2 Constructing a compensator directly from in-system Step Response data without a plant model

In-system measured step response data from an unknown plant is used to directly construct a compensator without modeling the plant. The resulting closed-loop system is simulated and compared to the original uncompensated Step Response.

Immediately, we want to ask the question: “why bother creating a compensator without first modeling the plant?” The answer is: “because it’s quick and easy, and I can close the loop with very little effort.” This may be appealing in certain situations, where there is an urgent need to get something up and running immediately, and the plant’s uncompensated step response is acceptable. In situations where overshoot and oscillation is an important consideration, or accelerating the performance of sluggish plants, then modeling the system and shaping plant input and output is a better course of action.

We are constructing a compensator that *exactly* replicates the in-system measured plant Step Response, warts and all. When placed in a feedback loop, the simulated system response will *exactly* match the in-system uncompensated plant’s Step Response as originally measured. Obviously, this is not a traditional PID solution, and should only be considered as an interim solution, not a production solution.

Before we continue on, it is important to recognize the advantages of plant modeling we are giving up when we bypass modeling altogether and include at least the following:

- System drift may not be properly accounted for and removed
- Plant input and output shaping is easier with plant modeling
- Achieving higher performance systems is easier with plant modeling
- Noise in the Step Response data is not removed, and will show up in the Impulse Response, and control effort applied to the plant
- Noise in the Impulse Response will feed noise into simulation
- Runtime computational requirements may be unacceptably high

On the other hand, we recognized the advantages of this approach even without plant modeling and include at least the following:

- A functional (but not optimal) compensator is quickly constructed
- System delay is properly managed
- Steady-state error is removed, even with a sub-optimal compensator

Let’s take a moment to clarify terminology and understand system construction arrangements.

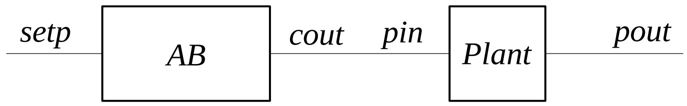

Figure 1 (AB compensator)

Figure 1 shows a compensator AB (Adjustment Block) followed by a Plant model. The purpose of this arrangement is to shape plant input and output using simulation to confirm system design goals are met, such as overshoot, oscillation, plant input remaining within bounds, plant input sequence, plant output sequence, shape of step response, and so on. This arrangement is normally part of the design workflow but is a trivial step in this example. This compensator is not deployed in a real physical system.

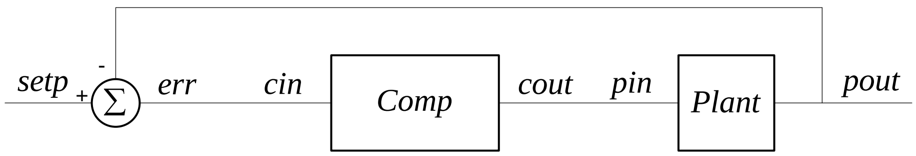

Figure 2 (closed loop compensator)

Figure 2 shows a closed loop compensator (with integrator included) followed by a Plant model. When we are satisfied with system performance using the AB compensator shown in figure 1 above (as determined by system simulation), the closed loop compensator is directly computed from the AB block. In simulation, the same setpoint (aka reference) sequence applied in figure 1 or figure 2 will produce the identical plant output sequence $pout$. This arrangement is deployed in a real physical system.

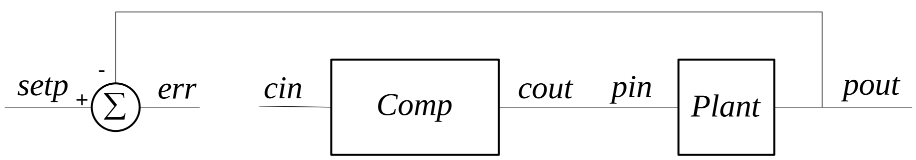

Figure 3 (closed loop compensator operating open loop)

Figure 3 shows the closed loop compensator open at the compensator input cin. In all other respects, this is the same arrangement that is shown in figure 2 (the compensator and plant is identical). The purpose of this arrangement is to obtain a bode plot of open loop system operation with the frequency sweep applied directly to the compensator input cin, and system response observed at the plant output $pout$ using either the plant model or the real physical plant. From the bode plot, the general appearance of the response, the crossover frequency f_x, the gain margin, and the phase margin can all be observed. Alternate methods, such as a frequency response analyzer can also be used, as appropriate.

“Impulse Response” is terminology used in the context of continuous-time systems, whereas “Unit Response” is terminology used in the context of discrete-time systems. In every situation in which “Impulse Response” is used in the context of discussing discrete-time systems, it is intended to convey the meaning of “Unit Response.”

