Simulating linear systems in the MatLab software package using the structural blocks of the Simulink application

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Abstract. The paper considers the peculiarities of linear system simulation in the MatLab software package using the structural blocks of the Simulink application. Typical links of linear systems and their transfer functions are described. The simulation process is exemplified by the system of the object control by its rotation angle. A structural diagram is built for such a system, the mathematical model of which is made in the form of an aperiodic link of the first order. The parameters of the controllers forming the control signal are calculated. A detailed description of the model construction is provided in the Simulink application of the MatLab software package. As a result of simulation, the authors obtained the graphs during the study of the object control system: 1) under external impact without changing controller parameters; 2) under external impact when using a PID controller. The final model was built; it allows comparing the curves of the object rotation control signal in the system with the PD controller and the PID controller as well as displaying the transient curves of the object rotation angle.

1 Introduction

To analyze the operation of complex systems (objects), their structural diagrams are widely applied; here they are provided in the form of blocks (links) with certain characteristics [1-3].

The structural diagrams of linear systems consist of typical links, which may include aperiodic, oscillatory, amplifying, integrating, differentiating, and other link types [4-6].

In the general case, the link corresponds to a transfer function of the form:

$$W(s) = \frac{Y(s)}{X(s)}, \quad (1)$$

where $X(s)$, $Y(s)$ are the image of the input and output signals, respectively.

Table 1 shows the transfer functions of the main link types.

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Table 1. Transfer functions of the links.

Link name	Transfer function
Aperiodic link of the first order	$W_{(s)} = \frac{K}{Ts+1}$
Oscillatory link of the second order	$W(s) = \frac{K}{T_1T_2s^2 + T_2s + 1}$
Amplifying (proportional) link	$W(s) = K$
Differentiating link	$W(s) = Ts$
Integrating link	$W(s) = \frac{1}{Ts}$

The following notation is used in the table: T is the time constant; K is the gain (proportional) factor; s is the operator.

2 Research method

This paper considers the system controlling the object rotation angle exemplified by the study of linear systems using the structural blocks of the Simulink package [7-9]. The system structural diagram is provided in Figure 1 [10].

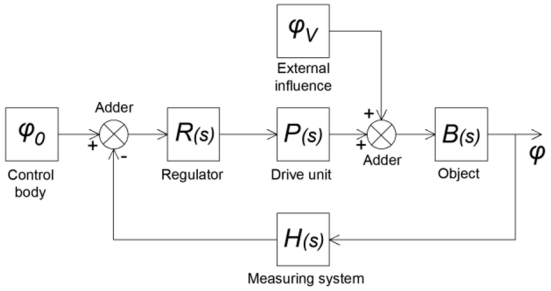

Fig. 1. The structural diagram of the system controlling the object rotation angle.

The system comprises: a control body that sets the required object rotation angle φ_0, a controller, a drive, a control object, a measuring system, two adders and a block setting the external impact φ_V.

The object motion is described by a second-order linear mathematical model in the form of the following transfer function [11]:

$$B(s) = \frac{K}{s(T_Bs+1)}, \quad (2)$$

where T_B is the object time constant; K is a constant coefficient.

The object drive is simulated as an integrating link covered by a single negative feedback, so that its transfer function has the form [12]:

$$P(s) = \frac{1}{T_Ps+1}, \quad (3)$$

where T_P is the drive time constant.

To measure the object rotation angle, a measuring system is used; its mathematical model is written in the form of a first-order aperiodic link with a transfer function [13]:

$$H(s) = \frac{1}{T_H s+1}, \quad (4)$$

where T_H is the time constant of the measuring system. The controllers are used to generate a control signal to obtain the required control accuracy and the transient process quality.

A proportional-integral-derivative (PID) controller generates a signal being the sum of three summands the first of which is proportional to the difference between the input signal and the feedback signal (mismatch signal) while the second is the integral of the mismatch signal, the third is the derivative of the mismatch signal [14-16]. If some of the components are not used, such a controller becomes proportional-integrating (PI), proportional-derivative (PD), proportional (P), etc.

If the object does not change its structure and its parameters, the systems equipped with PID controllers provide the necessary control quality with large external disturbances and interferences [17-19].

The paper investigates object control systems with PD and PID controllers [20].

