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DYNAMIC BEHAVIOUR OF A TRACKING SYSTEM WITH TWO DEGREES OF FREEDOM USED FOR PV PANELS

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Abstract: The paper presents the dynamic behavior of a tracking system which assures the orientation of the solar collectors through the daily and seasonal motions. The simulations are made for a tracking system designed for PV panels. The actuators of the tracking systems are represented by two rotational electric motors and they have implemented a proportional-integrative-derivative controller. The results are represented by the rotational motions, the torques and the errors of the motions from the revolute joints.

1. Introduction

The PV panels are used in the conversion of the solar energy in electricity. The PV panels efficiency is depending on the normal incident direct solar radiation which is the transporter of the solar energy [3]. Figure 1 shows the Sun-ray angles and the Sun's relative motions: the daily and the seasonal motion [4].

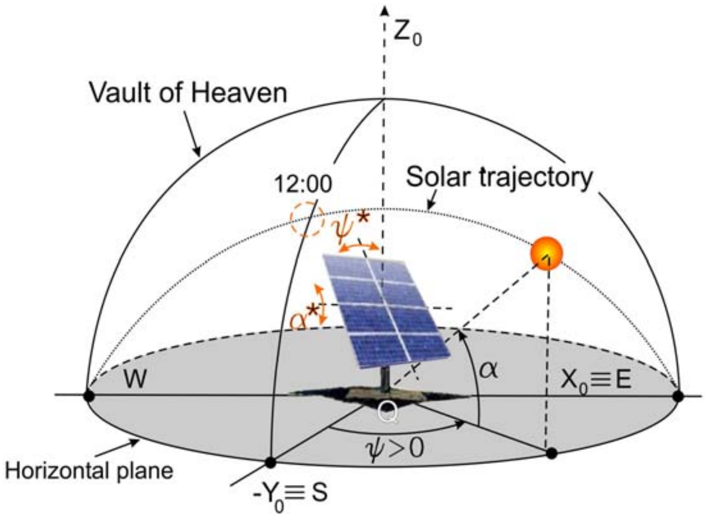


Figure 1: The sun-ray angles

2. The tracking system

To maximize the amount of the incident direct solar radiation on the PV panels surface tracking systems are used. Depending on the number of degrees of freedom, the tracking systems could be: with one degree of freedom (for the daily motion) or with two degrees of freedom (for the daily and seasonal motions both). Higher efficiencies are obtained in the case of tracking systems with two degrees of freedom (figure 2) [4]; the variables q1 and q2 are corresponding to the seasonal and to the daily motion, respectively.

The paper presents (according to the Romania's latitude) the dynamical behavior of a tracking system with two degrees of freedom, with rotational electric motors, which have implemented, each of them, a proportional – integrative – derivative control system.

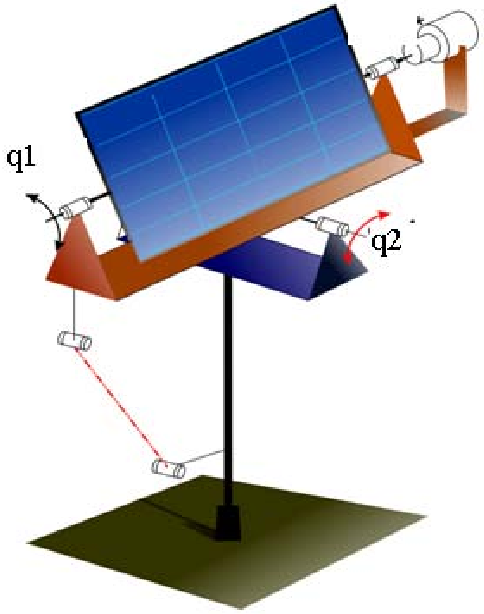


Figure 2: The tracking system with two degrees of freedom

3. The modeling of the control system

The control of the tracking system is focused on the imposed daily and seasonal motions, described by the variables q_2 and q_1 respectively.

The aim of the control system is represented by small transitory periods and small positions errors; due to these is chosen the solution of a PID (proportional – integrative – derivative) control system. The control law, for each motion (the input signal in the tracking system) is given by the equation [1, 2, 5]

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt}, \qquad (1)$$

or, if it is applied the *Laplace* transformation

$$U(s) = \left[K_p + \frac{K_i}{s} + K_d s\right] E(s). \qquad (2)$$

The meaning of the parameters from the equations (1) and (2) is: $e(t)$ – the position's error; K_p – the proportional gain; K_i – the integrative gain; K_d – the derivative gain; τ - the generalized load; $U(s)$ – the *Laplace* transformation of the output signal; $E(s)$ – the *Laplace* transformation of the position's error.

