EN4610 Lab Report 2: Liquid Level Control

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1. The Open Loop Unit Step Response

The system's open-loop response to a unit step input (1/s) was analysed to estimate the gain and time constant (ref: open loop step response).

- Gain: $K = (6 - 2) = 4$
- 63.2% of K: $0.632 * K = 2.5$
- Time Constant: $\tau = 150 - 20 = 130s$

Which allows an approximate open loop model for the system:

$$\frac{4}{1 + 130s}$$

2. Closed Loop Controller Design

Applying unit feedback and rearranging into the characteristic 2nd order form, noting that the effect of s and s^2 terms (or zeros) in the numerator are what separate this controller from the 2nd order characteristic equation, adding unwanted system dynamics.

$$\frac{\frac{4}{4K_d + 130}(K_d s^2 + K_p s + K_i)}{s^2 + \frac{4K_p + 1}{4K_d + 130}s + \frac{4K_i}{4K_d + 130}}$$

Initially a PI controller was implemented (k_d=0), to meet zero overshoot constraint $\zeta = 1$ and settling time constraint T_s = 90s following the standard 2nd order characteristic equation:

- $T_{s2\%} = 90s$
- $\omega_n{}^2 = \frac{4K_i}{130}$
- $K_p = \frac{\frac{8 \cdot 130}{90} - 1}{4} = 2.6$
- $\omega_n \leq \frac{4}{90}$
- $2\zeta\omega_n = \frac{4K_p + 1}{130}$
- $K_i = \frac{4^2 \cdot 130}{90^2 \cdot 4} = 0.064$

However, through experimentation 2 factors introducing overshoot to the system response were discovered:

- The remaining zeros were having too large of an effect on the system's response.
- The system itself displayed a cut-off value for input voltage, essentially negating the effect of the integrator (K_i) due to the system's inherent gain K.

To resolve these problems, the experiment was repeated with a pseudo-derivative feedback (PDF) controller:

- The Inner Loop TF becomes: $\frac{C(S)}{U_i(S)} = \frac{4}{1 + 4K_p + 130s}$
- Hence the new closed loop transfer function:

$$\frac{C(S)}{R(S)} = \frac{\frac{4K_i}{130}}{s^2 + \frac{1 + 4K_p}{130}s + \frac{4K_i}{130}}$$

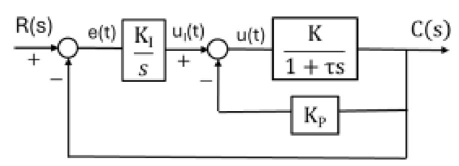

Figure 1: PDF Control Architecture

From this transfer function, we can see that the values of K_p and K_i will remain the same, but the unwanted system dynamics attributed to the zero in the numerator have been eliminated, and the input to the system will be lesser, retaining the effect of the integrator.

3. Implementation & Results

The closed loop controller was implemented and the responses recorded for both PI and PDF unit step inputs. The PI 3-4V response shows steady-state error and overshoot in the system. The 2% settling time, however, is 90s as designed. With the PDF system, the response time was quite similar regarding rise and settling times, though with less steady state error and overshoot (the scale of the PDF provided graphs vary from the initial PI figures).

The response of a negative unit step was also recorded for analysis purposes. The negative unit step response of the controllers show that the system settles faster when undergoing a negative step in voltage. The 2% settling time is within 70s, and the rise time appears proportional to the faster settling time.

4. Analysis

The similar settling times between controllers are appropriate to the designed restraints, and the minimised overshoot and steady state error of the PDF controller is due to the zero being removed from the system, and the preservation of the effect of the integral gain for when it feeds into the system.

Both controllers designed for the system were successful in achieving the 2% settling time within 90s, as required and designed. However, error remains in the overshoot and steady-state constraints, particularly the positive PI step response, and less so the PDF positive step response. This error is in response to:

- Inaccuracy of human measurements
- Non-Linearities in the water column:
  - The non-linearities associated with fluid compressibility of the fluid column.
  - The non-linearities associated with fluid flow in the pump and exit valve.
  - The values for K and τ were calculated using a 5-6V unit step. The further from this setpoint, the less accurate the model's linearisation will be.
- Quantisation errors and high frequency noise from the Digital Analog Converter (+ADC).
- Approximations used in design methodology (settling time approximation)
- The open loop model is a 1st order system. There will be higher order dynamics present throughout the system. These may be almost negligible yet are still unaccounted for.
- The system has inherent delays, likely caused by the pump. This negatively affects system dynamics, potentially limiting bandwidth, response times, accuracy, stability, overshoot and oscillatory behaviour as the pump tries to meet the controller demands.

Furthermore, the positive and negative unit step responses of the closed loop system vary significantly. The negative' responses are faster than the positive. This is because the pump is being controlled, but not the valve's discharge rate (i.e. only the rate fluid is added can be controlled). When comparing the step responses, the negative unit step achieves maximum flow rate faster and replicates the controller's output signal more accurately, suggesting that water cannot be added to the container as fast as the controller desires, limited by the pump dynamics.

5. Future Changes

Derivative control can be Implemented, if boundary constraints 1 and 2 are kept as outlined in the controller design section ($\zeta \geq 1$). This design could raise gain while further countering higher order dynamics and nonlinearities, overall introducing a faster response.