The PID controller generally has a transfer function [21]:

$$R(s) = K_P\left(1 + \frac{1}{T_I s} + T_D s\right), \quad (5)$$

where K_P is the proportionality factor; T_I is the integration constant; T_D is the derivative action time.

In case of filter use, the transfer function is equal to [22]:

$$R(s) = K_P\left(1 + \frac{1}{T_I s} + \frac{T_D s}{T_F s+1}\right), \quad (6)$$

where T_F is the filter constant ($T_F = T_D/n$, while, as a rule, $n = 2 \div 20$).

The following parameters are set for the control system of the object studied: the object rotation angle $\varphi_0 = 10°$; the external impact angle $\varphi_V = 2°$; the object parameters $T_B = 12$ s, $K = 0.06$; the drive parameters $T_P = 3$ s; the measuring system parameters $T_H = 5$ s; the controller parameters $K_P = 0.5$, $T_I = 100$ s, $T_D = 1$ s, $T_F = 0.1$ s.

At the same time, this system is studied in 3 modes: without external impact using a PD controller; with external impact using a PD controller; with external impact using a PID controller [23, 24].

3 Research results

Start MatLab and Simulink. Add the Transfer Fcn block (transfer function) from the Continuous group of the Simulink library to the model window, designed to obtain functional flowcharts of various devices. Place the block in the window in accordance with the structural diagram of the simulated system shown in Figure 1. Assign the name of the Object to the Transfer Fcn block. Set the coefficients of the transfer function in the parameters window:

$$B(s) = \frac{0,06}{s(12s+1)} = \frac{0,06}{12s^2+s}. \quad (7)$$

The numerator coefficients (Numerator coefficients: [0.06]) and denominator (Denominator coefficients: [12 1 0]) of the transfer function are entered in square brackets separated by a space in the order of decreasing the operator degree*s*.

Similarly, add two more blocks of the Transfer Fcn type; designate them as the Drive and the Measuring System, respectively, and enter their parameters. Correspondingly, the drive transfer functions and the measuring system have the following form:

$$P(s) = \frac{1}{3s+1};\ H(s) = \frac{1}{5s+1}. \quad (8)$$

Add the PID Controller block from the Continuous group. Initially, the PD controller is used as a controller, thus, in the window of parameters one needs to select Controller: PD. Set Form: Ideal and, in accordance with the type of transfer function being implemented (Compensator formula), set the regulator's parameters *P*, *D*, *N*: $P = K_P = 0.5$; $D = T_D = 1$; $N = 1/T_F = 10$.

Add the Sum block from the Math Operations group to the model window and set it to the left of the controller. Set a minus sign for the adder bottom input (for negative feedback). Add another Sum block and install it between the drive and the object.

Add a Step block from the Sources group to the model window, set it to the left of the adder and designate it as the Control Body. The block parameters window is used to set the signal time (0 in the Step time field) and the signal value, the object rotation angle φ_0 (10 in the Final value field). Redo the procedure for the External impact block. Set the value of the external impact signal $\varphi_V = 0$ for it.

Connect all the model blocks in compliance with Figure 1. Add two Scope (oscilloscope) blocks from the Sinks group to the model window and set them in the right field part. Send a signal to the first Scope block from the output of the second adder (the input signal of the Object block) and the output signal of the Object block (Figure 2) to the second Scope block.

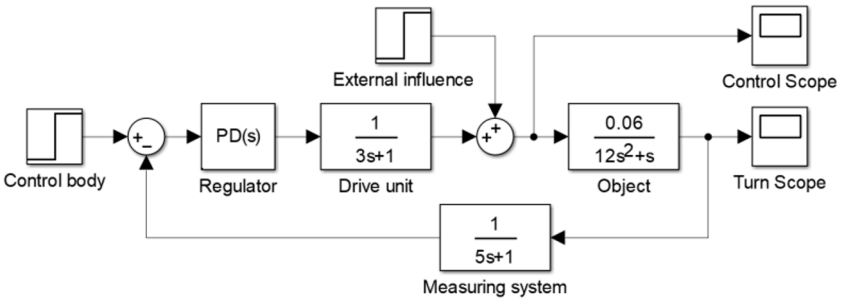

Fig. 2. Model of the object control system by its rotation angle.

Set the simulation time to 300 s (Simulation/Model Configuration Parameters; Start time: 0, Stop time: 300). In the Solver area, choose a variable sampling step Variable-step.

