Modeling, Feedback Control Design and Simulation of an Industrial Motion Application

Overview:

You are to design and simulate a positioning control system for an industrial application. The system consists of a digital controller, a DC motor drive (motor and power amplifier), and a load of 235 lbs that is to be moved linearly by 12 inches in 0.3 second with an accuracy of 1% or better. A belt and pulley mechanism is used to convert the motor rotation to a linear motion. The design process involves:

1. Selection of components including: motor, power amplifier, the belt-and-pulley, the feedback devices (position sensor and/or speed sensor)
2. Modeling of the plant
3. Control design and simulation
4. Implementation and tuning

Steps 1 and 2 have been completed by Profs Don and Jack Zeller. The result is shown below. You are to complete step 3. Hopefully, you will find a chance to do step 4 as part of your job later on.

System Parameters:

1) Electrical:
   - Winding resistance and inductance Ra = 0.4 ohm, La = 8 mH
   - back emf constant Ke = 1.49 v/(rad/sec)
   - power amplifier gain Kpa = 80
   - current feedback gain Kcf = 0.075 v/amp
   - control voltage Vc = ± 8 volts
   - motor voltage Vm = ± 160 volts
   - armature current Ia = ± 100 amps

2) Mechanical:
   - Torque constant Kt = 13.2 in-lb/amp
   - motor inertia Jm = 0.05 lb-in-sec^2
   - Pulley radius Rp = 1.25 in
   - load weight W = 235 lbs (including the assembly)
   - total inertia Jt = Jm + Jl = 0.05 + (W/g)Rp^2 = 1.0 lb-in-sec^2

With the maximum armature current set at 100 amp, the maximum torque = KtIa = 13.2*100 = 1320 in-lbs; the maximum angular acceleration = 1320/Ia = 1320 rad/sec^2, and the maximum linear acceleration = 1320*Rp = 1650 in/sec^2 = 4.27 g’s (1650/386). As it turned out, they are sufficient for this application.

Simulation Model:

From the above discussion, the Simulink model of the plant is constructed as in Figure 1. In Simulink, this can be defined as a single block subsystem, as shown in Figure 2. The closed-loop control with a PID controller can now be simulated.

Tasks:

1. Construct the model in Simulink.
2. Determine the transfer functions from V_c to V_el and to P_pos, ignoring saturation.
3. Determine the type, relative order, poles, and, zeros of the plant.
4. Simulate and plot the open loop step response, $V_{el}$, of the plant in Figure 1 with $V_c = 2$ and 10 volt, respectively. Compare that with the one obtained from the open loop transfer function model in #2.

5. Design the PID controller, as shown in Figure 2, so that the load is moved 12 inches in 0.3 second with no overshoot. Select the controller parameters so that armature voltage and current are as smooth as possible. Simulate the closed-loop system and verify the design by observing the step response.

6. Extra Credit: Tune the controller using Zeigler-Nichols tuning rules and plot the closed loop response. Retune the controller by hand to meet the requirements, plot the results on the same plot, and comment.

**Report:**

Write the report as a formal technical document with a title page, table of contents, sub-section titles, appendices, etc. It should include an introduction, the design process, reasoning, the simulation results, and a summary of what you have learned in this process. The graphs should flow with the text. Document all of your Simulink programs and m-files.

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**Figure 1: Plant**

*Diagram showing the plant with inputs and outputs labeled.*

**Figure 2: Closing the Loop with PID**

*Diagram showing the closed-loop system with PID control.*