Chapter II-4

Control of Motor Speed Error

II-4.1 Objectives

The objective of this lab is to study and control the speed of a DC motor and its actuation error using a P and PI controllers.

II-4.2 Introduction

Figures II-4.1 and II-4.2 show the block diagrams of speed and position feedback control systems of a DC motor. The objective of this laboratory is to study the actuation error of both systems and its relation with the type of the system. The error signal is denoted by e in both figures.

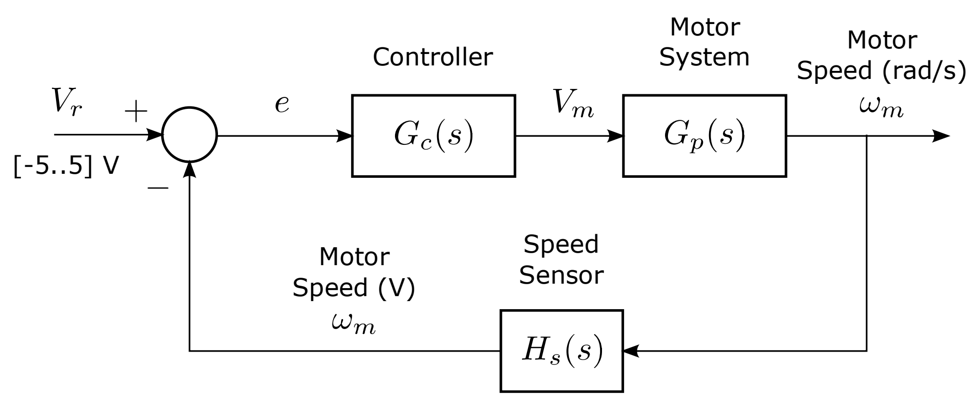

Figure II-4.1: Block diagram of a speed feedback control for the motor system

As we did previously, the motor (plant) will be modeled by its first-order approximation,

$$G_p(s) = \frac{K}{\tau\, s + 1}$$

where K and τ are process' DC gain and time constant, respectively.

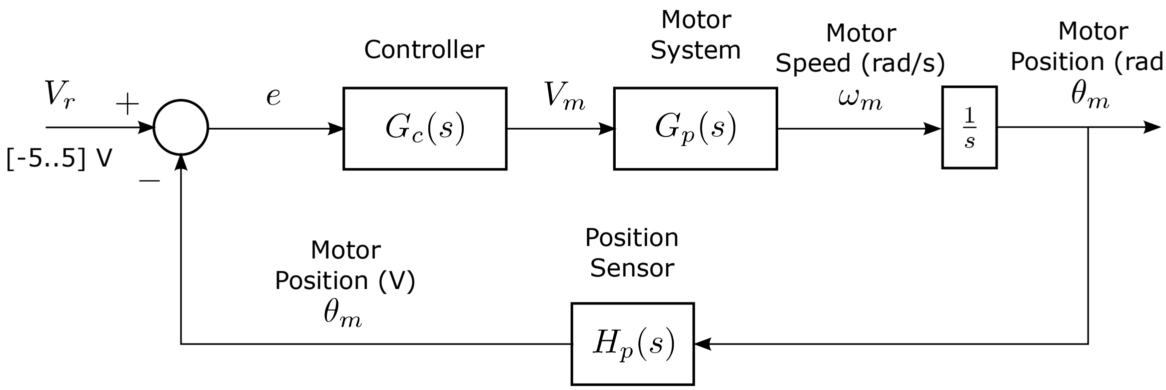

Figure II-4.2: Block diagram of a position feedback control for the motor system

The speed sensor converts the motor's rotational speed in rad/s to its corresponding voltage. The sensor's transfer function is approximated by a positive constant (K_ω) which is also known as the sensor's sensitivity. In other words,

$$H_s(s) = K_\omega.$$

Likewise, the position sensor converts the motor's angular position in rad to its corresponding voltage. The sensor's transfer function is approximated by a positive constant (K_θ) which is also known as the sensor's sensitivity. In other words,

$$H_p(s) = K_\theta.$$

The values of K_ω and K_θ are reported in Table I-1.1.

In this laboratory, the focus will be on controlling the motor speed and its error (see Fig. II-4.1).

Pre-lab

(2 pts) P-II-4.1. Find the value of the reference signal v_r to pass as an input to the system which is equivalent to a constant value of 7.2 rad/s.

