Lab 3

Simulation of Control Systems with Simulink

Objective

The lab aims to teach the students to simulate control systems using Simulink.

Background Materials

Simulink is a very useful Graphical User's Interface (GUI) software which works directly with the block-diagram of a control system (rather than differential equations, or transfer functions) to produce a simulation of the system's response to arbitrary inputs and initial conditions. Another advantage of using Simulink is that it works with MATLAB. With advanced features one can also use Simulink for practical implementation of control systems.

The basic entity in Simulink is a *block,* which can be selected from a *library* of commonly used blocks. Alternatively, a user can devise special blocks out of the common blocks through the *S-function* facility. The Simulink demos and the User's Guide for Simulink are very helpful in explaining the advanced usage and extension of Simulink block library.

The best way to learn Simulink is by doing.

Tasks

Task 1

Cascade structure for control of motor angular velocity is shown in Figure 1. The control system consists of the following blocks: velocity controller (VC), current controller (CC), power supply device (PS), current sensor (CS), DC motor (M), velocity sensor (VS), gearbox (G) and load (L). The system has an inner current control loop and an outer velocity control loop.

A simplified block diagram of the velocity control system is shown in Figure 2. The current control loop is represented approximately by a second-order fransfer function. The controlled variable (angular velocity), the reference variable and the disturbance variable are denoted by y, r and d, respectively. The values of the system parameters are

$$k_1 = 5 \text{ Nm}/(\text{rad}/\text{s}), \quad T_1 = 0.06 \text{ s},$$

$$c_0 = 0.00005 \text{ s}^2, \quad c_1 = 0.01 \text{ s}, \quad J = 0.1 \text{ kgm}^2.$$

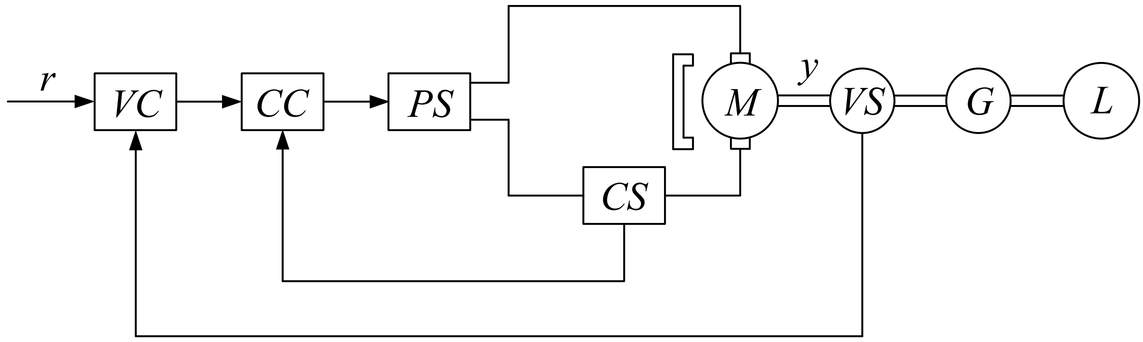

Figure 1 Cascade control of motor angular velocity.

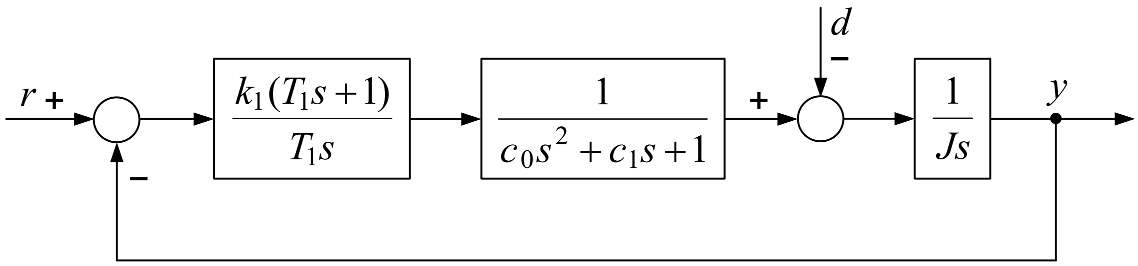

Figure 2 Simplified block diagram of the velocity control system.

(a) Use Simulink to plot the response of $y(t)$ to

$$r(t) = r_0 1(t), \quad r_0 = 20 \text{ rad}/\text{s},$$

$$d(t) = \begin{cases} 0 & \text{if} \quad t < 0.4 \text{ s} \\ 10 \text{ Nm} & \text{if} \quad t \geq 0.4 \text{ s} \end{cases}.$$

(b) Simulate the control system for the following values of the PI controller parameters

$$k_1 = 10 \text{ Nm}/(\text{rad}/\text{s}), \quad T_1 = 0.06 \text{ s},$$

$$k_1 = 5 \text{ Nm}/(\text{rad}/\text{s}), \quad T_1 = 0.02 \text{ s},$$

$$k_1 = 10 \text{ Nm}/(\text{rad}/\text{s}), \quad T_1 = 0.02 \text{ s},$$

and compare the results obtained.

