Chapter II-2

Plant Modeling in Time Domain

II-2.1 Objectives

In Chapter II-1, a model of the motor system was derived in the Laplace domain. In this chapter, the plant will be modeled in the time domain. Hence, the objective of this lab is to find an open-loop state-space model of the motor system.

II-2.2 State-Space Representation

Control systems are often studied through their state-space representations rather than transfer functions. Some of the main advantages of state-space representations over transfer functions are the following:

- They can model SISO as well as MIMO systems.
- They are suitable for linear as well as nonlinear systems.
- They are capable of modeling time-independent and time-dependent systems.

II-2.2.1 Open-Loop Analysis

In this part, you will study the open-loop motor system through its state-space model

Pre-lab

P-II-2.1. Using the motor description and equations in Section II-1.2, derive a state-space model of the open-loop motor system. The system's output is the motor speed ω_m while the external inputs are the armature's applied voltage v_m and the disturbance torque T_d. You may adopt ω_m and the motor's armature current i_m as the system states. In other words, the state vector $\mathbf{x} = [\omega_m \ i_m]^T$, and the input $\mathbf{u} = [v_m \ T_d]^T$. (20 pts)

Pre-lab

(5 pts) P-II-2.2. From your state-space model compute the transfer function $\omega_m(s)/V_m(s)$ (without passing by the signal flow graph and Mason's formula). Compare your solution to that of Pre-lab question P-II-1.5.

(10 pts) P-II-2.3. Use your state-space model to draw a signal flow graph of the open-loop motor system. Make sure to identify the nodes corresponding to the states and their time-derivatives in the graph. Compare the graph to your solution of Fig. II-1.2 in Chapter II-1. Comment on the similariries between the two?

(10 pts) P-II-2.4. Now, use the signal-flow graph to compute this transfer function $\omega_m(s)/V_m(s)$. Compare that to your solution of Pre-lab questions P-II-2.2 and P-II-1.5.

(10 pts) P-II-2.5. Repeat the previous pre-lab question to compute the transfer function $\omega_m(s)/T_d(s)$. Note that in this case, you are supposed to compare with your solution of Pre-lab question P-II-1.6.

(10 pts) P-II-2.6. Use your state-space model to compute the system's pole(s). Compare your result with that of Pre-lab question P-II-1.8. What can you conclude?

(5 pts) P-II-2.7. Use your state-space model to find an expression of the armature current at steady state (when all signals reach their final values) in terms of the motor parameters.

(10 pts) P-II-2.8. Simulate the state-space model in Matlab using the command `[y,t,x]=lsim(...)`[a] or `[y,t,x]=step(...)`[b] and plot the curves of the states (speed and current). Assume that there are no disturbances acting on the system. Note that you may also want to specify an initial condition if it is not zero. Use the following matrices in your simulation:

$$\text{system matrix} = \begin{bmatrix} -0.8315789474 & 1379423.59799655 \\ -385.4271817932 & -2117.6470588235 \end{bmatrix}$$

$$\text{input matrix} = \begin{bmatrix} 0 & 1052631.57894737 \\ 294.1176470588 & 0 \end{bmatrix}$$

[a] http://www.mathworks.com/help/control/ref/lsim.html
[b] http://www.mathworks.com/help/control/ref/step.html

II-2.2.2 Closed-Loop Analysis

In this section, we will use an approximation of the motor's open-loop transfer function as first-order model,

$$G_p(s) = \frac{\omega_m(s)}{V_m(s)} \equiv \frac{K_m}{\tau_m s + 1}$$

This is often a valid approximation of DC motor transfer functions, as shown in Chapter II-1.

Attention

The values of the DC gain and time constant will be provided by the instructor.

Pre-lab

P-II-2.9. In Matlab, simulate the step response of the open-loop motor $G_p(s)$, and include the transient response graph. The plot must clearly show the transient response characteristics of the system (time constant, settling time, and output steady-state value).
In practice, do you think it is easy to change the model of the plant? Explain. (10 pts)

We are now interested in changing the system behavior. One way of achieving this is by introducing an output feedback which results in relocating the system's pole(s).

Let $e = v_r - K_\omega \omega_m$ and the control signal (input to the motor) $v_m = K_p\, e$, where K_ω is the motor's speed sensor gain (see Table I-1.1), acting as a feedback gain, and K_p is a positive design gain.