With terminology clarified, we press on so that we can see what is possible with this approach. Consider the following plant, which has offset, delay and noise:

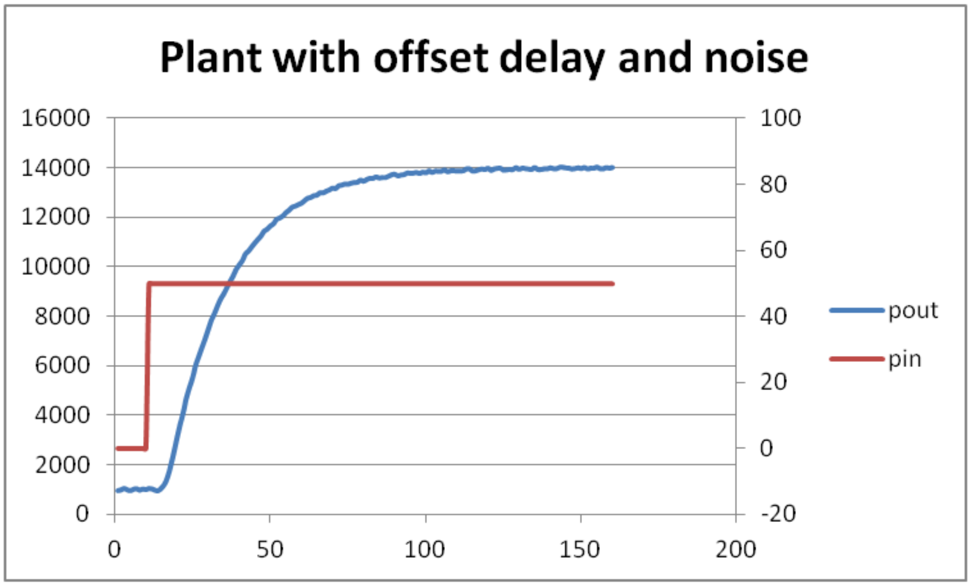

Figure 4

Figure 4 shows that the uncompensated Step Response of this system has no overshoot or oscillation, so we consider this system to be a candidate for this method. As we can see in this chart, there is quite a bit of noise in the Step Response, which will feed noise into the Impulse Response computation as well as simulation.

Let's remove the offset and compute the Impulse Response:

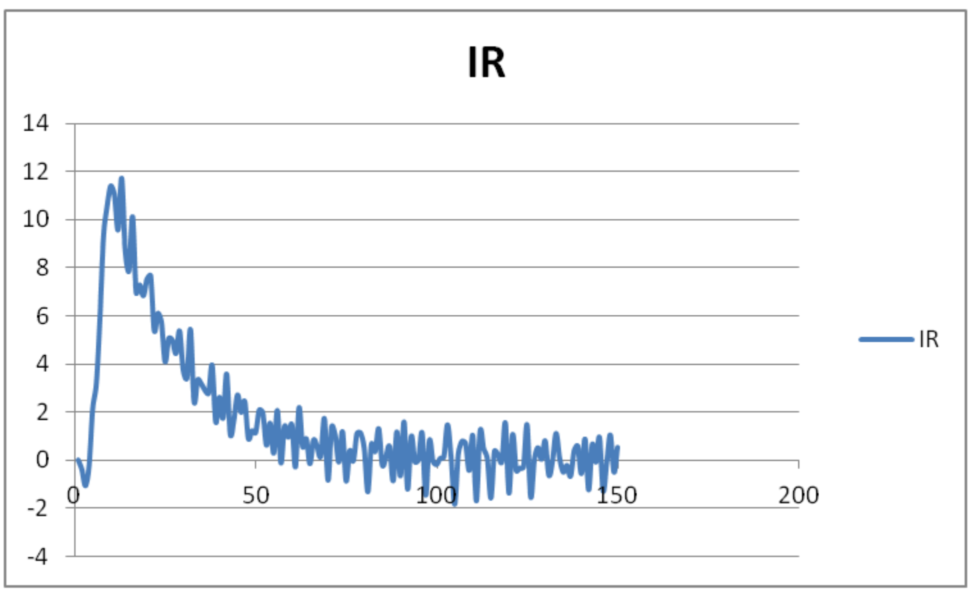

Figure 5

Figure 5 shows that there is quite a bit of noise in the computed Impulse Response, which was expected because the uncompensated Step Response directly feeds noise into this computation.

The goal of this method is to implement a closed-loop system that is equivalent to the uncompensated Step Response of the plant, while properly managing delay. Let's check that now.

