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!)).

   - Proportional sets available control effort (think potential/power). Big impact on ωd & 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.

   ![Diagram of strain gage](#)

   (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 Lα is approximately equal to the elongation of the link under the bending stress.

   (iii) Given an approximation of the arc length Lα, 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

   \[
   \alpha \approx (\text{Measurement in V}) \times \frac{1 \text{ in}}{1 \text{ V}} \times \frac{0.0254 \text{ m}}{1 \text{ in}} \times \frac{1 \text{ radian}}{L = 0.45 \text{ m}} = (\text{Measurement in V}) \times \frac{0.0254 \text{ radians}}{0.45 \text{ V}}
   \]

   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 (i.e., references gearbox from unconventional side).
   - The low gear ratio causes a relatively high reduction in the speed of the motor compared to the high gear ratio.
   - 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 \( \pm \alpha \) 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 \( \alpha \) 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 \( \pm 5 \) and rate limiter slew rate to \( \pm 1000 \).
• 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 (\( ts \leq 0.6 \) / P.O. \( \leq 2 \% \) / \( e_a \leq 0.5 \% \)) and link (\( ts \leq 0.6 \) / P.O. \( \leq 5 \% \) / \( e_a \leq 1 \% \))
  - 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 \([\text{Ctrl}]+[\text{Shift}]\) - \( E \).
• 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.