5 Constructing a maximum performance compensator using a plant model (Active Compensation™)

A plant model is used to construct a compensator with maximum (fastest) 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 a maximum (fastest) 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 performance of the shaped system, we construct the compensator that replicates the performance in a closed-loop system.

Before we get started, let's briefly discuss the differences that distinguish the maximum performance compensator from the enhanced performance compensator. The enhanced performance compensator is a passive design that has been pre-configured at design-time to remain within the input bounds of the plant. The enhanced performance compensator overdrives the plant input to accelerate performance and arrive on-setpoint faster. This is done while managing delay and without overshoot or oscillation. The plant must have excess capacity, or alternatively, the operating range of the plant is restricted so that the plant input is always within bounds. When we observe the plant input, we will see a single-cycle peak in the control effort, and then compensator reduces the control effort as the system approaches setpoint.

The maximum performance (Active Compensation™) compensator is an active design that is given limits on the plant input range and performs run-time computations to assure that these limits are enforced. As with the enhanced performance compensator, the maximum performance compensator also overdrives the plant input to accelerate performance, but the plant may be continuously overdriven for an extended number of cycles, as determined by run-time computations, whereas the enhanced performance compensator will maintain maximum overdrive for only one cycle, then immediately starts to reduce control effort.

This is akin to applying full-throttle for only a brief moment, then immediately reducing the throttle, vs. applying full-throttle for an extended period of time, then after some number of cycles, adjust the throttle as the system approaches setpoint. This is all done while remaining within the prescribed input bounds of the plant and is enforced by run-time computation.

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

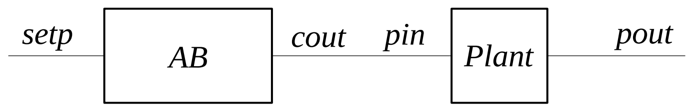

Figure 1 (AB compensator)

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.

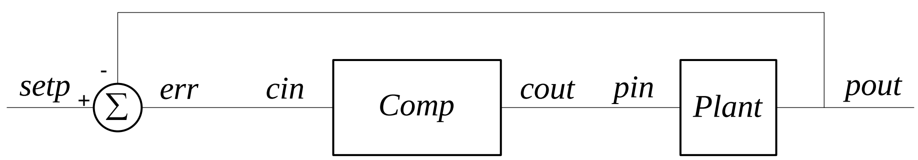

Figure 2 (closed loop compensator)

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.

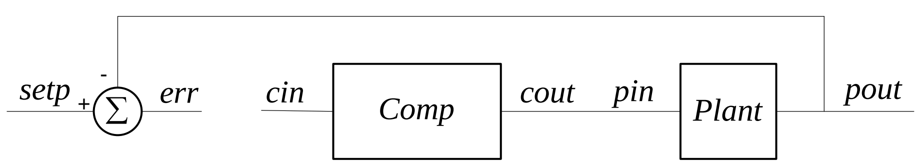

Figure 3 (closed loop compensator operating open loop)

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."

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:

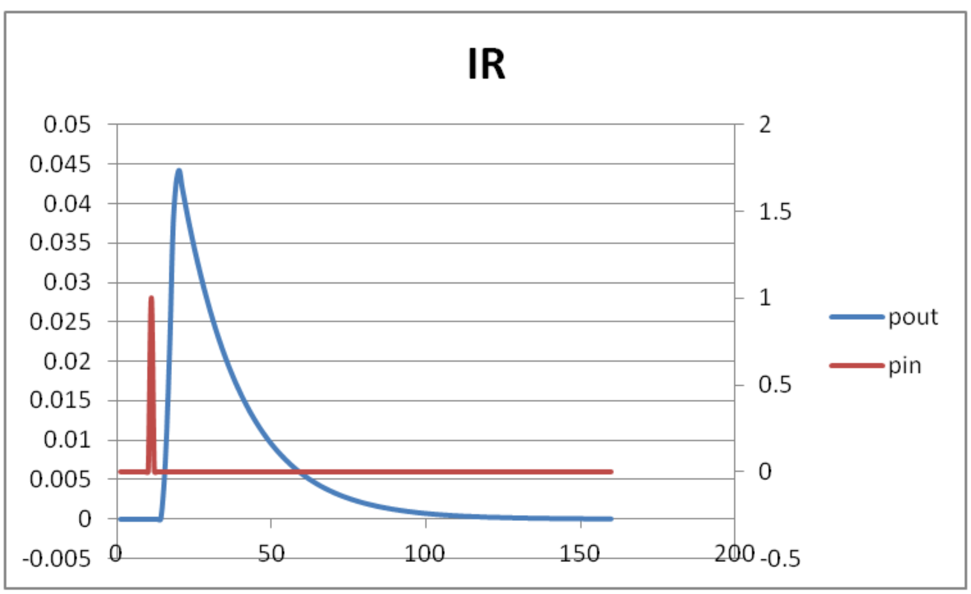

Figure 5

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. While it is beneficial for the plant to have excess capability to allow larger control effort, it is not strictly necessary when using Active Compensation™. Regardless of the specified operating limits, the plant input and resulting plant output will always remain within bounds.