The structure of the control system is presented in the figure 3 [1, 2, 5].

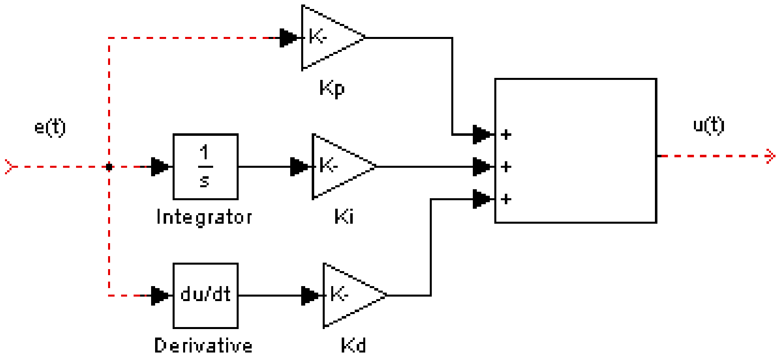


Figure 3: The structure of the control system

The gains K_p, K_i and K_d are chosen according to some considerations:

- by increasing the proportional gain K_p, the position's error and the transient period of the system's dynamic response will be reduced;
- the integrative gain K_i is generating a group of dynamic responses and it attenuate the history of the error (the transient period is reduced);
- the derivative gain K_d is generating a group of dynamic responses and is damping the position's error to a constant value;
- the system is considered with critical damping.

The equations of the motions are described by:

$$\ddot{q}_1 = \frac{T_{z1} + \ddot{q}_2 m_2 l_1 a_2 \sin q_2 + \dot{q}_2^2 m_2 l_1 a_2 \cos q_2 - 2\dot{q}_1 \dot{q}_2 \left(J_{2y} - J_{2z} - m_2 a_2^2\right)\sin q_2 \cos q_2}{J_{1z} + J_{2y}\sin^2 q_2 + J_{2z}\cos^2 q_2 + m_1 a_1^2 + m_2\left(a_2^2 \cos^2 q_2 + l_1^2\right)} + \\ + \frac{m_1 g a_1 \cos q_1 + m_2 g \left(l_1 \cos q_1 - a_2 \sin q_1 \cos q_2\right)}{J_{1z} + J_{2y}\sin^2 q_2 + J_{2z}\cos^2 q_2 + m_1 a_1^2 + m_2\left(a_2^2 \cos^2 q_2 + l_1^2\right)} \qquad (3)$$

and

$$\ddot{q}_2 = \frac{T_{x2} + \ddot{q}_1 m_2 l_1 a_2 \sin q_2 + \dot{q}_1^2 \left(J_{2y} - J_{2z} - m_2 a_2^2\right)\sin q_2 \cos q_2 - m_2 g a_2 \cos q_1 \sin q_1}{J_{2x} + m_2 a_2^2}. \qquad (4)$$

The equations of the motions are described in *Matlab/Simulink* by the scketch presented in figure 4.

