4 Constructing an enhanced performance compensator using a plant model

A plant model is used to construct a compensator with enhanced (faster) performance. There is considerable delay in the plant which is properly managed without overshoot or oscillation. System performance is adjusted as desired, a closed-loop compensator is constructed, and the resulting closed-loop system is simulated and compared to the desired system.

We start with already having the plant model from which we will construct an enhanced (faster) performance compensator. The original uncompensated Step Response is slow but otherwise acceptable. There is considerable amount of system delay from control effort to plant response.

Our task is to shape system performance so that the system is on-setpoint faster, while managing delay, and without overshoot or oscillation, and keeping the control effort within the input range of the plant. After we are satisfied with the enhanced performance of the shaped system, we construct the compensator that replicates the performance in a closed-loop system.

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

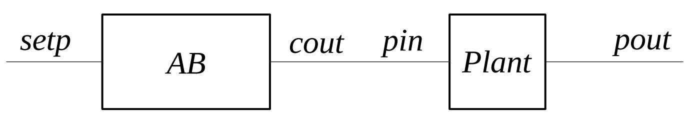

Figure 1 (AB compensator)

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 compensator is not deployed in a real physical system.

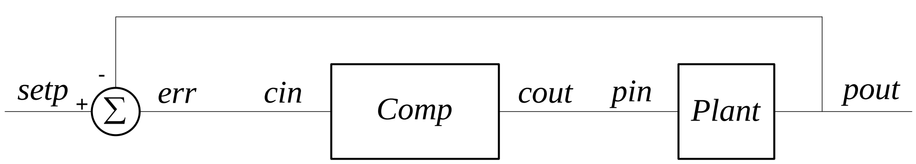

Figure 2 (closed loop compensator)

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.

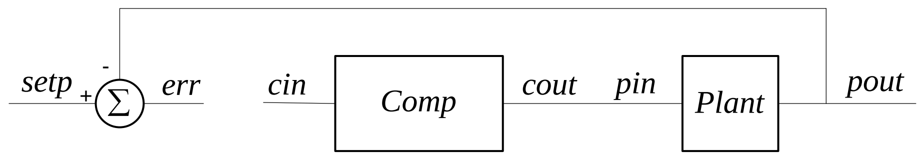

Figure 3 (closed loop compensator operating open loop)

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.”

In this example, there is an underlying assumption that the plant has excess capacity so that we can “overdrive” the control effort and then reduce the control effort as the system approaches setpoint. If excess capacity is not available, the system’s operationg range could be restricted so that plant input always remains within bounds.

Let’s start with the original plant model:

Figure 4

Figure 4 shows the plant's Step Response. The delay from control effort to plant response is very noticeable.

Let's compute the Impulse Response:

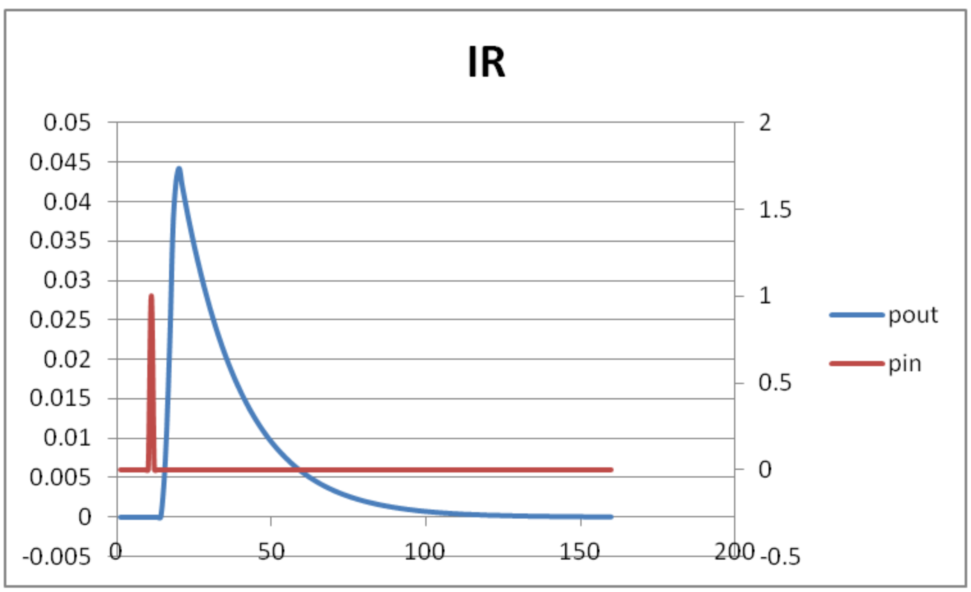

Figure 5

Figure 5 shows the system delay that was evident in Figure 4.

Next, we overdrive the plant input to shape plant output and achieve faster performance without overshoot and oscillation. The plant must have excess capability to allow larger control effort, or we must restrict the operating range of the plant so that commanded control effort at the plant input and resulting plant output are always within bounds.

In this example, we are allowing a doubling of the maximum value of the control effort applied to the plant.

