GF1 Control System: 2nd Interim Report

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Introduction

The aim of this week was to make the simulation more realistic, and to explore basic control of the separator level using both proportional and integral control. The effects of lagged inputs is explored, as well as the effects of constraining the values of some quantities.

Lagged Inputs

To realise the system practically, there are control valves controlled by servo-motors which have a small lag. We added first order lag to the product flowrate, steam pressure and cooling water flowrate inputs using an integrator and gain block with negative feedback with gain $\frac{1}{T}$. Across the integrator, $\frac{1}{T}\left(u(t) - x(t)\right) = \frac{dx(t)}{dt}$. Taking Laplace transforms, $\frac{X(s)}{U(s)} = \frac{1}{1+sT}$ i.e. first order lag, as desired. Step inputs were put into the process with and without the lag to verify the response looked sensible.

Proportional Control

It was now set out to control the separator level ($L2$) using a proportional controller to set the product flowrate ($F2$). A negative gain is required since the process has a negative gain from F2 to L2. The first approach is heuristic. The gain was increased until the response to a step in the L2 set-point gave a second order response with desired damping factor – we found K = -27. The response to changes in L2 set point and F1 was investigated (Fig. 1). There is a steady state error after the step, but also before due to initial disturbance from initial conditions. Hayman worked on this part whilst I looked at the linearised design method.

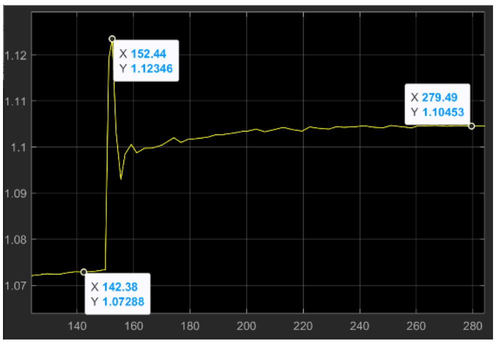


Fig. 1 – L2 response to step increase in F1 from 1 to 1.1

The process system was first linearised about the desired operating point, and the frequency response of the F2-L2 transfer function obtained (Fig. 2). The proportional gain desired is the one to give 45° phase margin. This gain can be calculated from the Bode plot; proportional control will scale the magnitude response, but have no effect on the phase response. Hence the required controller gain is the

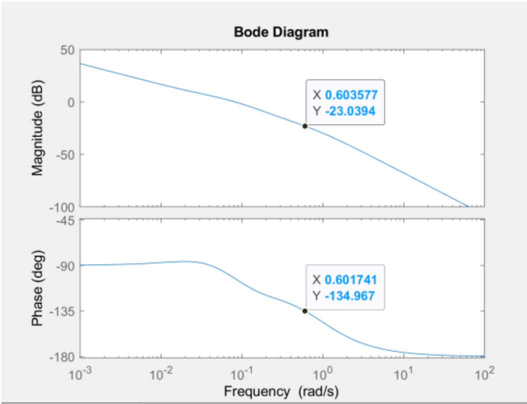


Fig. 2 – Bode Plot of the process linearised about the operating point

gain at which open-loop system has frequency response $-135°$.

In our case, this occurred at $0.6\ \text{rad s}^{-1}$ and required a gain of 23 dB (x14) to be achieved.

Clearly for the this method the phase margin of the controlled system is 45° by design. For the heuristically obtained gain, it can be calculated from the Bode Plot. Since $u = k(y - r)$, $\dot{x} = Ax + kB(y - r)$, so we scale the B matrix by k and read the phase margin from the Bode Plot. For the case of $k = -27$, the phase margin is $36°$.

Integral Action

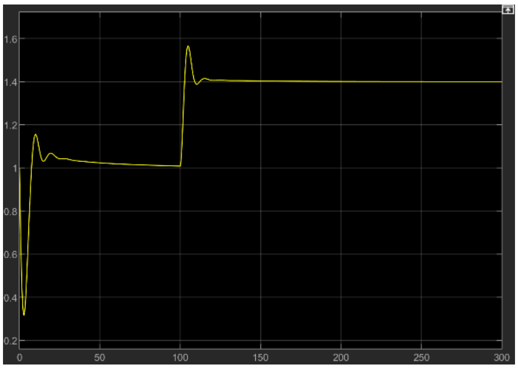


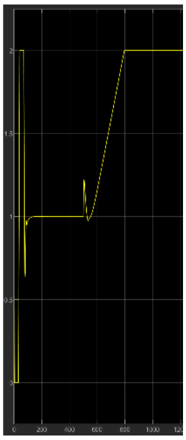
Fig. 2 – PI controlled system response to step in L2 set point.

It was observed before that with step changes in F1, a steady state error is induced in L2. Even though the plant (the separator in particular) contains an integrator, it also has a zero at the origin, so there is a pole-zero cancellation.

To remedy this, an integrator can be included in the controller – PI control: $K(s) = K_p\left(1 + \frac{1}{sT_i}\right)$

The proportional gain was kept as before, and the value of T_i calculated for give a controller phase lag of $5°$ at the crossover frequency of the plant, i.e. $\angle K(j\omega) = -5°$. With $\omega = 0.6\ \text{rad s}^{-1}$ as before, $T_i = 19$. The resulting system removes any steady state error as shown in Fig. 3.

Saturation



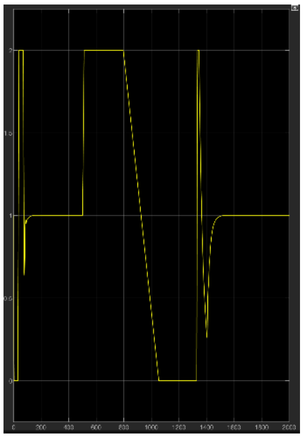


Fig. 3 (left)– PI controlled system response to step in F1 from 10 to 12.4 at 500 s.

Fig. 4 (right) – system response to step in X1 from 5% to 37% at 500 s.

Now, certain quantities such as flowrates, pressures and the separator level are constrained to make the simulation more realistic. For example, the real system will have an upper limit on pressures for safety reasons, and the separator will eventually become fully and cannot be empty. With the constraints applied, the controller still worked well. In steady state, no there were no errors as expected.

Disturbance rejection is good. The controller can reject disturbances in F1 up to 12.3 (+23%) from the operating value, with similar behaviour to Fig. 2. For disturbances any larger, the disturbance cannot be contained as in Fig. 3.

For disturbances in X1, the controller can handle step increases of 32% in feed composition (5% to 37%). However, the response suggests there is severe integrator wind-up present (Fig. 4). The control signal (L2) is saturating which contributes to the wind-up.