Exercises 6: Feedforward Control

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The dynamic relation between input voltage and rotor angle of a DC-motor is approximately described by

$$G(s) = \frac{1}{s(s+1)} \quad .$$

Design a controller for the DC-motor so that the closed-loop system has a steady state error of 0.15 rad for a ramp output disturbance and a steady state error of 0.05 rad for a ramp input signal. The command step response of the closed-loop system should also have a rise time $T_\mathrm{r} < 0.3$ sec and no overshoot ($M_\mathrm{p} = 0\%$).

1. **Design of the feedback loop**
   (a) Design a proportional feedback controller $K(s)$ so that the steady state error requirement for a ramp output disturbance is met.
   (b) Calculate the poles of the obtained closed-loop system. Analyze the pole locations using the dynamic behaviour heuristics in Table 1. Evaluate if the desired dynamic behaviour (T_r, M_p) is attained. How is the dynamic behaviour of the closed loop affected if we try to meet the steady state error requirement for the input signal?
2. **Design of an explicit feedforward controller**
   (a) Design an ideal explicit feedforward controller $K^*_{\mathrm{ff,u}}(s)$.
   (b) Alter the feedforward controller, if necessary, so that the resulting controller $K_{\mathrm{ff,u}}(s)$ is realizable for a servo control application. Make sure that the dynamic requirements (T_r, M_p) are met. You can ignore actuator saturation problems, and neglect the steady state error requirement for a ramp input.
   Hint: When altering the feedforward controller, it is appropriate to also extend the control structure with a setpoint filter. The rise time for a second order system with a double pole on the real axis is given by $T_\mathrm{r} \approx \frac{3.36}{|s_{1/2}|}$.
   (c) Tune the controller $K_{\mathrm{ff,u}}(s)$, so that a steady state error of 0.05 is attained for a ramp input signal.
3. **Design of a prefilter**
   (a) Determine the prefilter feedforward controller that meets the same requirements as the explicit feedforward controller designed above.
   (b) What improvements could be made for both alternative feedforward controllers if the future reference trajectory is known, i.e. if we are designing them for a trajectory tracking application? What changes when we have to take actuator saturation into account?

Peak time T_m	$\frac{\pi}{\omega_0\sqrt{1-\zeta^2}}$
Rise time T_r	$\frac{1.8}{\omega_0}$
Settling time $T_{5\%}$	$\frac{3}{\zeta\omega_0}$
Settling time $T_{2\%}$	$\frac{4.5}{\zeta\omega_0}$

ϕ_ζ	ζ	Δh
$66°$	0.4	25%
$54°$	0.58	10%
$45°$	0.7	5%
$37°$	0.8	2%

Table 1: Dynamic behaviour heuristics of a second order system with complex conjugate poles $\zeta\omega_0 \pm j\omega_0\sqrt{1-\zeta^2}$.