(2 pts) P-II-4.2. Repeat the above question for a ramp input with a slope of 0.369 rad/s^2.

II-4.3 Proportional Control of Motor Speed

You will first start by studying the performance of a Proportional compensator to control the motor speed.

$$G_c(s) = K_p > 0$$

Pre-lab

P-II-4.3. Find an expression of the system's transfer function $T(s)$. Do not substitute the parameters with their values yet.
Deduce the system's order and type (i.e., type 0, 1, 2, etc.) (4 pts)

P-II-4.4. Find the expression of the error transfer function $E(s)/V_r(s)$, and deduce the steady-state error for: (i) a step input V_r, and (ii) a ramp input $V_r\,t$. Do not substitute the parameters with their values yet. (10 pts)

P-II-4.5. Find the expressions of the static position and velocity error constants, K_{ep} and K_{ev}, respectively. Use these error constants to deduce the steady-state error for: (i) a step input V_r, and (ii) a ramp input $V_r\,t$. Do not substitute the parameters with their values yet. (10 pts)

P-II-4.6. Do you think a proportional controller is able to annihilate the system's actuation error for: (i) a step input, and (ii) a ramp input? Explain. (4 pts)

Attention

For the following questions, substitute the system parameters with their respective values. The motor's DC gain K and time constant τ will be provided by your instructor.

Pre-lab

P-II-4.7. For the input of Pre-lab Step P-II-4.1, what gain values of the controller lead to a constant steady-state error equivalent to $+1.6\,\mathrm{rad/s}$, if possible? (5 pts)

P-II-4.8. For the input of Pre-lab Step P-II-4.2, what gain values of the controller lead to a constant steady-state error equivalent to $+1.6\,\mathrm{rad/s^2}$, if possible? (5 pts)

II-4.4 PI Control of Motor Speed

You will now study the performance of a PI compensator to control the motor speed.

$$G_c(s) = K_p + K_i\,\frac{1}{s} \qquad\qquad K_p\ ,\ K_i > 0$$

Pre-lab

P-II-4.9. Is there an advantage of using a PI controller over its P counterpart in this case? Explain the theory behind your answer. (4 pts)

(38 pts) e-lab

P-II-4.10. Repeat Pre-lab Steps P-II-4.3 to P-II-4.8 with the PI controller.

II-4.5 Lab Procedure

In the laboratory, you will validate your earlier findings.

L-II-4.1. Connect the K-MCK and the K-ECS boards and launch the K-CSP, as described in Chapter I-1.

L-II-4.2. Upload the appropriate firmware (Hex file) to the K-ECS board.

L-II-4.3. Load this lab's configuration file (kcsp file), if any, to the K-CSP.

L-II-4.4. Apply the appropriate settings to the K-CSP. Remember, the "Main Fbk" signal must always correspond to the feedback error. In this case, it is the raw speed error.

L-II-4.5. Do not forget to choose PID Controller as your controller type.

L-II-4.6. Run the experiments corresponding to pre-lab questions P-II-4.7 and P-II-4.8 for the P and PI controllers.
If you have the luxury of having a free gain in the case of the PI controller, try to choose it conveniently to avoid signal saturations and to clear illustrate the purpose of the experiment.
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.

Demo

(20 pts) D-II-4.1. Make sure you demo to the TA all 4 your experiments with your original calculated gain values before leaving the lab.

(20 pts) D-II-4.2. In case the computed controller gains didn't lead to the target error, fine tune them until the error is experimentally shown to be as close as possible to the desired one, and demo your results to the TA.
Save your plots and copy the raw data (csv file) on your personal storage media.

II-4.6 Laboratory Report

Report

R-II-4.1. Include all the figures you demonstrated to the TA in steps D-II-4.1 and D-II-4.2. Make sure they are clear enough to make the TA reach the same conclusion you did. (20 pts)

R-II-4.2. In which cases didn't your computed controller gains lead to the target error? Enumerate some possible reasons for that. (5 pts)

R-II-4.3. Is the steady-state error proportional to the magnitude of a step input when a P-controller is used? Justify your answer formally (mathematically). (10 pts)

R-II-4.4. Do you think it is possible to completely annihilate the speed control system's error to a step input with a P-controller? Explain. (10 pts)

Attention

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