EENG307: Controlling DC Motors*

Lecture 21

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Contents

1 Pre-requisite Material

This lecture assumes that the reader is familiar with the following material:

- Lecture 17: Proportional-Integral-Derivative (PID) Control Design, Simulation, and Evaluation
- Lecture 20: Modeling DC Motors

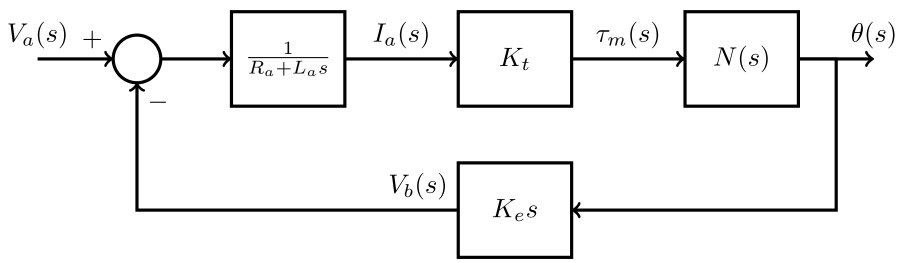
2 Feedback Control for DC Motors

As mentioned in Lecture 20: Modeling DC Motors, DC motors are used in many applications. Although the process for modeling the DC motor may seem a little more complicated than for other types of systems we have studied, the control design process and verification is essentially the same. We will likely still have specifications in terms of the steady state response (e.g., reference tracking, disturbance rejection) and transient response (e.g., rise time, settling time, and percent overshoot in response to a step input) that will impact both our choice of controller structure and the gain values K_P, K_I, and K_D that we select.

Starting with the DC motor plant system with arbitrary load:

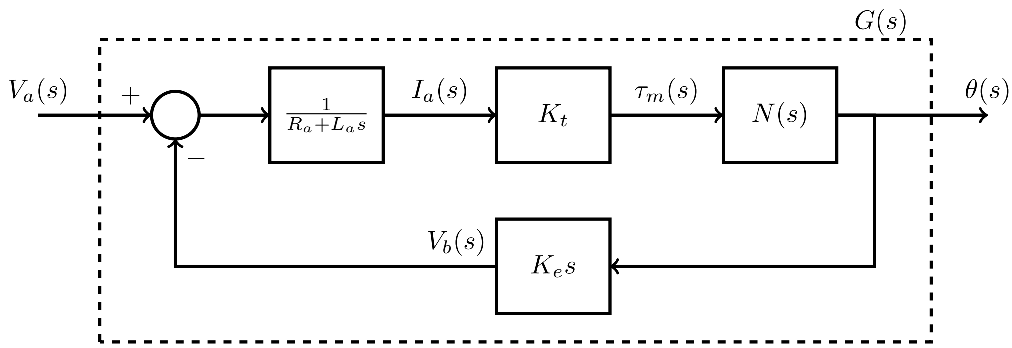
DC motor block diagram with arbitrary load

†Developed and edited by Tyrone Vincent and Kathryn Johnson, Colorado School of Mines, with contributions from Salman Mohagheghi, Chris Coulston, Kevin Moore, CSM and Matt Kupilik, University of Alaska, Anchorage

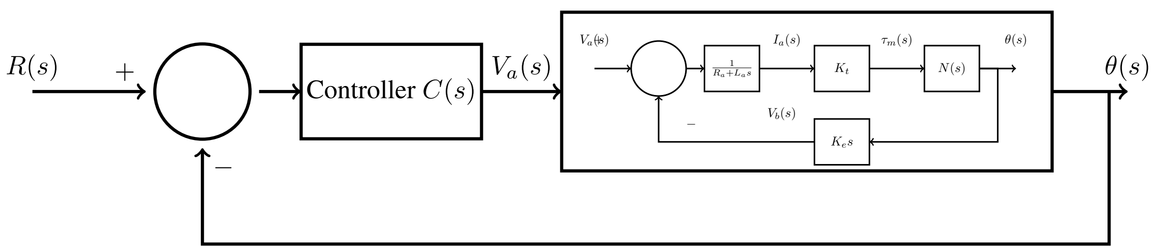


we first emphasize that this system with input $V_a(s)$ and output $\theta(s)$ is the *open loop plant*, i.e., the $G(s)$ that is a single block in our standard closed-loop feedback control system, as is shown in the next two block diagrams.

DC motor block diagram is the open loop plant



Feedback control of DC motor with plant shown



DC Motor Control Video Example

Consider the DC motor control problem shown in the video https://www.youtube.com/watch?v=dTGITLnYAY0.

While watching the video, please respond to the following prompts:

DC Motor Control Prompts

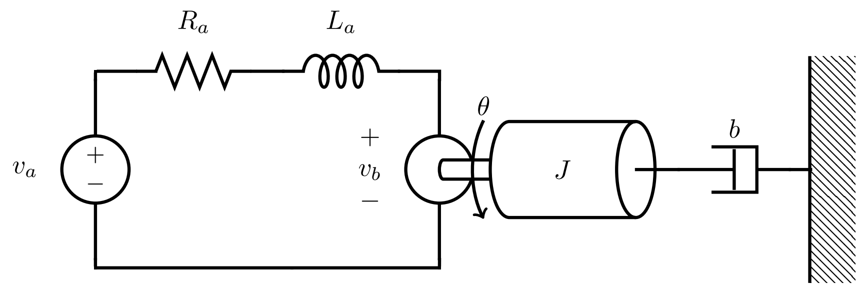
- What hardware is needed? Consider plant (DC motor), sensor, actuator and controller.
- What two physical components are considered as part of the "plant" in the video?
- What is the reference input signal called in the video?
- What kind of controller is used in the video?
- How are the integral and derivative terms estimated in this discrete-time control algorithm?
- What is the performance of the feedback controller at the first test? Consider both steady-state and transient (rise time, settling time, and percent overshoot) response.

