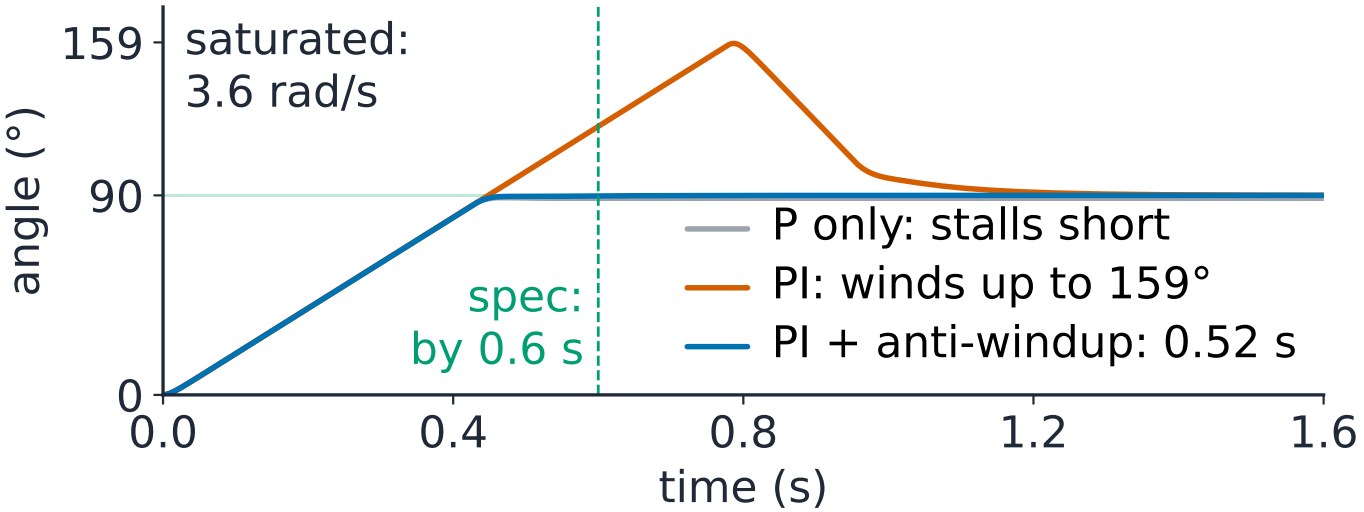
Exercise walk-through

12.7
Mechatronics project

University Mechanical Engineering

The project, simulated



Spec $\pm 0.5°$ by 0.6 s, 5 N · m load: P fails (1.29° short), PI fails (159°), PI + **anti-windup** passes at $\mathbf{0.52}$ s.

Reporting the limits

1. **No load** A 5° step overshoots 18% - the integral zero, normally hidden by the load.
2. **Margin** 0.52 s against 0.6 s; at 11 V only 0.58 s.
3. **Untested** Encoder faults, sticking, copper R $+0.4\%/\mathrm{K}$.

Decision

Passing is a result with a margin and limits, never just a tick.

Check yourself

- The tank and the motor? (τ 2.3 h, 10 K; 19.9 rad/s/V, 9.6 ms, 3.0 V holding.)
- The P loop? (K_p 134, ω_n 74.4, 4.6%, 77 ms; PM 65.2°; 1.29° error.)
- The PI loop? (K_i 993; 159° with windup; 0.52 s with clamping.)
- The digital side and the sensor? (2.1° at 1 kHz, 21° at 100 Hz; 0.042 K/LSB, $\pm$0.24 K.)

Exercises 2.1·2.2

2.1 Give the three checkpoints a simulation must reproduce, with their values: slew rate under load, P-only error, and small-step overshoot. [3]

2.2 Rewrite “the valve must move quickly and accurately” as a measurable spec line. [2]

Exercises 2.1·2.2

2.1 Give the three checkpoints a simulation must reproduce, with their values: slew rate under load, P-only error, and small-step overshoot. [3]

2.1

- Slew rate $\omega_{max} = (V_s - V_{load}) \times 0.414 = (24 - 7.84) \times 0.414 = \mathbf{6.69}$ rad/s (90° in 0.235 s plus start-up).
- P-only error $d/K_p = 7.84/79.4 = 0.0988$ rad $= \mathbf{5.66}°$.
- Small unloaded step with P: $M_p = \mathbf{4.6}\%$ for $\zeta = 0.7$.

2.2 Rewrite “the valve must move quickly and accurately” as a measurable spec line. [2]

2.2

- For example: ”From rest, under an 8 N · m load at 24 V, reach 90° ± 0.5° within 0.40 s and stay there, with overshoot below 5%.”

Exercise 3.1

3.1 Simulation gives: P only, steady 5.66° short; PI without anti-windup, peak 141°, in band at 0.71 s; PI with clamping, in band at 0.31 s with no overshoot; small 5° step without load overshoots 16%. (a) Tabulate pass or fail for each candidate on the band, time and overshoot metrics. (b) State the passing design's time margin. (c) Find the slew time for 90° at 22 V and say whether the margin survives a supply sag, given the clamped design spends 0.08 s beyond the pure slew time. (d) Name two limits the report must state. [9]

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3.1

- (a) P: band fail (never inside), so time fail; overshoot pass.
- PI, no anti-windup: band reached but at 0.71 s, time fail; overshoot 51° (57%), fail.
- PI with clamping: band, time and overshoot all pass.
- (b) $t_{spec} - t_{band} = 0.40 - 0.31 = \mathbf{0.09}$ s.
- (c) At 22 V: $(22 - 7.84) \times 0.414 = 5.86$ rad/s, so the slew takes $1.571/5.86 = \mathbf{0.268}$ s.
- Adding 0.08 s gives about 0.35 s: still inside 0.40 s, with 0.05 s margin.
- (d) Any two: unloaded small steps overshoot 16% (the integral zero); results depend on the supply voltage; untested encoder faults, valve sticking, or winding resistance rising with temperature.