This control scheme is depicted in Fig. II-2.1, where $H_s(s) = K_\omega$ and $G_c(s) = K_p$.

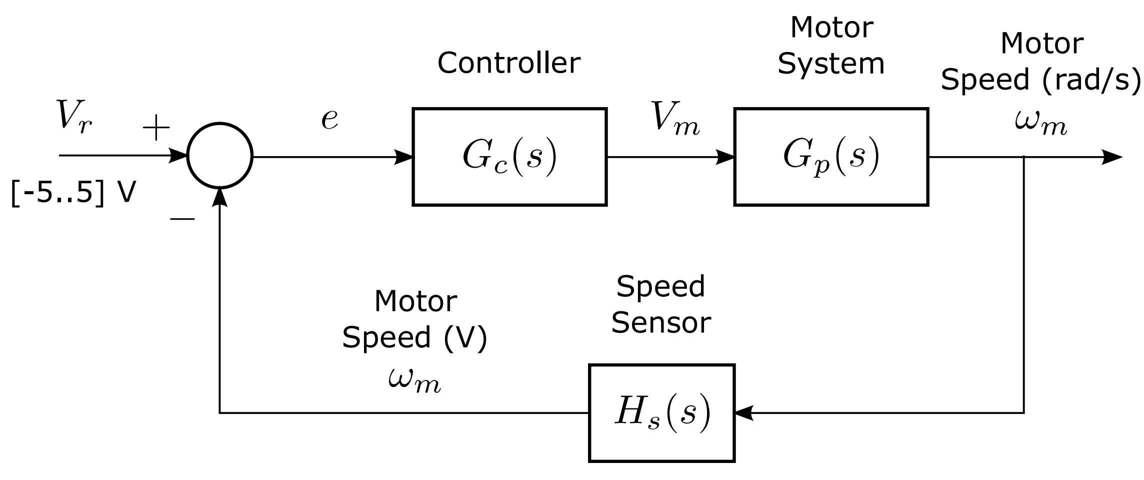

Figure II-2.1: Block diagram of a speed feedback control for the motor system

Pre-lab

P-II-2.10. Derive the state-space model of the closed-loop system. You may take the motor speed as a state. (10 pts)

P-II-2.11. Compute the closed-loop poles. What effect does increasing the free parameter K_p have on the closed-loop poles, and so on the closed-loop response? (10 pts)

(10 pts) Pre-lab

P-II-2.12. Simulate the state-space model in Matlab for four positive values of K_p. Include the step response figures of the simulations in your pre-lab report. Avoid choosing too close values, and do not choose values that may saturate the control signal v_m. Check Fig. I-1.4 for the saturation limits. Your plots must clearly show the transient response characteristics of the system (time constant, settling time, and output steady-state value).

II-2.3 Lab Procedure

In the laboratory, you will validate the simulations you conducted earlier for the open- and closed-loop system.

L-II-2.1. Connect the K-MCK and the K-ECS boards and launch the K-CSP, as described in Chapter I-1.

L-II-2.2. Upload the appropriate firmware (Hex file) to the K-ECS board.

II-2.3.1 Validation of Open-Loop Model

You will begin by validating your plant's open-loop response. To do so, follow the following procedure.

L-II-2.3. Load this part's configuration file (kcsp file), if any, to the K-CSP.

L-II-2.4. Apply the settings shown in Fig. II-2.2 with the following exceptions:

a) Make sure you pick the right communication port.

L-II-2.5. Run the experiment and save your plots and copy the raw data (csv file) on your personal storage media, such as a USB key, for later use. You may want to give them meaningful names so that they do not get mixed up with the files of other experiments.

(10 pts) Demo

D-II-2.1. Make sure you demo to the TA your run before leaving the lab.

(20 pts) Report

R-II-2.1. Include the plots of your experimental and simulation results (from pre-lab question P-II-2.9). To plot experimental data, use the experimental raw data you saved in the lab, to plot the transient response of the system.