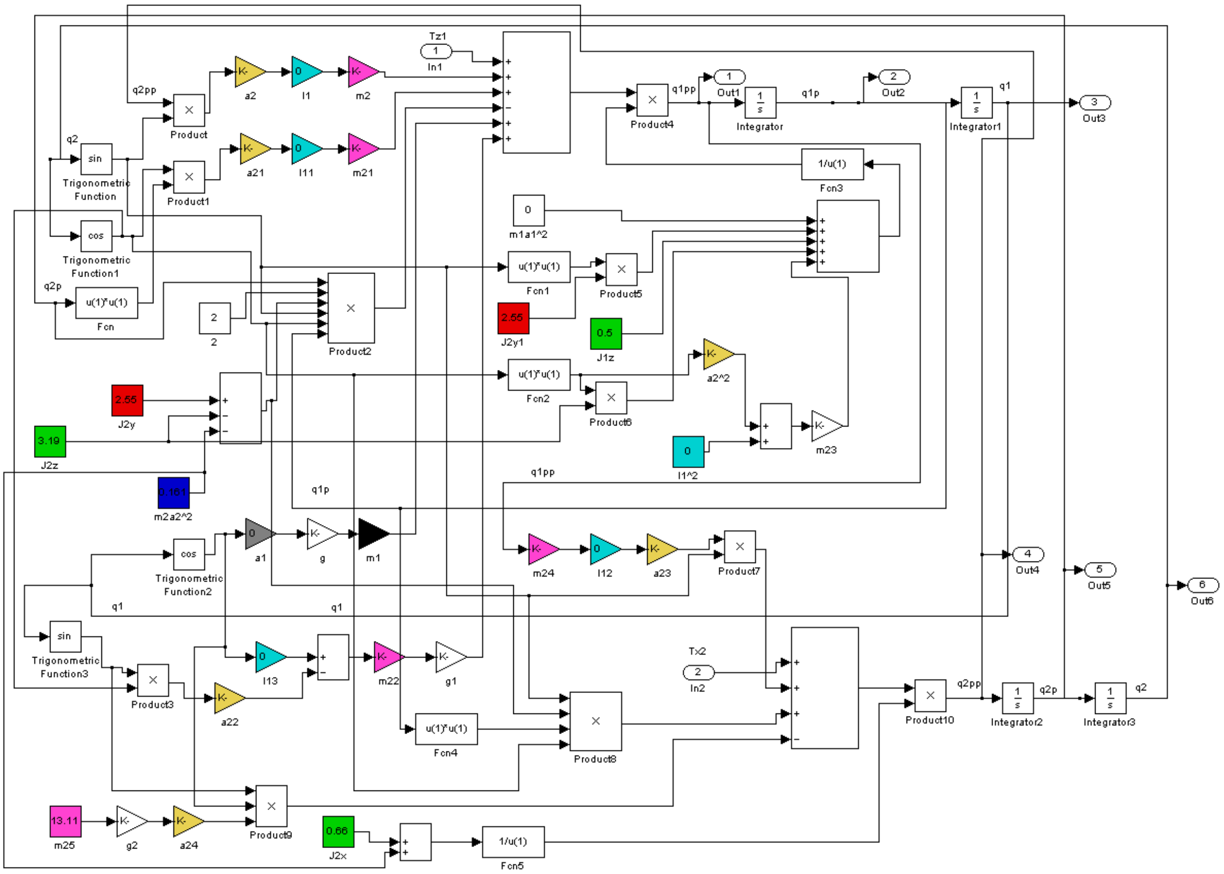


Figure 4: Matlab/Simulink description of the equations of motions

The parameters from the figure 4 are represented by:

*q*1, *q*1p, *q*1pp – the angular position, velocity and acceleration for the seasonal motion, respectively;

$q2$, $q2p$, $q2pp$ – the angular position, velocity and acceleration for the daily motion, respectivelly;
$a2=a21=a22=a23=a24=0.111$ m – the distance between the daily rotation axis and the centre of the PV panel;
$a2$^2=a_2^2;
$a1=0$ – the distance between the seasonal rotation axis and the mass centre of the sustaining rod;
$m1=8.44$ kg – the mass of the sustaining rod;
$m2=m21=m22=m23=m24=m25=13.11$ kg – the mass of the PV panel;
$m1a1$^2=$m_1a_1^2$;
$J1z=0.5$ kg·m^2 – the inertia of the sustaining rod, through the seasonal rotation axis;
$J2x=0.66$ kg·m^2 – the inertia of the PV panel, through the daily rotation axis;
$J2y=J2y1=2.55$ kg·m^2 – the inertia of the PV panel, through the axis normal to the PV panel's plane;
$J2z=3.19$ kg·m^2 – the inertia of the PV panel, through the axis parallel to the PV panel's plane;
$l1=l12=l13=0$ – the distance between the seasonal rotation axis and the daily rotation joint;
$l1$^2=l_1^2;
$Tz1$ – the torque at the seasonal rotation joint;
$Tx2$ – the torque at the seasonal rotation joint.

The sketch of the control system designed for the tracking mechanism is presented in figure 5.