Conduct the simulation. Figure 3 shows the simulation results, which can be seen by opening the windows of the Scope blocks.

If the set simulation time is not enough for the transition process to be fully displayed on the graphs or it is too long, it is necessary to set a new time and repeat simulation. It can be seen from the graph that, provided no external impact is present, the object will turn at a given angle of 10° after about 150 seconds.

Transfer the simulation results from both Scope blocks to the MatLab workspace in the form of matrices (Array) where the first column is the time, and the second is the signal (rotation angle). To do this, click the Parameters button and select the History tab at the open panel of the Scope block. Next, set Variable name: Control (for the “Object Management” block) and Turn (for the “Object rotation” block), Format: Array (saving data as a matrix).

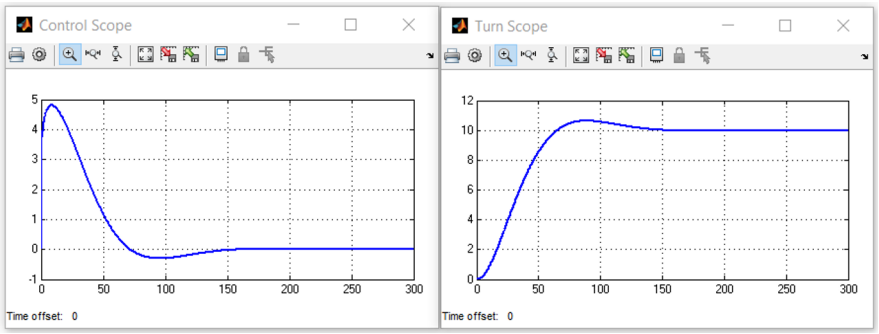

Fig. 3. Simulation results with no external impact.

Go to the MatLab command window and create a new window for the graph where two curves will be built on different axes. Divide the window into two parts vertically and activate the first graph. The first number in the subplot command shows the number of cells with the graphs vertically, the second refers to the number of cells horizontally while the third identifies the cell number to be activated.

Plot a graph for the object control signal. Using the plot command, firstly, specify an array of abscissas, and further select an array of ordinates; a colon shows that all strings are used. Enter the graph title. Enter the names of the coordinate axes. It is allowed using LaTeX commands inside apostrophes to enter Greek letters. For example, \phi means the Greek letter φ, \delta means the letter δ. Similarly, in the second cell, plot the change in the object rotation angle using data from the Turn array obtained after simulation.

An example of the graphs for the signals “Object Control” and “Object rotation” is shown in Figure 4. The graphs shown were formatted (grid lines were added, line thickness was increased) using the corresponding properties window (View/Property Editor).

```
>> figure(1);
subplot(2,1,1);
plot(Control(:,1),Control(:,2));
title('Control');
xlabel('Time,s');
ylabel('\phi,deg');
subplot(2,1,2);
plot(Turn(:,1),Turn(:,2));
title('Turn');
xlabel('Time,s');
ylabel('\delta,deg');
>>
```

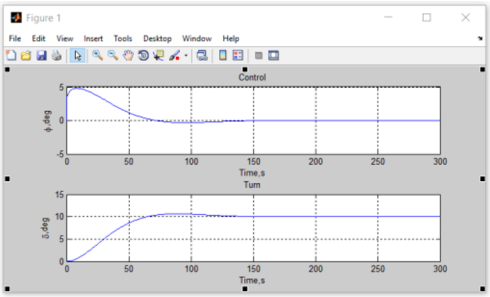

Fig. 4. Simulation results with formatting elements.

Next, study the control system of the object under external impact with no change in the controller parameters. To do this, in the parameters window of the External impact block, the Final value field, set the signal value to 2 (corresponding to the angle of the external impact of 2°), and conduct simulation.

Review the simulation results in Figure 5.

