

ECE 557: Control, Signals, and Systems Laboratory

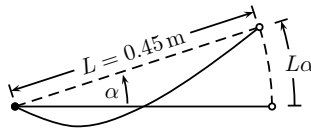
Notes for Labs 8 and 9 (Position Control for a Flexible Link and a Flexible Joint)

1. Return PID pre-lab and give some notes (as in class, use **fixed-step ode45/ode5** solver in *Simulink*).
2. Return lead compensation post-lab and give notes (not just for speed: adds phase margin (and **noise!**)).
3. Review PID tuning rules (proportional/potential/power, integral/introduces, derivative/damping).

- **Proportional** sets available control effort (think *potential/power*). Big impact on ω_d & *rise time*.
- **Integral** reduces steady-state error but *introduces* overshoot/lag (systems today are already slow).
- **Derivative** reduces overshoot but can increase steady-state error (think *damping*).
 - By damping *transients*, derivative can make system faster with respect to *settling time*.
 - A fast system *tracks* the input faster — transients quickly die out.
 - This statement does not simply involve the system’s bandwidth.
 - If the system simply has high bandwidth but no damping, its transients may *ring* for a long time causing annoyance or instability.
 - But **too much** derivative can amplify noise or demand too much control effort.

4. Explain strain gage gain.

- Book asks you to explain “how we obtained the strain [gage] gain” of 0.0254/0.45.
- The book notes the length of the link is $L = 0.45$ m and hopes that you’ll know the strain gage is calibrated to give you deflection in inches (note: 1 in = 0.0254 m).
- Despite what it seems, the strain gage gain is *not* simply a unit conversion from inches to meters.



- (i) As the link deflects, its shape changes and the strain gage, which is located near the axis of rotation, is stretched (or compressed). We measure the magnitude of this stretch.
 - (ii) For **small** deflection α , the arc length $L\alpha$ is approximately equal to the elongation of the link under the bending stress.
 - (iii) Given an approximation of the arc length $L\alpha$, dividing it by L gives an approximation of α .
 - (iv) The strain gage is calibrated so that 1 in of deflection corresponds to 1 V of measurement.
- So

$$\alpha \approx \overbrace{(\text{Measurement in V}) \times \frac{1 \text{ in}}{1 \text{ V}} \times \frac{0.0254 \text{ m}}{1 \text{ in}}}^{\sim L\alpha} \times \overbrace{\frac{1 \text{ radian}}{L = 0.45 \text{ m}}}_{\frac{\alpha}{L\alpha}} = \overbrace{(\text{Measurement in V}) \times \frac{0.0254 \text{ radians}}{0.45}}^{\sim \alpha} \frac{1}{\text{V}}$$

This **linear approximation** is only valid for **small** α . The actual relationship is nonlinear.

5. We use a **low** gear ratio, which is one reason why the system is **slower**.

- The book uses the wrong term.
- The slow system is easier to control.

6. Complete the *Position Control for a Flexible Link and a Flexible Joint* labs.

- ★ FOR PRACTICE, partners should **switch roles** between **joint** and **link** labs.
- Implement PID control for position regulation of both **joint** and **link**.
 - In *Simulink*, choose **Summers** from **Math** section of library (change **++**); adjust shape).
 - Do **not** use PID block. Use components from **Math** and **Continuous** (note: $K_i = 0$).
 - * Implement K_p with gain.
 - * **If needed**, implement K_i with (very small) gain and *integrator*.
 - * Implement K_d with (very small) gain and **transfer function**.
 - Use **transfer function** to implement $as/(s + a)$ “derivative+filter.” Set $a = 200$.
 - Wire from **output** and *not* error. Control will start far too high otherwise.
 - Make sure you **subtract** eventual result (because we’re wiring from *output*).
 - These modifications slow response, but they make derivative *safe* and *realizable*.
 - *If you wish*, wire up a simulated system for comparison. Capture its output as well.
 - * You might relate this to using an *observer* (a subject of ECE 650 and ECE 750).
 - ★ Because it is upside down, encoder for angle α for the **JOINT** needs a $\times -1$ gain as well.
 - ★ You **MUST** implement a **SAFETY STOP** to stop simulation on an extreme measurement.
 - * Make sure DAC block has **0 V Termination** checked **ON**.
 - * Use *relational operator* to compare output to *constant* and trigger a *stop simulation*.
 - ★ **MAKE SURE** you change **saturation** settings to ± 5 and **rate limiter** slew rate to ± 1000 .
- For **link** configuration, adjust **alpha offset** so that $\alpha = 0$ at initial rest.
 - Run control with $K_p = K_i = K_d = 0$. Adjust **alpha offset** with *numeric input* until $\alpha = 0$.
- PID tuning: **joint** ($t_s \leq 0.6$ s / P.O. $\leq 2\%$ / $e_{ss} \leq 0.5\%$) and **link** ($t_s \leq 0.6$ s / P.O. $\leq 5\%$ / $e_{ss} \leq 1\%$)
 - Initial output magnitude is K_p . If $K_p > 5$, initial output will be clipped.
 - Quantization noise from encoder makes derivative very noisy. Keep K_d very low.
 - Use numeric inputs in *ControlDesk* for tuning K_p and K_d gains.
 - **Save YOUR FINAL ITERATION** for the **joint** and for the **link**.
 - While tuning, recall the similar process in the gain compensation lab. Is PID more flexible?
- You do not need separate controllers for the slow version of system, but keep slow system in mind when analyzing data in report! (e.g., compare expected *slow* response to data)
- ★ AT ANY TIME, IF MOTOR STARTS CLICKING VERY QUICKLY, STOP THE EXPERIMENT — DISCONNECT THE MOTOR IF NECESSARY!! High-frequency switching can cause **permanent damage!** It can be caused by unstable systems (e.g., high gains or positive poles).
- ★ This nominally type-1 system may still have some steady-state error due to nonlinearities. Because it is already slow and has a low gear ratio, only a **very little** integral control should be needed.
- ★ The **dangling cables** can add significant dynamics. Keep them loose and out of the way.
- Tips:
 - Do **work** out of directory on **local** hard drive — use as MATLAB working directory.
 - In *Simulink*, the hotkey for building a model is **Ctrl** - **B**.
 - Start *dSPACE ControlDesk* before doing *Simulink* builds.
 - In MATLAB, change *Termination* settings for DAC block — check box to set 0 V stop value.
 - In *dSPACE* add a **simState** control.
 - (i) Wire **simState** to 2-option radio button — Setup options “Run” (**2**) and “Stop” (**0**).
 - (ii) Set **Capture Settings** to *automatically* restart and set *capture time* to simulation time.
 Restart simulation as needed by using **simState** control (i.e., no need to change modes).
 - (i) To stop early, change **simState** to **Stop**.
 - (ii) Before restarting, re-initialize **Capture Settings** by clicking **Stop** and then **Start**.
 - (iii) When you’re ready to start (e.g., after changing gains), set **simState** to **Run**.