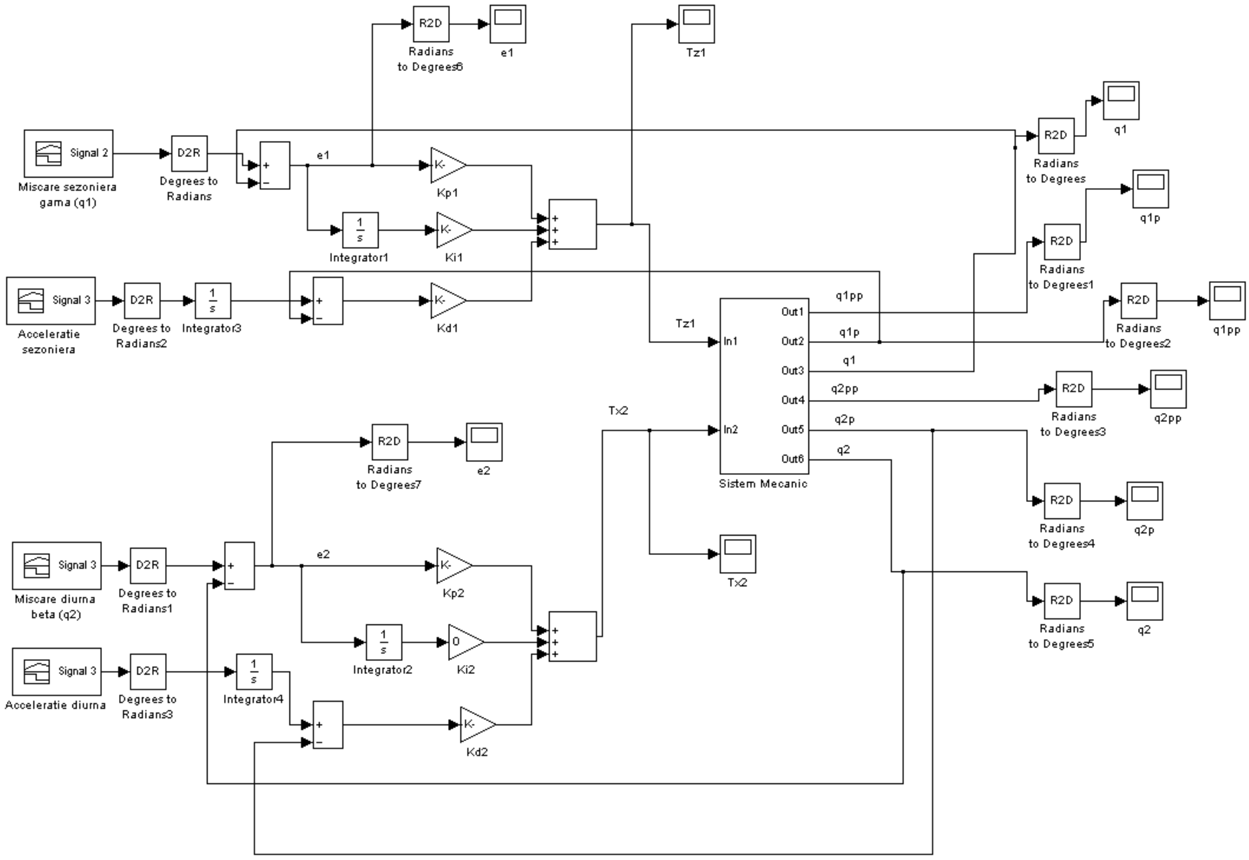


Figure 5: The control system

The parameters from the figure 5 are presented as following:

*e*1, *e*2 – the errors of the angular positions for the seasonal and daily motions, respectively;
*Ki*1=*Ki*2=5 – the integrative factors;
*Kd*1=*Kd*2=40– the derivative factors;
*Kp*1=*Kp*2=400– the proportional factors;

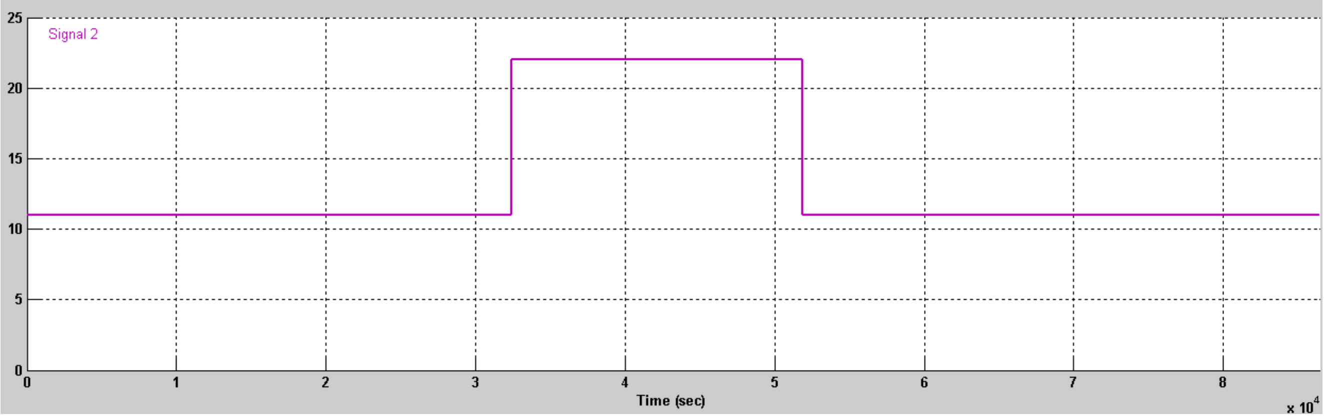
To achieve the dynamical simulation, the positions functions are imposed.

