$ a quantity $\dot{\varepsilon}_k\left(t>0{,}1\,\mathrm{s}\right)$ rises with rising a value $A\left(\dot{\vartheta}\right)$. From diagrams in the Fig. 5b see that $\Delta\varphi\left(t>0{,}1\,\mathrm{s}\right)\neq konst.$ In spite of $\dot{\varepsilon}_k\left(t\right)=\Delta\varphi\left(t\right)\cdot k$, when we implemented formula (5) the error of measurement arises the more the bigger is value $A\left(\dot{\vartheta}\right)$.

Now we will analyse the case when $\dot{\varepsilon}\left(t\right)\neq \mathrm{konst}$. It is means that the change course of angle $\varepsilon\left(t\right)$ in time is not linear rising, i.e. $\varepsilon\left(t\right)\neq k\cdot t$, but values of angle ε are dispersed about σ_ε from mean value. This course corresponds to case, when the changes are produced by propagation optic radiation in atmosphere from target. The turbulence of the atmosphere, among others, causes random change of diversion from original direction propagation and thus imaginary change of position of the aim in space. It is show as fluctuation of the position of the target image in detector plane. The experiment for obtaining the impact of turbulence on position of the target image in detector plane was realized and the results are shown in the Figure 6a and 6b.

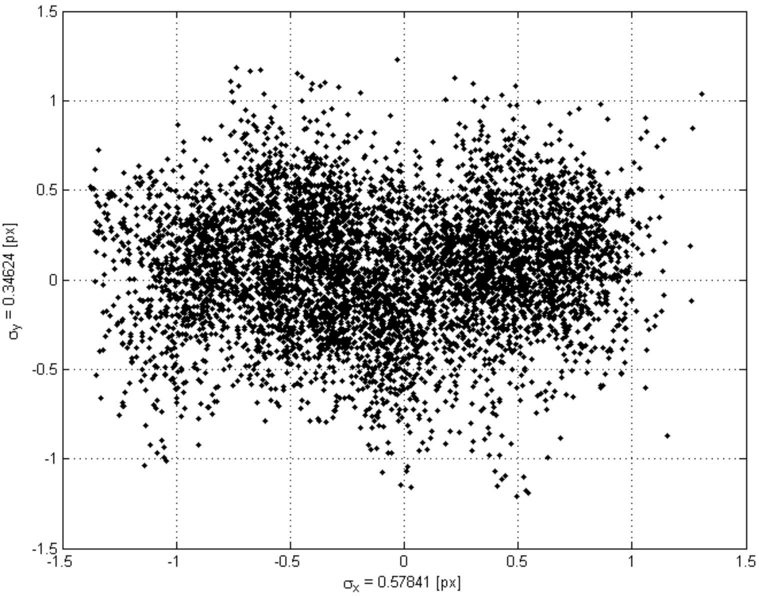

Figure 6a – Fluctuation of instantaneous position of "centre" of target in detector plane

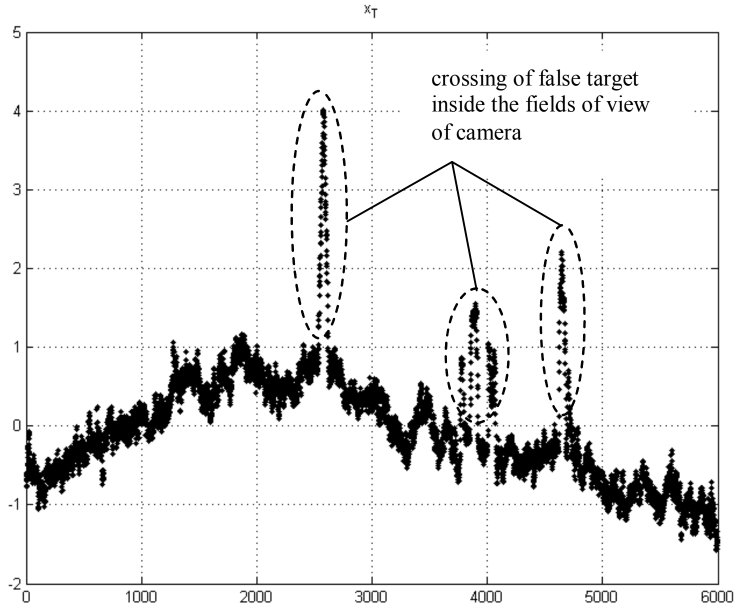

Figure 6b – Fluctuation of instantaneous position of "centre" in direction axis *x*