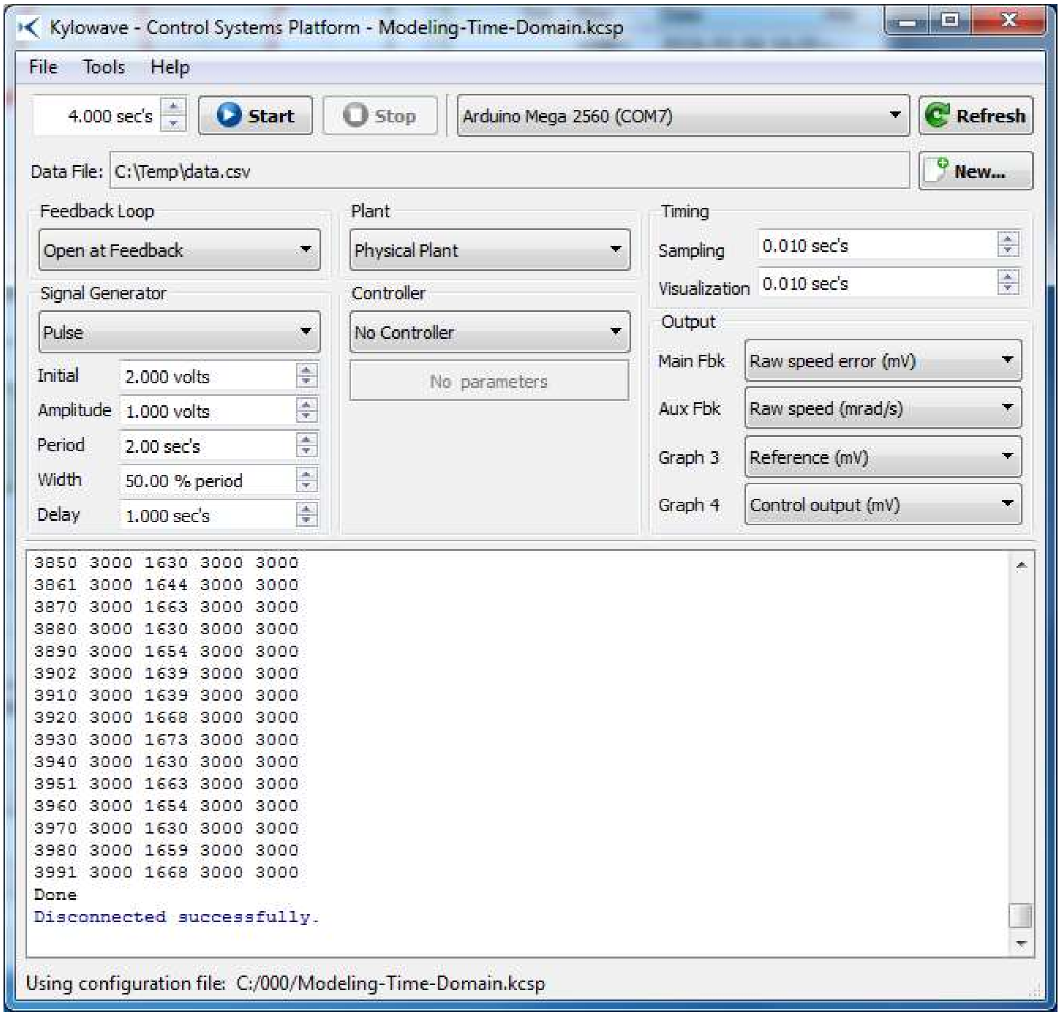

Figure II-2.2: K-CSP settings for open-loop system

Report

One excitation cycle is enough. Make sure to shift the x- and y-axis scales so that the graph starts from $(0, 0)$. All your numerical and experimental plots must clearly show the time constant, settling time, and output steady-state value.
Compute the response characteristics (DC gain, time constant, and settling time) from your simulation and experimental plots. Comment on how close (or far) they match.

II-2.3.2 Validation of Closed-Loop Model

You will validate the closed-loop response you simulated earlier.

L-II-2.6. Load this part's configuration file (kcsp file), if any, to the K-CSP.

L-II-2.7. Apply the settings shown in Fig. II-2.3 with the following exceptions:

a) Make sure you pick the right communication port.

b) Enter your value of K_p in front of "Kp Gain".