4. The dynamic behavior

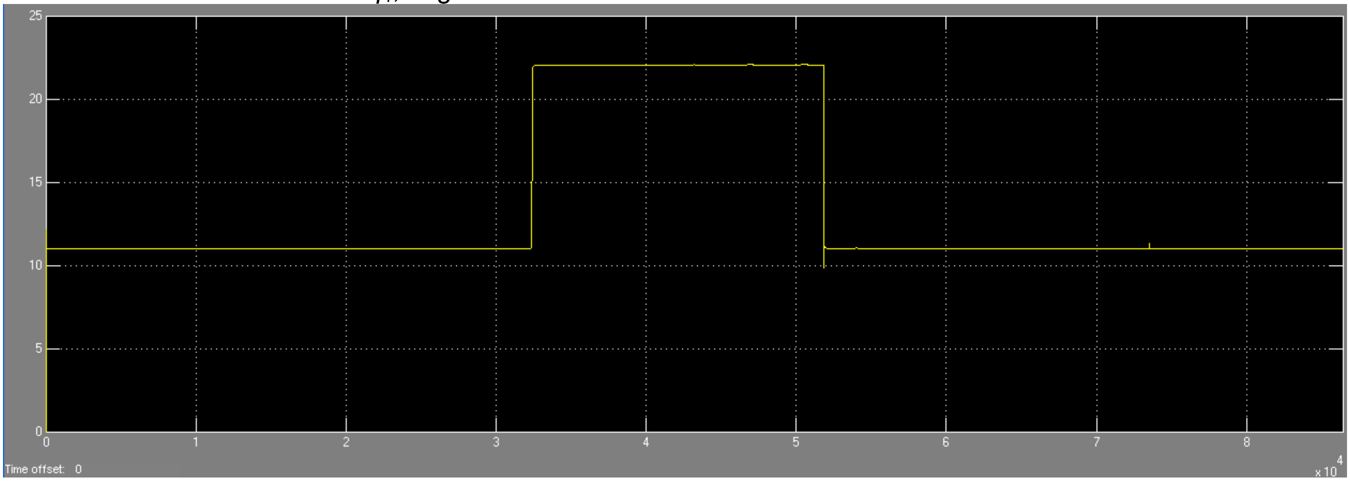
The simulation is achieved for a time period equal with a day (from 00:00 to 24:00.

Figure 6 and figure 7 show, by comparing, the diagrams for the imposed and achieved motions, in the case of seasonal and daily motions, respectively.

The seasonal imposed motion q_1, degrees



The seasonal obtained motion q_1, degrees



Time, s

Figure 6: The seasonal motion

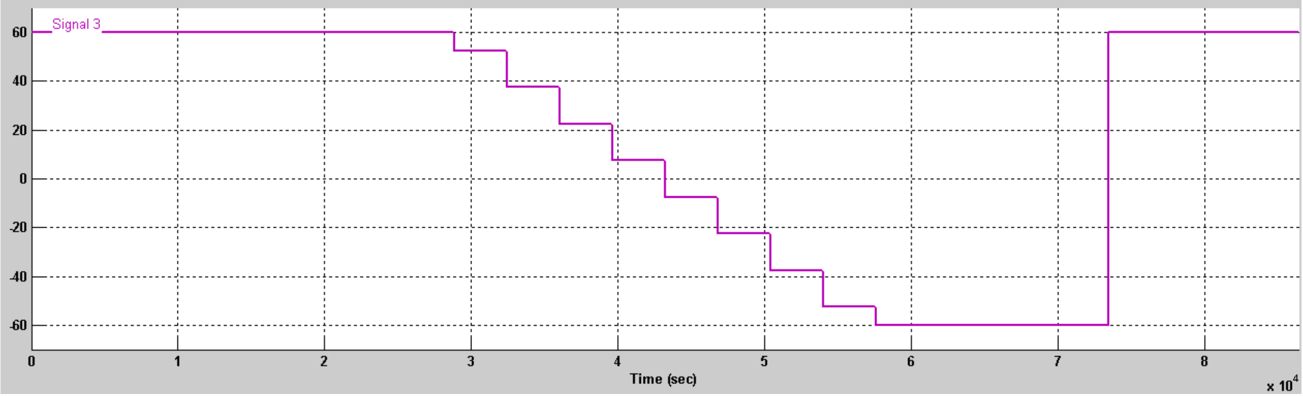
The position errors are presented in figure 8 (due to the graphic conditions is presented a short simulation period – 5 s).