(c) Use Simulink to plot the response of $y(t)$ if in the control system P controller

$$G_c(s) = k_1, \qquad k_1 = 5\ \text{Nm}/(\text{rad}/\text{s})$$

is used. Compare the results obtained for PI and P controllers.

Directions:

To build a Simulink model of the control system, follow the steps:

- Start MATLAB. Open the Simulink Library Browser by selecting the Simulink icon in the Toolbar or by typing `simulink` in the Command window. The Simulink Library Browser contains all the blocks you may use in Simulink.
- Open a new Simulink model window by selecting File/New/Model.
- Drag the needed blocks from their respective library folders to the Simulink model window, as follows:
    - Transfer Fcn – from Continuous;
    - Step – from Sources;
    - Scope – from Sinks;
    - Sum – from Math Operations (or from Commonly Used Blocks);
    - Mux – from Signal Routing (or from Commonly Used Blocks).
- Arrange the blocks in the proper order.
- When a block is dragged into the model window, it will be given a generic name. To rename a block, simply click on the existing name once and edit.
- Double-click on the surface in order to write labels or comments.
- Double-click on any block having parameters that must be established, and set these parameters. For the Transfer Fcn block, the numerator and denominator parameters are the coefficients of the polynomials of the numerator and denominator of the transfer function. The coefficients are in order of decreasing power. For instance, if denominator is set to [0.1 1], then the denominator of the transfer function is $0.1s + 1$.

- Interconnect the blocks by dragging the cursor from the output of one block to the input of another block. Another wiring technique is to select the source block, then hold down the Ctrl key while left-clicking on the destination block. The Simulink model of the velocity control system is shown in Figure 3.
- Set the stop time by clicking on the Simulation/Configuration Parameters entry on the Simulink toolbar. Most often, the simulations are performed with default parameters (variable time-step *ode45* solver with relative error tolerance of 10^{-3} and absolute tolerance of 10^{-6} per element).
- Save the Simulink model.
- Start the simulation by clicking the Start Simulation icon in the Toolbar.
- Once the simulations are done, double-click on the scope icon and observe the results.

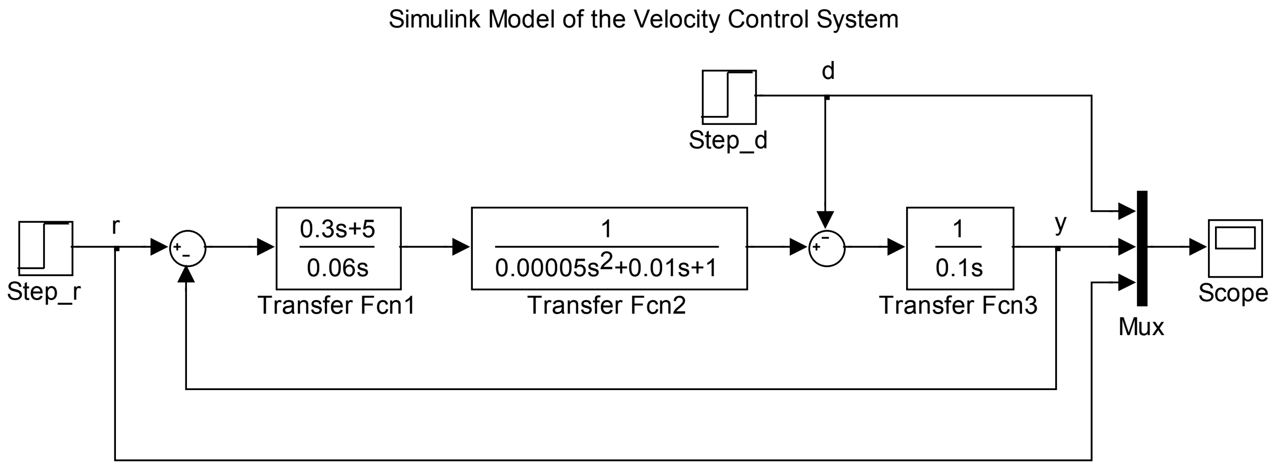

Figure 3 Simulink model of the velocity control system.

Task 2

Consider the temperature control system in Figure 4, where the plant model is

$$G(s) = \frac{k}{a_0 s^3 + a_1 s^2 + a_2 s + 1},$$

and the controller is a PID controller given by

$$G_c(s) = k_c + \frac{k_c}{T_I s} + \frac{k_c T_D s}{T_a s + 1}.$$

The controlled variable, the reference and the disturbance are denoted by y, r and d, respectively.