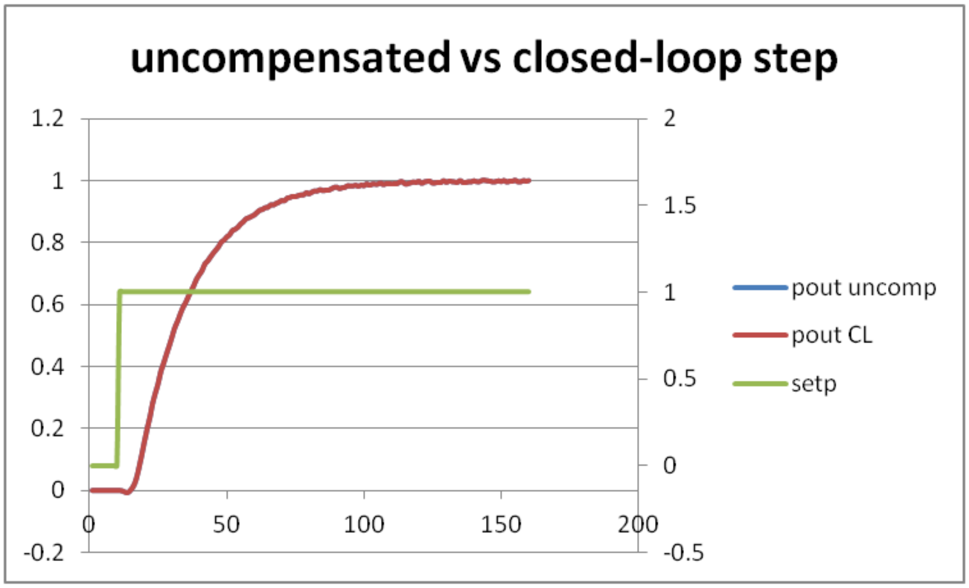

Figure 6

Figure 6 shows the setpoint as a step input to both the uncompensated and closed-loop implementations. The closed-loop response *exactly* overlays the uncompensated response, warts and all. Delay is properly managed.

Let's compare performance with a different setpoint sequence:

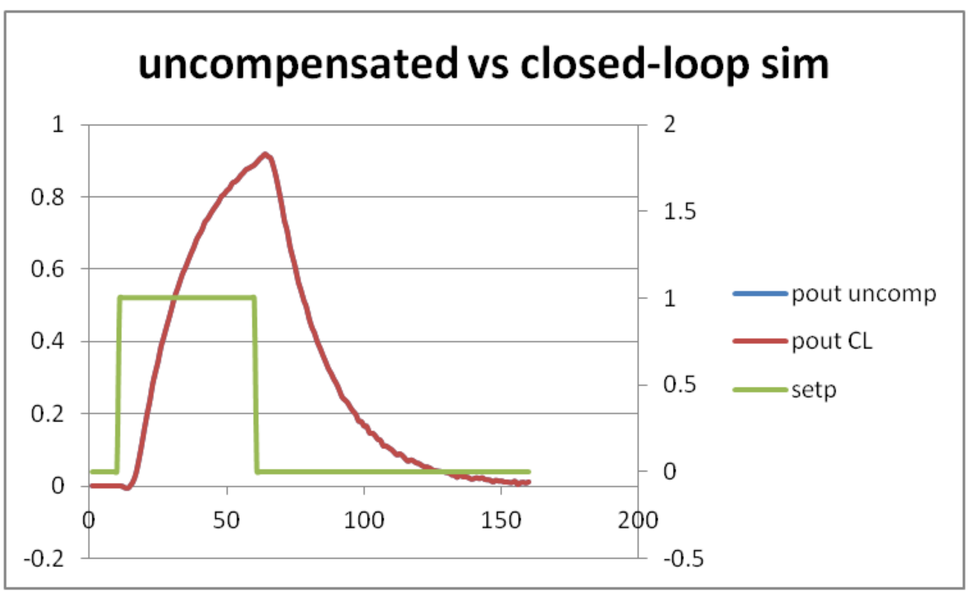

Figure 7

The simulation in figure 7 shows both the uncompensated and closed-loop response to the new setpoint sequence to be identical.

Summary:

This method of compensator construction uses data collected directly from in-system operation, and is useful in situations where there is an urgent need to get a closed-loop system running quickly *and* the output of the uncompensated plant Step Response is acceptable, *and* there is no drift, *and* runtime computational requirements are not a concern, *and* plant input / output shaping is not required, *and* higher system performance is not required. This method should only be considered as an interim solution, not a production solution.

On the positive side, offset, delay, and slow response are handled appropriately, and steady-state error is removed.

Simulation is possible, but noise in the computed Impulse Response feeds into the system simulation.

An accurate plant model enables us to do a better job of simulation and creating controllers that match the real physical system. Constructing compensators based upon plant models will be explored further in future papers.