UNIVERSITY MECHANICAL ENGINEERING • EXERCISE SHEET

12.7 Mechatronics project

Name: _____ Class: _____ Date: _____ **Total: 14 marks**

KEY WORDS PID controller PID • integrator windup • anti-windup • rate limit

Objective

Turn a requirement into a measurable spec, check a simulation against results known without simulating, judge candidate controllers against every metric, and report the margins and the limits honestly.

1 Key knowledge and worked examples

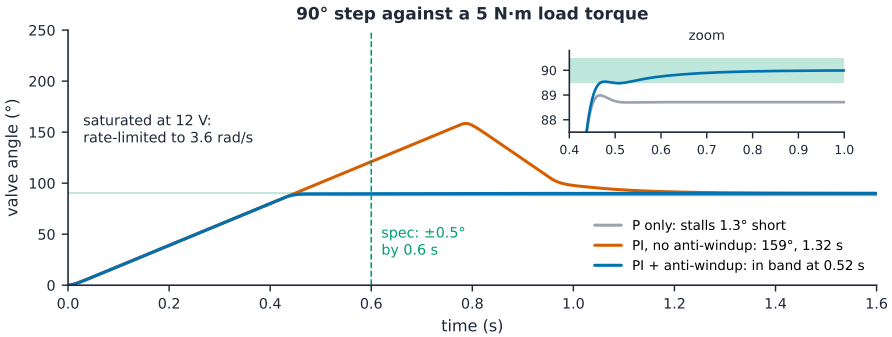
Spec, checkpoints, table, limits

- A spec names a metric, a threshold and the conditions (load, supply).
- Before trusting a nonlinear simulation, check it against hand results: saturated **rate limit** , P-only steady error d/K_p, small-step overshoot of the designed ζ.
- Compare every candidate (P, PI, PI with **anti-windup**) against every metric in one table.
- Report the margin, the conditions it depends on, and what was not tested; **integrator windup** is the usual surprise.

Worked example. The spec table

90° within ±0.5° by 0.6 s, overshoot below 5%, under 5 N · m.

- P only: stops $3.0/134 = 1.29°$ short: **fails**.
- PI without anti-windup: overshoots to 159°, in band at 1.32 s: **fails**.
- PI with clamping: in band at **0.52 s**, no overshoot: **passes**, with 0.08 s of margin.



2 Practice

The 24 V valve drive of sheets 12.2 to 12.4: 0.414 rad/s per volt at the valve, load 7.84 V, $K_p = 79.4$ V/rad, $\zeta = 0.7$. Spec: 90° within ±0.5° by 0.40 s, overshoot below 5%.

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]

3 Exam-style questions

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]

Solutions

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

- 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%."

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.