Solutions

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

- $K_i = K_p\omega_n/10 = 79.4 \times 46.0/10 = \mathbf{365.2}$ 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.

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.

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