The transient period is shown in figure 9 (is the period necessary to obtain a constant torque in the rotational joints).

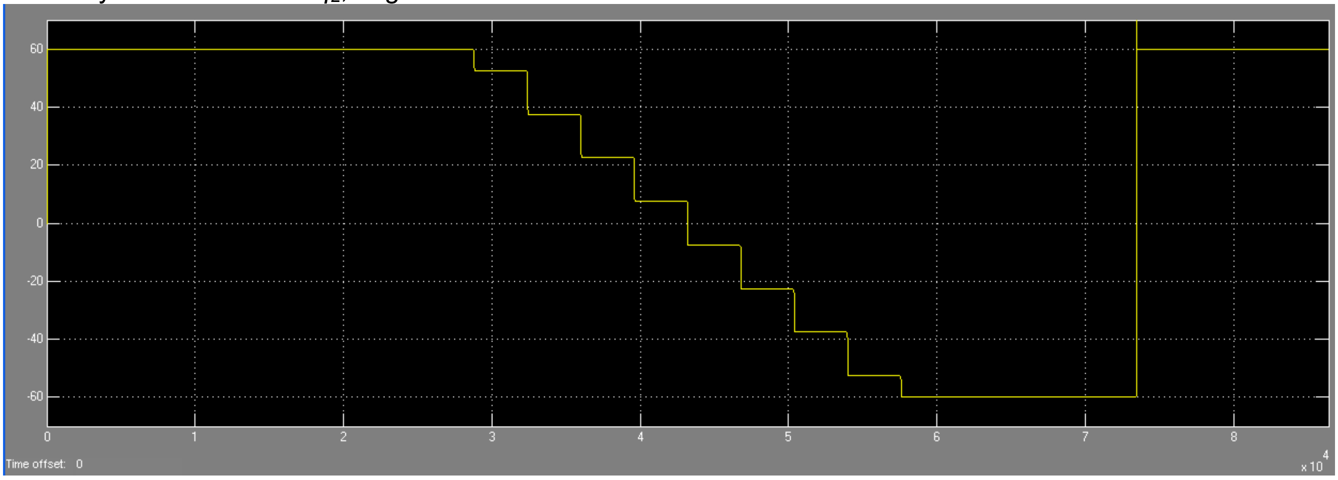
5. Conclusions

According to the obtained diagrams the following conclusions can be expressed:

The daily imposed motion q_2, degrees



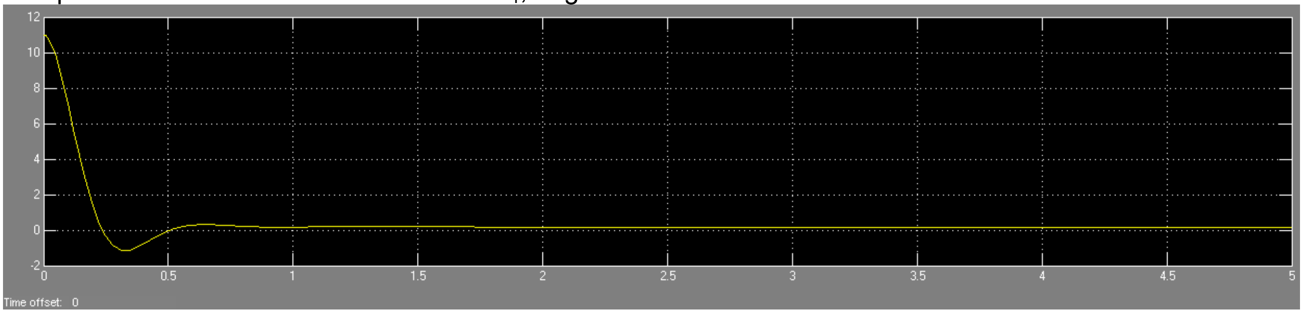
The daily obtained motion q_2, degrees



Time, s

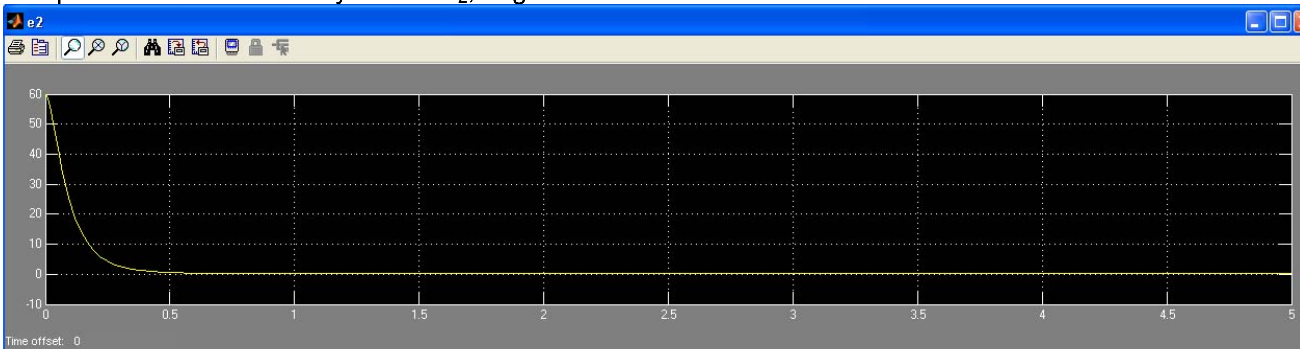
Figure 7: The daily motion

The position error of the seasonal motion e_1, degrees



Time, s

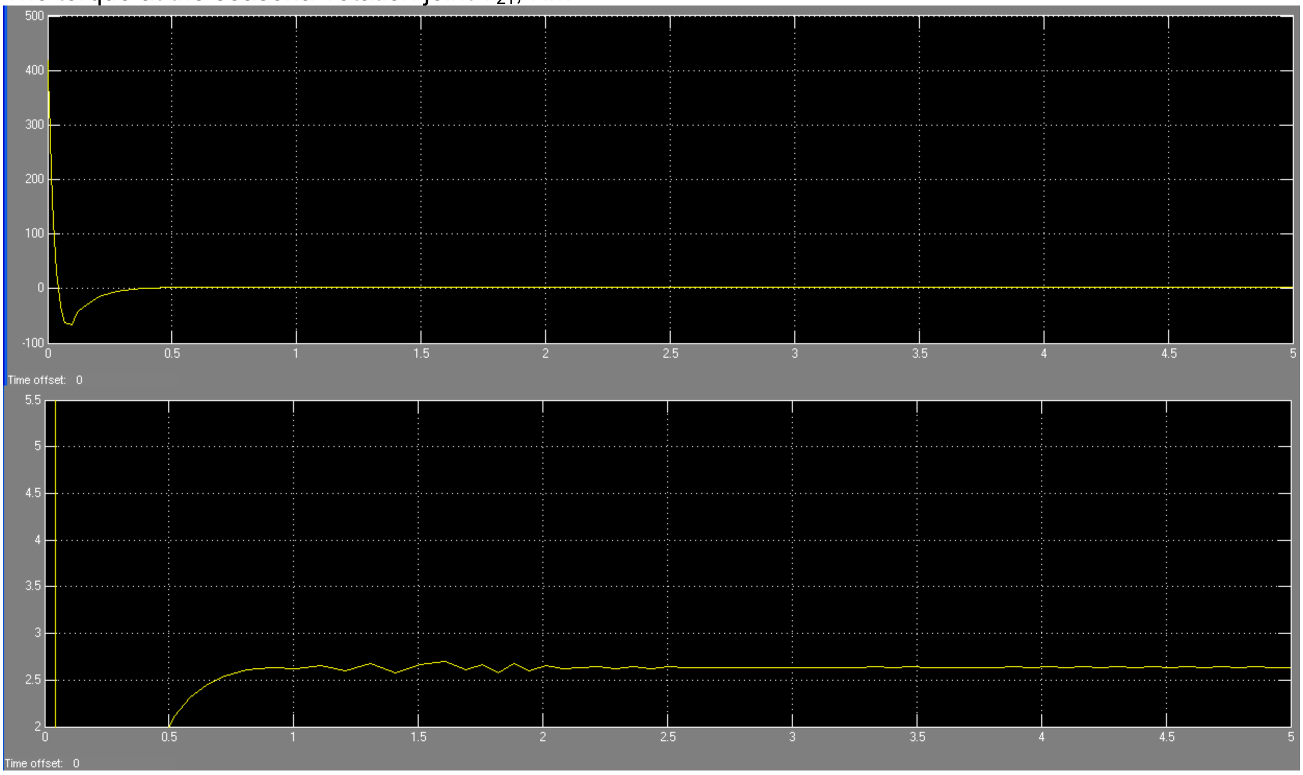
The position error of the daily motion e_2, degrees