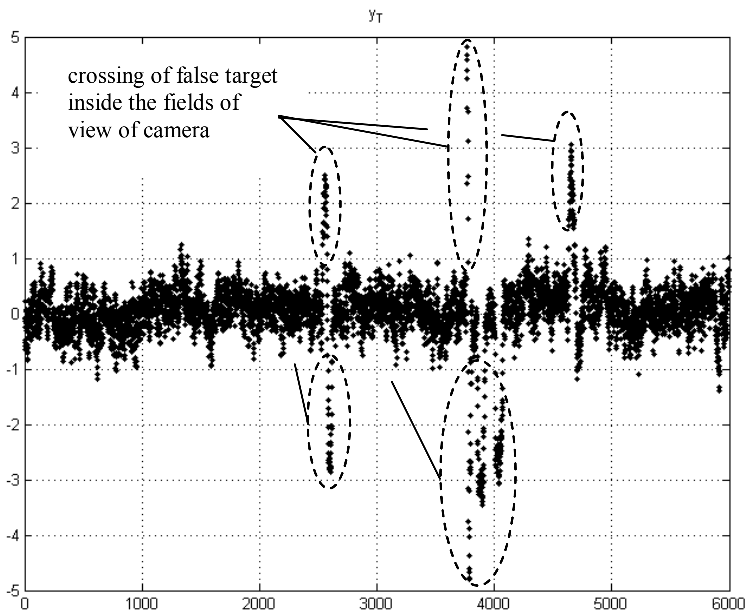

Figure 6b – Fluctuation of instantaneous position of "centre" in direction axis *y*

These experimental taken data can be used as an input signal of the OE TC by means of conversion for vertical (formula 6 and Figure 7) and horizontal (formula 7) plane

$$\varepsilon(t) = k_y \cdot t + \Delta\varphi_y = k_y \cdot t + f' \cdot y_T \quad \text{and} \tag{6}$$

$$\sigma(t) = k_x \cdot t + \Delta\varphi_x = k_x \cdot t + f' \cdot x_T \, , \tag{7}$$

where f' is focal distance of camera objective; $k_{x,y}$ are mean values of angular velocity of rotation of target aiming line.

The simulation model *SledKoord2.mdl* was formed for an investigation manner of the OE TC and his output signals include the impact of fluctuation instantaneous position of "centre" in direction axis *x*, Figure 8. The element parameters of OE TC are the same as previous examples.

The results of simulation function the OE TC by means of model *SledKoord2.mdl* (Fig. 8) with input signal influenced of real atmosphere, here describe by formula (6), are showed for time range $(0 \div 1)s$ in diagrams in the Figure 9a, 9b, 9c.

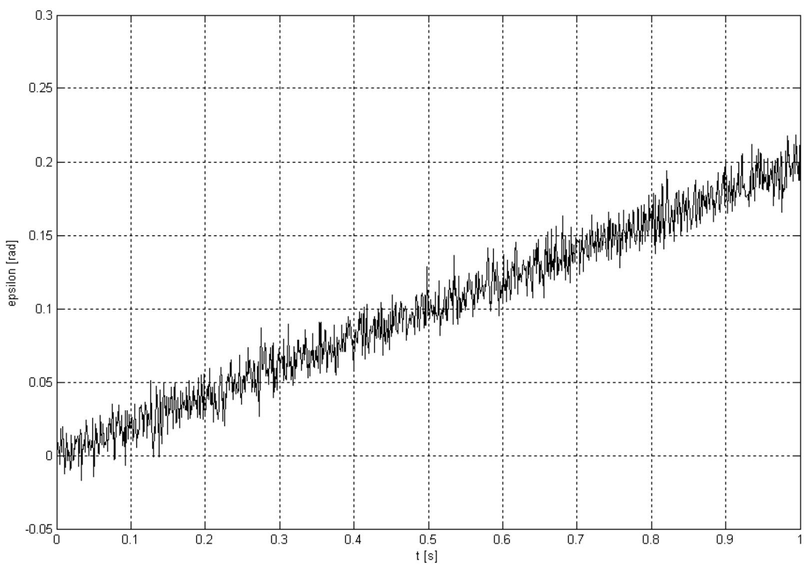

Figure 7 – Input signal of the OE TC $\varepsilon(t) = k_y \cdot t + \Delta\varphi_y = k_y \cdot t + f' \cdot y_T$ when $\dot{\varepsilon}(t) \neq konst$

