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.

exercises.lol exercises.com.cn