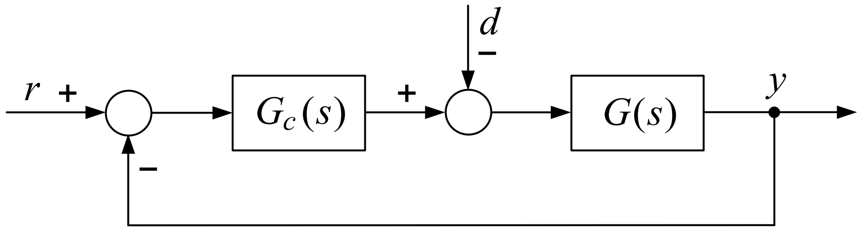

Figure 4 Block diagram of the temperature control system.

The parameter values are

$$k = 2\ ^\circ\mathrm{C}/\%, \quad a_0 = 86000\ \mathrm{s}^3, \quad a_1 = 6100\ \mathrm{s}^2, \quad a_2 = 140\ \mathrm{s},$$

$$k_c = 1\ \%/\ ^\circ\mathrm{C}, \quad T_I = 120\ \mathrm{s}, \quad T_D = 20\ \mathrm{s}, \quad T_a = 1\ \mathrm{s}.$$

(a) Use Simulink to plot the response of $y(t)$ to

$$r(t) = r_0 1(t), \qquad r_0 = 80\ ^\circ\mathrm{C},$$

$$d(t) = \begin{cases} 0 & if \quad t < 1000\ \mathrm{s} \\ 8\ \% & if \quad t \geq 1000\ \mathrm{s} \end{cases}.$$

(b) Simulate the control system for the following values of the controller parameters

$$k_P = 2\ \%/\ ^\circ\mathrm{C}, \quad T_I = 120\ \mathrm{s}, \quad T_D = 20\ \mathrm{s}, \quad T_a = 1\ \mathrm{s},$$

$$k_P = 1\ \%/\ ^\circ\mathrm{C}, \quad T_I = 35\ \mathrm{s}, \quad T_D = 20\ \mathrm{s}, \quad T_a = 1\ \mathrm{s},$$

$$k_P = 1\ \%/\ ^\circ\mathrm{C}, \quad T_I = 35\ \mathrm{s}, \quad T_D = 7\ \mathrm{s}, \quad T_a = 1\ \mathrm{s}$$

and compare the results obtained.

Directions

A Simulink model of the temperature control system is shown in Figure 5. The PID controller block is taken from the Continuous library group.

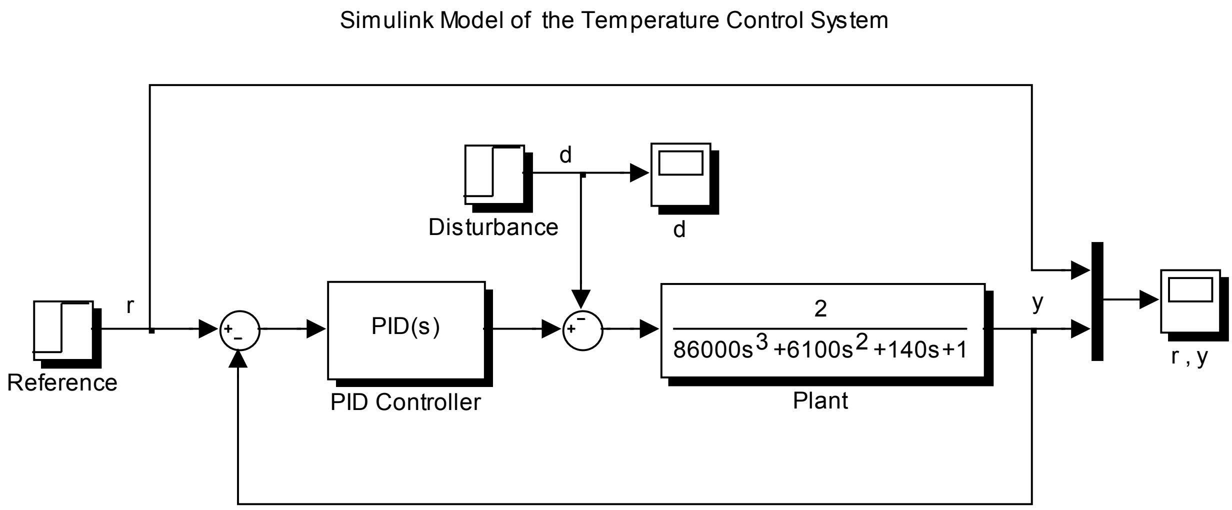

Figure 5 Simulink model of the temperature control system.

Report Content

The lab report should contain the following:

- The objective of the lab.
- Formulation of the tasks.
- Simulink models and obtained plots.
- Discussion of the obtained results.
- Conclusion.