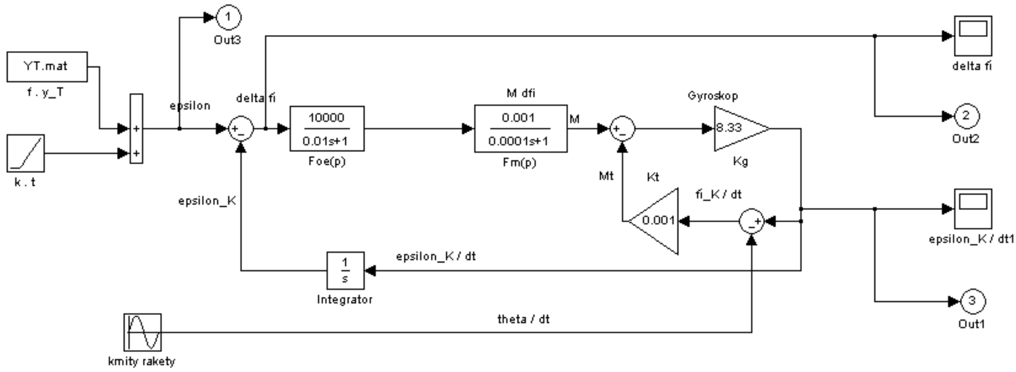

Figure 8 – Chart of the simulation model *SledKoord2.mdl*

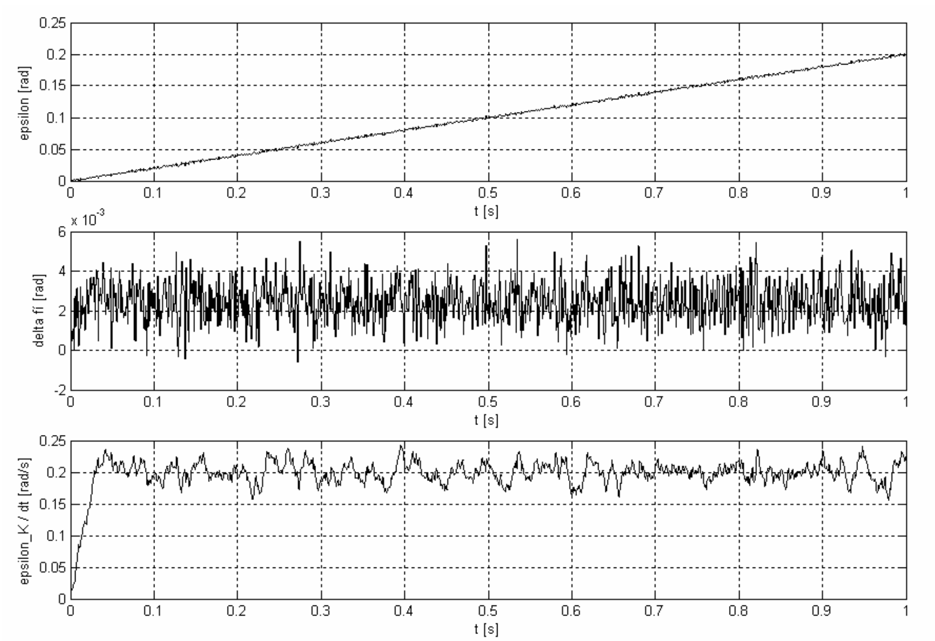

Figure 9a – Signals for vibrations $A\left(\dot{\vartheta}\right) << 0{,}1$ rad , $K_t \rightarrow 0$ and dispersion $\sigma_\varepsilon = 1 \cdot 10^{-6}$ rad ;

