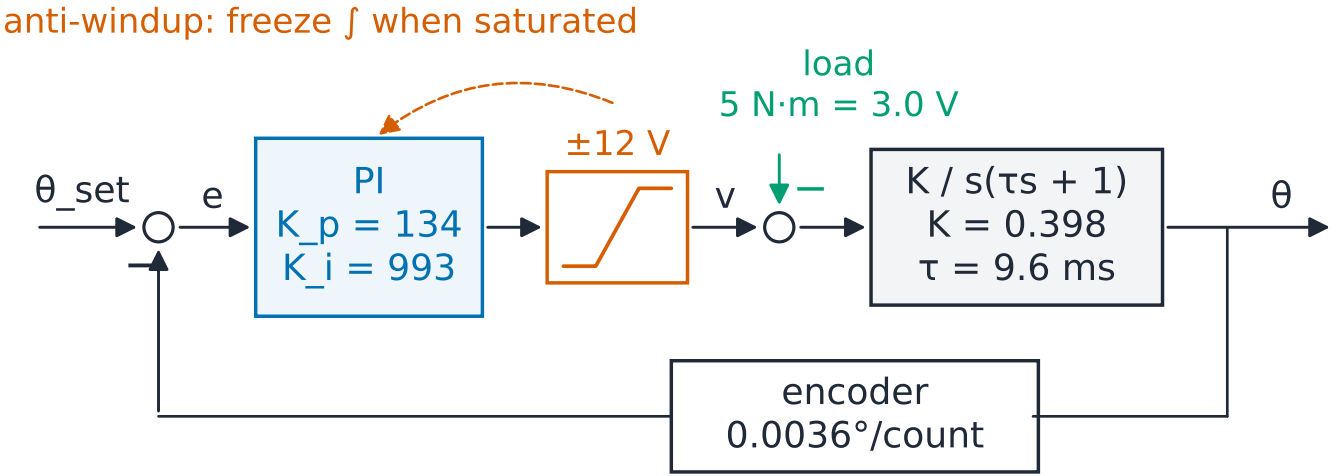
Exercise walk-through

12.4
Feedback and PID control

University Mechanical Engineering

The position loop



P alone stops $3.0/134$ rad $=$ $\mathbf{1.29}^\circ$ short under load; $K_i = K_p\omega_n/10 = \mathbf{993}$ removes it.

Saturation and windup

1. **Demand** 90° step $\times$ 134 V/rad $=$ **210** V asked of a 12 V driver.
2. **Rate limit** $0.398 \times (12 - 3.0) = 3.58$ rad/s under load, for about 0.4 s.
3. **Windup** Integral grows unused; valve carries on to **159**°, in band only at 1.32 s.
4. **Clamp** Hold the integral while saturated $\rightarrow$ no **overshoot**, in band at 0.52 s.

Decision

Test large steps, not only the small ones the linear design predicts.

Exercises 2.1·2.2

2.1 Find the steady error under P control (four decimals, rad, and two decimals, degrees). Does it meet a $0.5°$ spec? [3]

2.2 Choose K_i by the decade rule (one decimal) and give the steady error with it. Why is derivative action usually left out with an encoder? [3]

Exercises 2.1·2.2

2.1 Find the steady error under P control (four decimals, rad, and two decimals, degrees). Does it meet a 0.5° spec? [3]

2.1

- $e = d/K_p = 7.84/79.4 = \mathbf{0.0988}$ rad.
- $= \mathbf{5.66}°$: eleven times the 0.5° spec, fails.

2.2 Choose K_i by the decade rule (one decimal) and give the steady error with it. Why is derivative action usually left out with an encoder? [3]

2.2

- $K_i = K_p\omega_n/10 = 79.4 \times 46.0/10 = \mathbf{365.2}$ V/(rad · s); steady error 0, since the integral grows until the motor sees 7.84 V with $e = 0$.
- Speed from counting encoder steps is coarse, and $K_d\dot{e}$ amplifies that noise into the drive.

Exercise 3.1

3.1 A 90° step is commanded. (a) Find the voltage P control asks for at once (one decimal, V) and say what happens. (b) Find the valve speed at the rate limit under load (two decimals, rad/s) and the time the slew takes. (c) Explain integrator windup during the slew and its effect on arrival. (d) Describe clamping anti-windup and one other remedy. [8]

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3.1

- (a) $u = K_p e = 79.4 \times 1.571 = \mathbf{124.7}$ V against a 24 V supply: the drive saturates and the loop is open.
- (b) $\omega_{max} = (V_s - d) \times 0.414 = (24 - 7.84) \times 0.414 = \mathbf{6.69}$ rad/s; $1.571/6.69 \approx \mathbf{0.23}$ s plus start-up.
- (c) The error stays large while saturated, so $\int e\,dt$ grows with no effect on u. On arrival the stored integral still pushes, driving the valve well past 90° until it unwinds.
- (d) Clamping: stop integrating while the output is saturated and the error would push it further.
- Or back-calculation (bleed the integral by the saturation excess), or rate-limiting the set point so the drive never saturates.