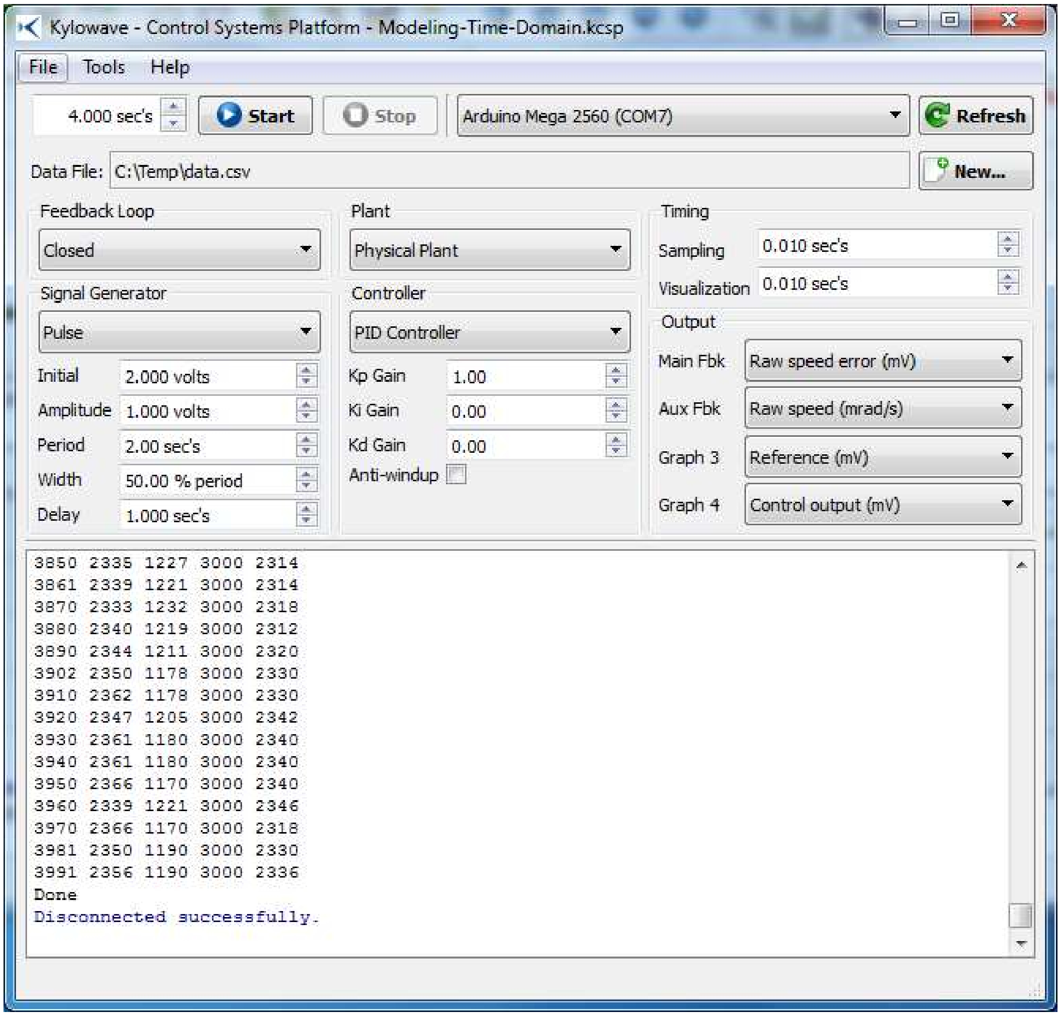

Figure II-2.3: K-CSP settings for closed-loop system

L-II-2.8. Run the experiments with the the gain values K_p that you chose earlier.

Save your plots and copy the raw data (csv file) on your personal storage media, such as a USB key, for later use. You may want to give them meaningful names so that they do not get mixed up with the files of other experiments.

(10 pts) **Demo**

D-II-2.2. Make sure you demo to the TA at least one of your runs before leaving the lab.

Report

R-II-2.2. Include the plots of your experimental and simulation results (from pre-lab question P-II-2.12). To plot experimental data, use the experimental raw data you saved in the lab, to plot the transient response of the system. One excitation cycle is enough. Make sure to shift the x- and y-axis scales so that the graph starts from $(0, 0)$. All your numerical and experimental plots must clearly show the time constant, settling time, and output steady-state value. (20 pts)

Comment on how close (or far) they match, and whether your earlier analysis on the effect of increasing K_p is confirmed experimentally.

Attention

When answering pre-lab or lab report questions, ALWAYS indicate the number of the question you are answering.