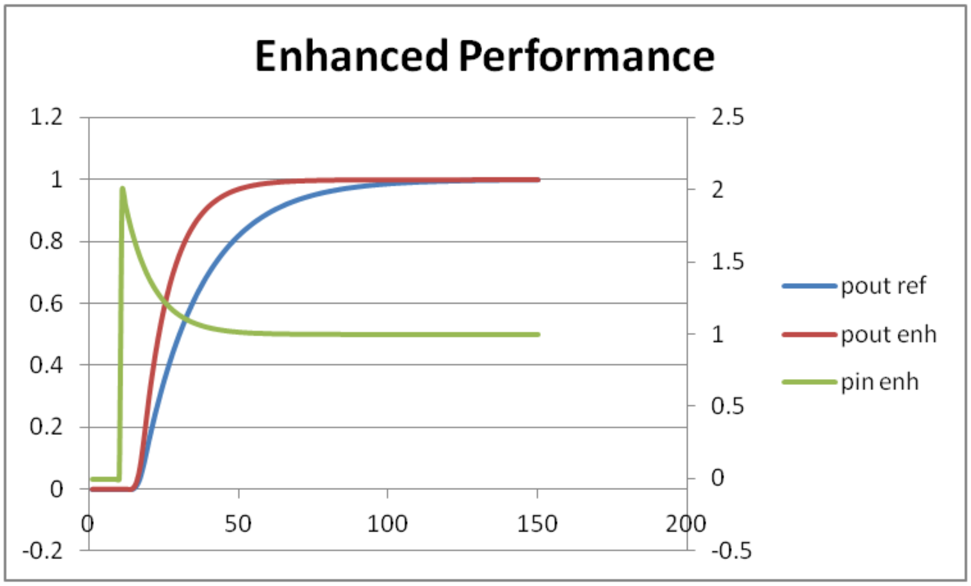

Figure 6

Figure 6 shows the system delay that was evident in Figure 5. It also shows the standard Step Response as the plant output reference. This is the benchmark against which we compare our enhanced performance system. The enhanced plant input illustrates the concept of overdriving the plant input, then reducing the control effort as the plant approaches the setpoint. The maximum control effort for this example is double the final value, so the plant must tolerate control effort values within this range. Additionally, the plant must be able to tolerate the abrupt change in control effort at its input. If the control effort is unacceptably vigorous or the plant is unable to tolerate the increased maximum control effort, then this method of compensator design is not appropriate. Other, more appropriate methods are discussed in future papers.

Figure 6 also shows the improvement in plant output – the system is on-setpoint much faster than the reference system, while properly managing delay, and without overshoot or oscillation.

We continue on, assuming the plant input can tolerate control efforts of this shape and range.

Since we are satisfied with this enhanced performance, the next step is constructing the compensator that achieves identical closed-loop performance. Let’s do that now and simulate a setpoint sequence.

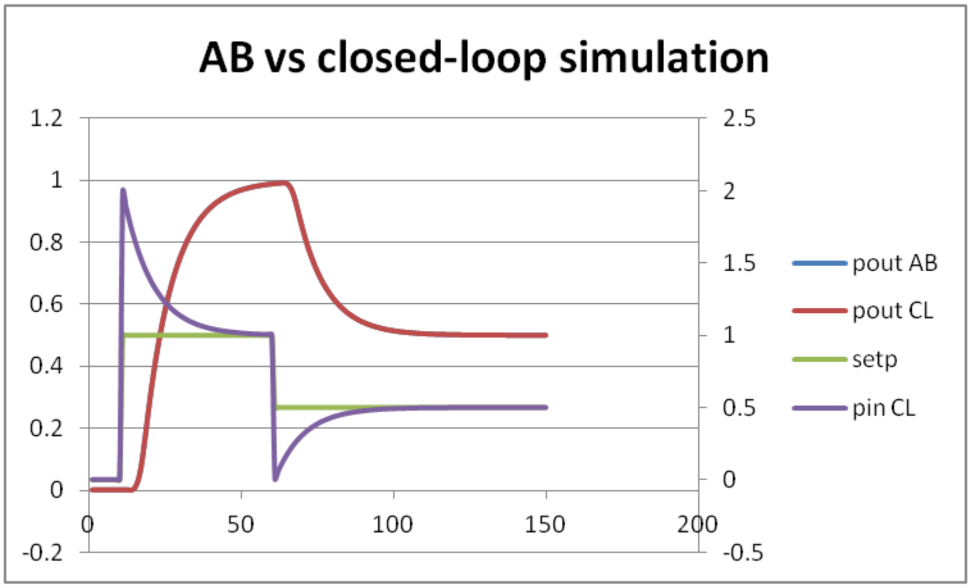

Figure 7

The simulation in Figure 7 shows both the AB and closed-loop response to the setpoint sequence to be identical. The plant input shows the control effort shape and magnitude required to achieve this performance.

Summary:

This method of compensator construction starts with a derived plant model already in hand, and creates a compensator that overdrives the plant to achieve higher performance. The plant must be able to tolerate the shape and magnitude of the plant input. Alternatively, the system's operating range could be restricted so that the plant's input is always within range.

Significant delay from control effort to plant output is properly managed without overshoot and oscillation.

This example is similar to "Constructing a standard performance compensator using a plant model." Similarities include:

- The same plant is used
- The same plant model is used
- The plant model is derived from in-system measured plant Step Response
- Offset, drift and noise are removed in the plant model
- System delay is properly managed
- There is no overshoot or oscillation
- Runtime computational requirements are similar

Differences include:

- Faster system performance is achieved
- The plant input is overdriven
- The plant input is more vigorous
- Excess plant capacity is required
- Alternatively, system operating range may be restricted so that plant input is always within range