Time, s

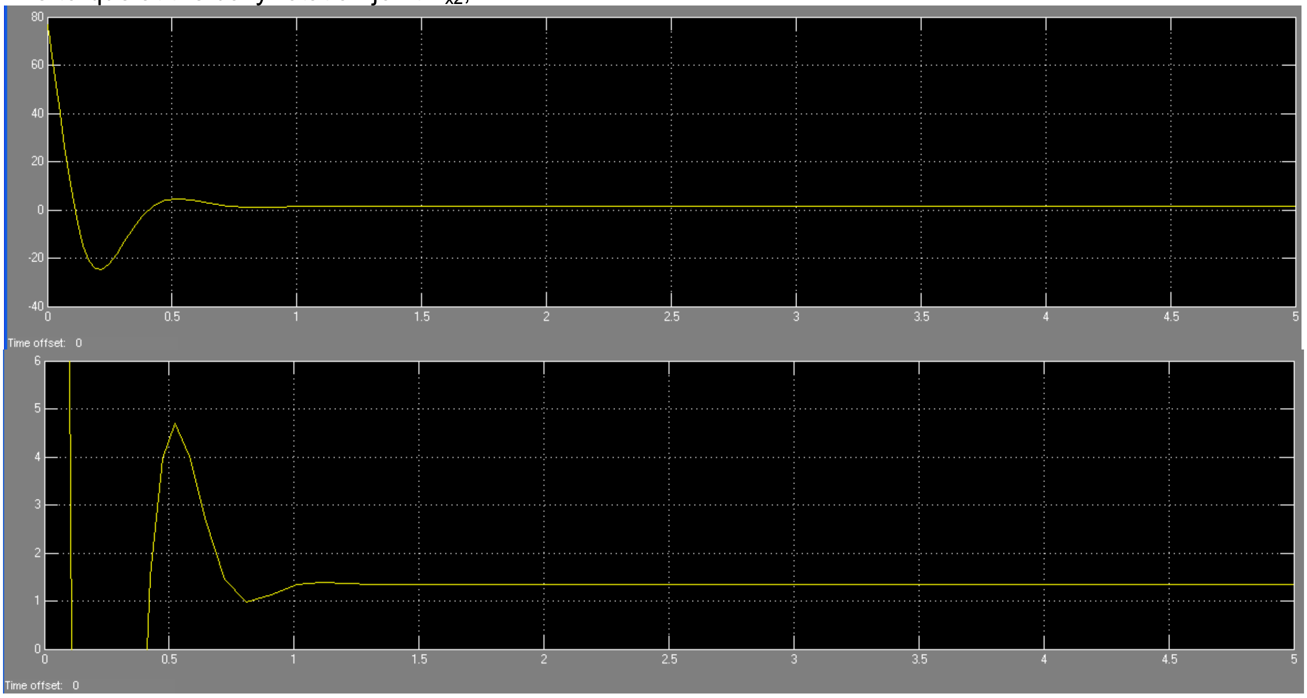
Figure 8: The position errors

The torque at the seasonal rotation joint T_{z1}, Nm



Time, s

The torque at the daily rotation joint T_{x2}, Nm



Time, s

Figure 9: The torques

- the values for the error of the positions are small (less than 0.5 degrees for the seasonal motion and less than 0.7 degrees for the daily motion), so the system is a precise one;
- the transient period is small (less than 2.5 s for the seasonal motion and less than 1 s for the daily motion), so the system is a stabile one.

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