- What control term is tuned to solve the problem identified in the previous step?
- What reference input signals are used?
- What types of disturbances are expected to impact the DC motor system?

Note that the video shows some Arduino code that goes beyond what we will learn specifically in EENG307 but that could be helpful if you have a control-related project in another class.

3 DC Motor Position Control Example

Example 1. Let's look at the problem of designing a controller so that a motor can accurately position a rotational load. In other words, we want the output signal θ to track a desired reference r with parameters and specifications to be provided below.



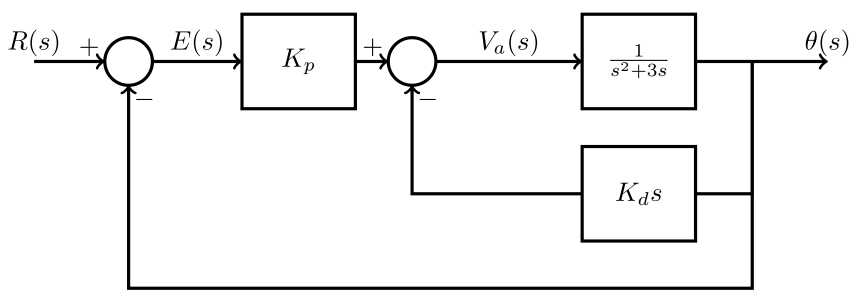
The system parameters are: $R_a = 1$, $L_a = 0$, $J = 1$, $b = 2$, $K_e = K_t = 1$. We want to design a controller so that the orientation θ will follow a step reference with specifications:

- rise time, $t_r = .1$ s
- overshoot, $\%OS = 10\%$.

By comparison of this example to the one in Lecture 20: Modeling DC Motors, we can see that the (open loop) transfer function $\theta(s)/V_a(s)$ is

$$\frac{\theta(s)}{V_a(s)} = \frac{K_t}{s((Js+b)(R_a+L_as)+K_tK_e)} = \frac{1}{s((s+2)+1)} = \frac{1}{s^2+3s}$$

Notice that both of the specifications are related to transient response, so it might be a good idea to try a PD control structure first. Let's use the "Physically-derived" system configuration (Lecture 13) for this example, in which case the closed-loop system block diagram looks like the following:



Because the system is second order with no zeros, it is possible to choose the gains K_p and K_d directly from the closed loop transfer function. In this case, the closed loop transfer function from the reference command is

$$\frac{\theta(s)}{R(s)} = \frac{K_p}{s^2+(3+K_d)s+K_p}$$

This looks like our canonical second order system

$$G(s) = K \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

with $\omega_n^2 = K_p$, $2\zeta\omega_n = 3 + K_d$ and $K = 1$.

To choose K_p and K_d, we find a set of complex conjugate poles that will meet our specifications. Remember that we have already parameterized our specifications in terms of ζ and ω_n:

- $t_r = \frac{2.2}{\omega_n} = .1$ implies $\omega_n = 22$
- $\%OS$ =10% implies $\zeta = \frac{-\ln\left(\frac{10\%}{100\%}\right)}{\sqrt{\ln\left(\frac{10\%}{100\%}\right)^2 + \pi^2}} = .59$

Thus

$$\begin{aligned} K_p &= \omega_n^2 = 22^2 = 484 \\ K_d &= 2\zeta\omega_n - 3 = 2(.59)(22) - 3 = 22.96 \end{aligned}$$

4 Application Example

Consider the DC motor control example shown in the video https://www.youtube.com/watch?v=ojuAATNIfNE. Respond to these prompts for the example in this video, which are similar to those in Section 2.

- What hardware is needed? Consider plant (DC motor), sensor, actuator and controller.
  A Quanser DC motor is shown but not specified.
- What kind of model validation is done in the video prior to developing a feedback controller?
  The video shows a "bump test", which entails changing the open-loop plant's input voltage $v_a(t)$ in a series of steps and adjusting the model parameters to better match the experimental results. We will do something similar in the upcoming Lecture 23: System Identification.
- What kind of controller is used in the video?
  PID control
- What is the performance of the feedback controller at the first test? Consider both steady-state and transient (rise time, settling time, and percent overshoot) response.
  In the speed control experiment, we see high percent overshoot and a long settling time. In the position control experiment
- What control term is tuned to solve the problem identified in the previous step?
  In the speed control experiment, proportional and integral gains. In the position control experiment, proportional and derivative gains.
- What reference input signals are used?
  In both experiments, the reference signals are steps (i.e., "stepwise constant" changes in desired speed or desired position).
- What types of disturbances are expected to impact the DC motor system?
  step

5 Lecture Highlights

The primary takeaways from this article include

1. A common point of confusion with DC motors is that the feedback path inherent in the DC motor path is a feedback controller, but it is not.
2. Once the plant model $G(s)$ has been obtained, controlling a DC motor requires the same process of evaluating specifications, selecting control parameters, and verifying performance as the design of controllers for other types of systems that we have done in this class.