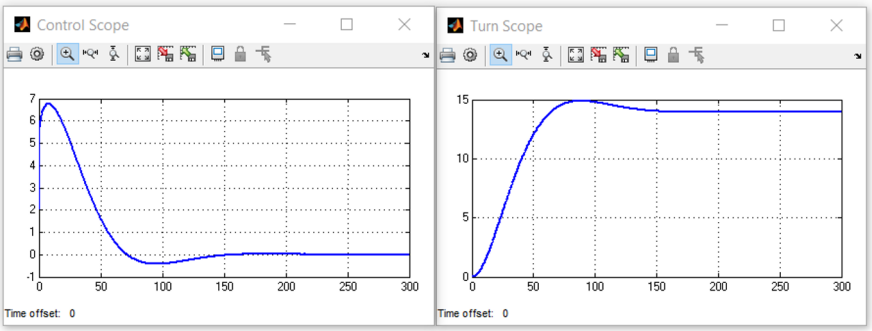

Fig. 5. Simulation results at the external impact.

It is clear from the graph that, providing the external impact and the PD controller use, the object did not turn at a given angle of 10°. Go to the MatLab command window and remember the simulation results in new arrays. They will be necessary to compare the system original and adjusted versions. To make the controller compensate for the time-independent disturbance, an integral channel must be added to it. To do this, in the parameters window of the PID Controller block, select Controller: PID, Form: Ideal and set the parameter value I: $I = 1/T_I = 0.01$.

Conduct simulation of the control system for the object with external impact when using a PID controller. View the simulation results in Figure 6.

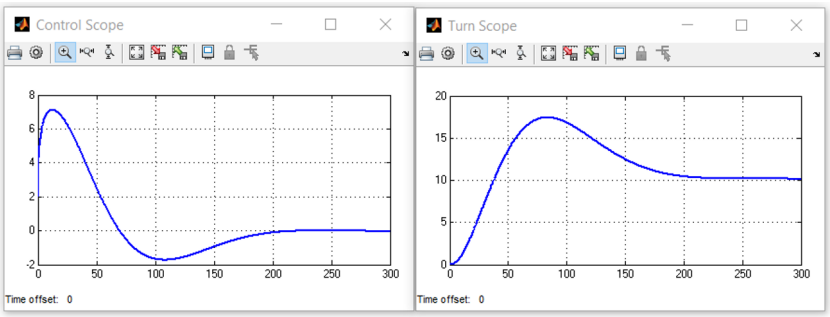

Fig. 6. Simulation results with external impact when using a PID controller.

The graph shows that the controller with an integral channel was able to compensate for the time-independent external impact while the object turned to a predetermined angle of 10° after about 230 seconds.

Save the final model of the object management system. Go to the MatLab command window. In the upper graph part, plot the curves of the object rotation control signal of the system with a PD controller and a PID controller, and the curves of transients of the object rotation angle in the lower graph part. To do this, the plot command should list all pairs of arrays separated by commas, while the first pair should correspond to the first graph. To distinguish curves, it is recommended to use a different type of lines set with optional symbolic variables. Three dots at the end of the line indicate the transfer of the command to the next line. The legend command is used to output the legend: character strings describing each of the graphs built.

The results of simulation and analysis of the object control with a family of curves are shown in Figure 7.

```
>> subplot(2,1,1);
plot(Control1(:,1),Control1(:,2),'-',...
Control(:,1),Control(:,2),'--');
>> title('Control');
xlabel('Time,s');
ylabel('\phi,deg');
legend('PD-Controller',...
'PID-Controller');
subplot(2,1,2);
plot(Turn1(:,1),Turn1(:,2),'-',...
Turn(:,1), Turn(:,2),'--');
title('Turn');
xlabel('Time,s');
ylabel('\delta,deg');
legend('PD-Controller',...
'PID-Controller');
```

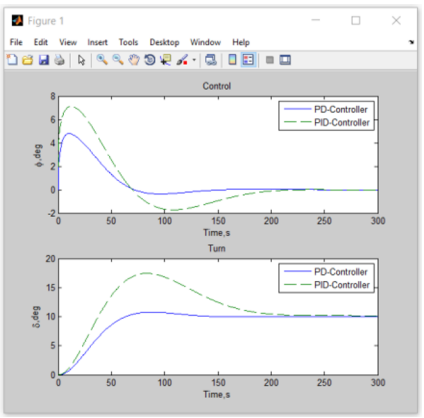

Fig. 7. Final results of simulation and control analysis of an object with a family of characteristic curves.

4 Conclusion

Using the MatLab software package, a linear control system was simulated in the Simulink application for the parameter values of the blocks included in the model. A structural diagram of the investigated linear object control system was developed; transfer functions of this system blocks were calculated; the results of simulation and analysis of object control with a family of characteristic curves were provided.

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