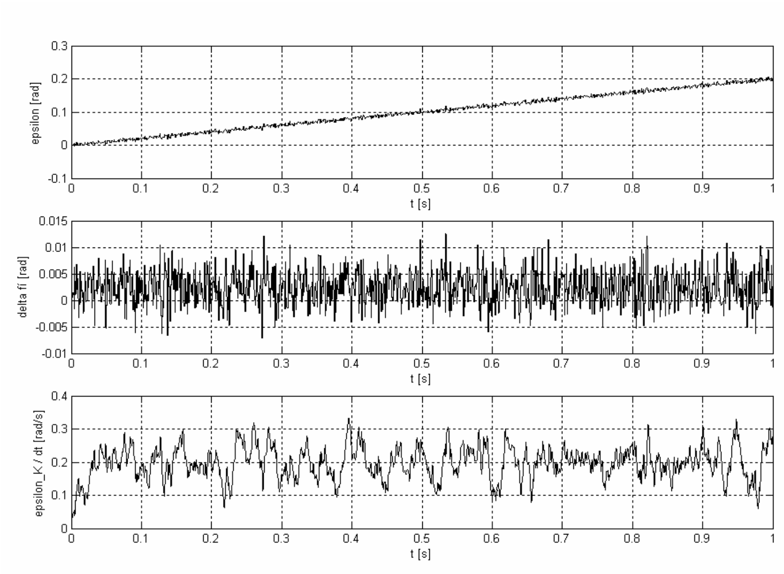

Figure 9b – Signals for vibrations $A\left(\dot{\vartheta}\right) << 0{,}1\ \mathrm{rad}$, $K_t \rightarrow 0$ and dispersion $\sigma_\varepsilon = 1 \cdot 10^{-5}$ rad

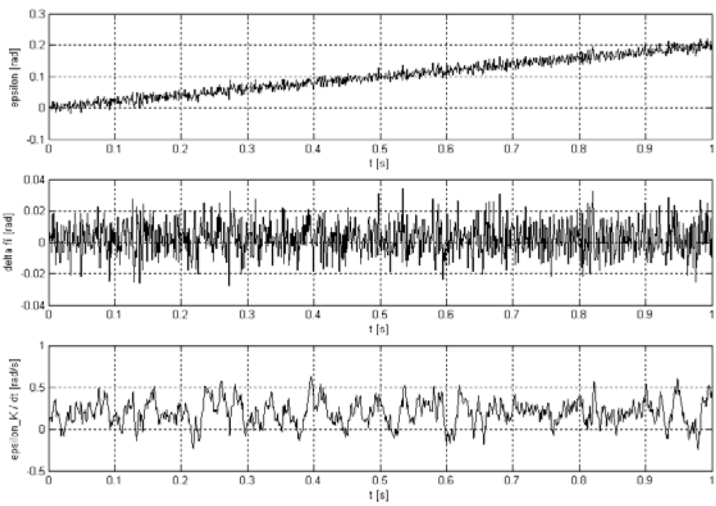

Figure 9c – Signals for vibrations $A\left(\dot{\vartheta}\right) << 0{,}1\ \mathrm{rad}$, $K_t \rightarrow 0$ and dispersion $\sigma_\varepsilon = 1 \cdot 10^{-4}$ rad

4. Conclusion

1. From computed courses in the Figure 9 we can see that signals of deviation $\Delta\varphi(t)$ and angular velocity $\dot{\varepsilon}_k(t)$ are impacted on atmosphere very substantially contrary to signals in the diagrams in the Figure 5. And it more the bigger is value of dispersion σ_ε of input signal $\varepsilon(t)$.

2. If dispersion approximately $\sigma_\varepsilon \le 1\cdot 10^{-5}$ rad, implementation of filters would lead to suppression of high-frequency part of signal $\Delta\varphi$ and $\dot{\varepsilon}_k$, and his smoothing too. Course of signal would be approximately constant, i.e. $\Delta\varphi(t \ge 0{,}1\,\mathrm{s}) \approx \mathrm{konst}$ and $\dot{\varepsilon}_k(t \ge 0{,}1\,\mathrm{s}) \approx \mathrm{konst}$. Subsequently it would allow using of formula $\dot{\varepsilon}(t) = \Delta\varphi(t)\cdot k$ for realization proportional method of guidance.

3. If dispersion $\sigma_\varepsilon \ge 1\cdot 10^{-4}$ rad, signals of deviation $\Delta\varphi(t)$ and angular velocity $\dot{\varepsilon}_k(t)$ are impacted on atmosphere so more that using of filtration and realization proportional method of guidance would be very problematic and ineffective.

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