Although more restrictive operating limits may be used (such as $0.0 \leq pin \leq 0.8$), in this example, we are allowing a doubling of the maximum value of the control effort applied to the plant.

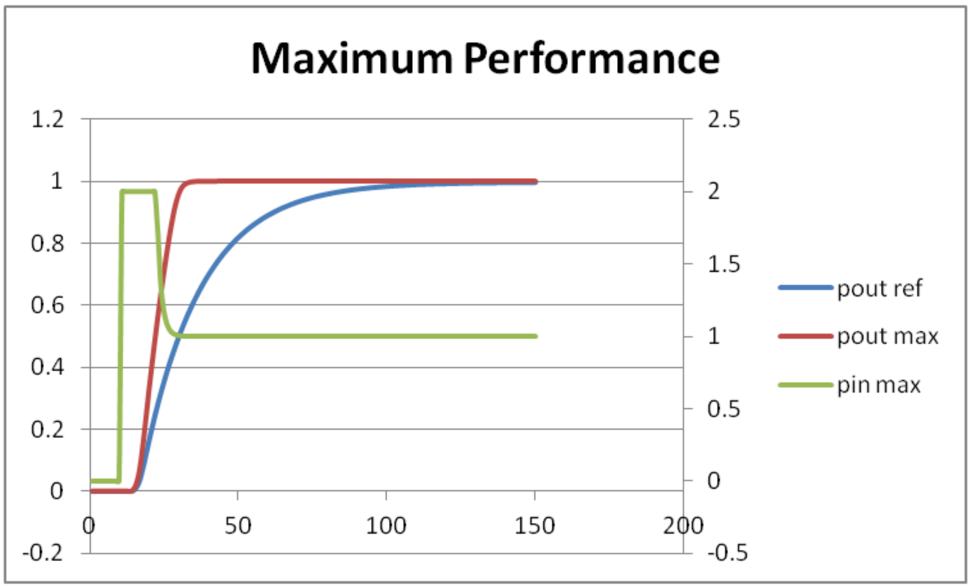

Figure 6

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 maximum performance system. The maximum performance plant input illustrates the concept of overdriving the plant input for multiple cycles, then adjusting 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 maximum performance, the next step is constructing the compensator that achieves identical closed-loop performance. Let's do that now and simulate a setpoint sequence.

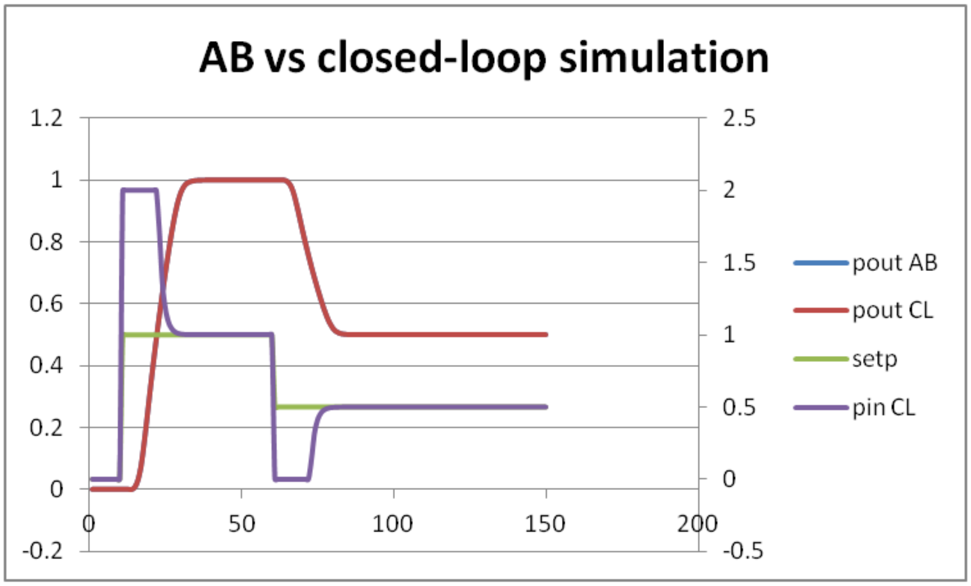

Figure 7

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 for an extended number of cycles to achieve maximum 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 an enhanced 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
- The plant input is more vigorous
- System operating range may be restricted so that plant input is always within range
- Runtime computational requirements are similar

Differences include:

- Faster system performance is achieved
- The enhanced performance compensator is a passive design that has been pre-configured at design-time to remain within the input bounds of the plant, whereas the maximum performance (Active Compensation™) compensator is an active design that is given limits on the plant input range and performs run-time computations to assure that these limits are enforced
- The plant input may be continuously overdriven for an extended number of cycles
- Excess plant capacity is beneficial, but not strictly required