GF1 Control System: 1st Interim Report

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Introduction

The focus so far has been on familiarisation with Simulink and the mathematical model of the Industrial Evaporator process. The process consists of four main subsystems: the separator, the evaporator, the steam jacket and the condenser. A model was made for each of these subsystems which were then unit tested before being connected together to form a model of the overall process.

Separator

The inputs into the model of the separator are the feed flowrate (F1), the product flowrate (F2) and the vapour flowrate (F4). The output of the model is the level of liquid within the separator (L2). Since the product and vapour flow out of the separator, their mass flow rates are subtracted from the feed flowrate which flows into the separator. The net flow rate is divided by the density of the liquid and the area of the condenser to get a rate of change of the liquid level, before being integrated to get the liquid level itself. Hence the model contains an integrator, which introduces a state into the system, which Simulink defines as the output of the integrator. This model was unit tested by providing inputs F1, F2 and F4 as a sine wave, step and noise respectively, and the output L2 checked to be sensible (Fig. 1). The step input in F2 is equivalent to turning on a tap to drain the product. In the test, the size of the step was set positive, whereas the sine wave and noise were zero mean. Hence it was expected that the overall liquid level would decrease over time, as seen. Note that at the moment, the model initialises the liquid level at 0.0 m and does not account for an empty container (i.e. the liquid level is not restricted from being negative).

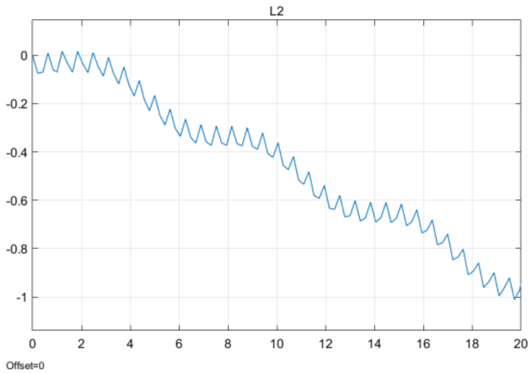

Figure 1: Output of the separator system during unit testing

Evaporator

The evaporator is the most complex of the models in that its behaviour is governed by five equations. Two of these equations contain a variable and its derivative (unlike the condenser equation which just contained a derivative). This requires the state to be fed back in the system, creating a feedback loop, whereas the condenser only contained open loop integration. The evaporator system is too large to check its performance by eye; more thorough methods are needed. To do this, step inputs were provided to all inputs. The total gain around the negative feedback loops can then be used to approximate the time constant of the responses. The loop can be modelled as an overall gain and an integrator, hence $-KX = \frac{dX}{dt} \Rightarrow X = Ae^{-Kt}$, so the time constant $\tau = \frac{1}{K}$. For the operating pressure (P2) loop, the total gain around the loop is 2.5527×10^{-4} giving an expected time constant of approx. 4000 minutes. The transient response of the pressure response shows the value reaches 63% $(1 - \frac{1}{e})$ of the final level after this time, validating the loop. This was also done with the X2 loop, with an overall gain of $\frac{1}{20}$ so a time constant of 20 minutes. This is much faster as the product composition depends on the inputs of feed and product composition and feed flowrate, whereas the operating pressure depends on the product temperature which takes longer to stabilise.

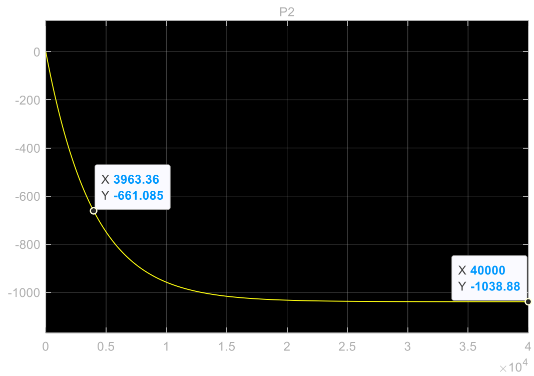

Figure 2: Response of the operating pressure P2 to step inputs during testing.

Heater Steam Jacket

This process models the heat transfer between the steam and the feed. The steam jacket model contains no integrators; the outputs are simply sums and products on constants. Hence, if the inputs are steps, the outputs should also be steps at the same time, with varying sizes. This is shown in Figure 3 as an example with the heater duty (Q100). It is simple to check the value against what is expected at each time point (each input is stepped 1 minute after the last in this case).

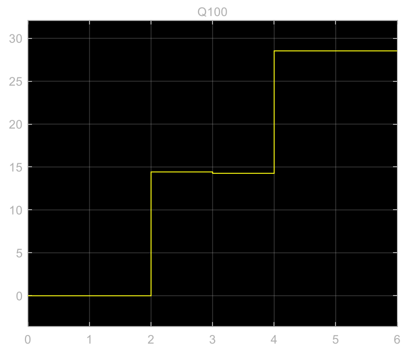

Figure 3: Testing the Heater Steam Jacket by stepping each input one at a time.

Condenser

The condenser model is like the steam jacket in that the outputs are sums and products of inputs; there are no states. However, in this case, there is division of some values in this case. For example, when calculating the cooling water outflow temperature, the condenser duty is divided by the mass flow rate to get the change in temperature of the water. If testing with a step input which starts at 0, this creates a zero division warning in Simulink, for which no output is defined. To get around this, the system was tested with constant inputs instead. There is no transient response to look at here anyway since there are no states in the model, so no information is lost.

Whole Process

After connecting all subsystems, the whole process was checked to be sensible. Expected steady state values were provided to the inputs, and the output were checked to ensure they converged to their expected value. As mentioned before, the separator liquid level consists of open-loop integration. In this case, the liquid level becomes negative. In order to converge at the suggested 1.0 m, the liquid level would have to start at 8.14 m. This is not a particularly useful transient response, since the system could likely not be initialised with non-zero inputs and zero outputs, but is useful to be aware that initial level of the liquid in the separator should be considered in the simulation to avoid emptying the separator and damaging the pump.