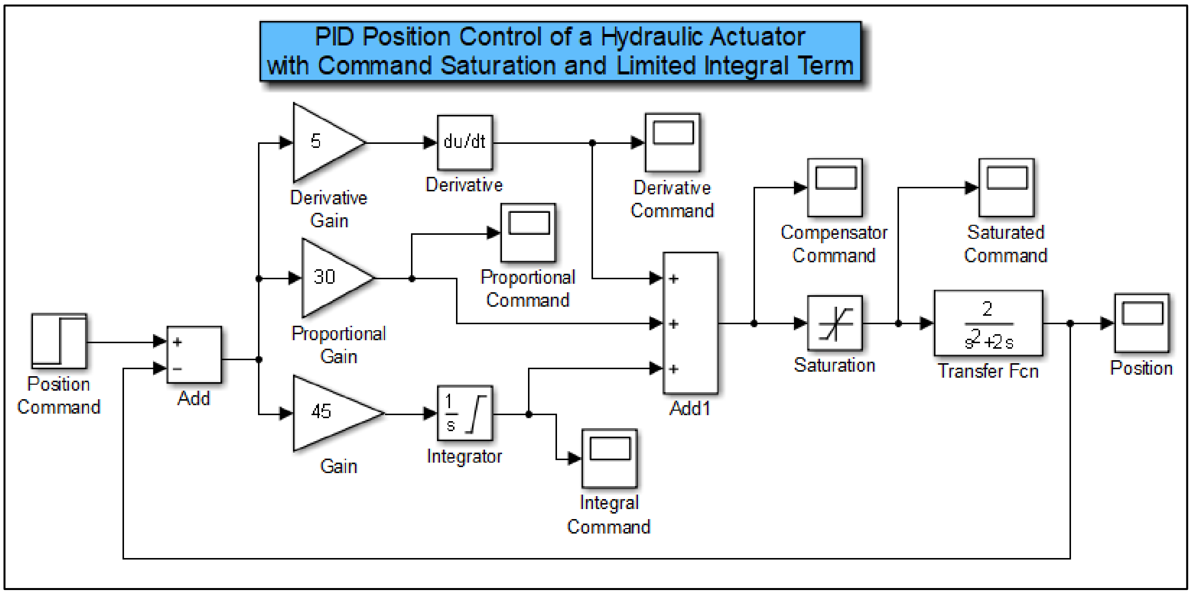
Introductory Motion and Control
Integrator Wind-up

Reference: Franklin, Powell, Emami-Naeini, *Feedback Control of Dynamic Systems*, Prentice-Hall, 2002.

The system shown below is a model of a closed-loop hydraulic actuator with a proportional-integral-derivative (PID) controller. As the system responds to a step position command, the ***integral term*** of a PID compensator ***will*** continue to ***increase*** until the actuator reaches its final position. If the integral term becomes ***too large*** during this response, it can create ***large overshoot***. As shown in the model, one way to ***correct*** this problem is to simply ***limit*** the ***magnitude*** of the integral term.

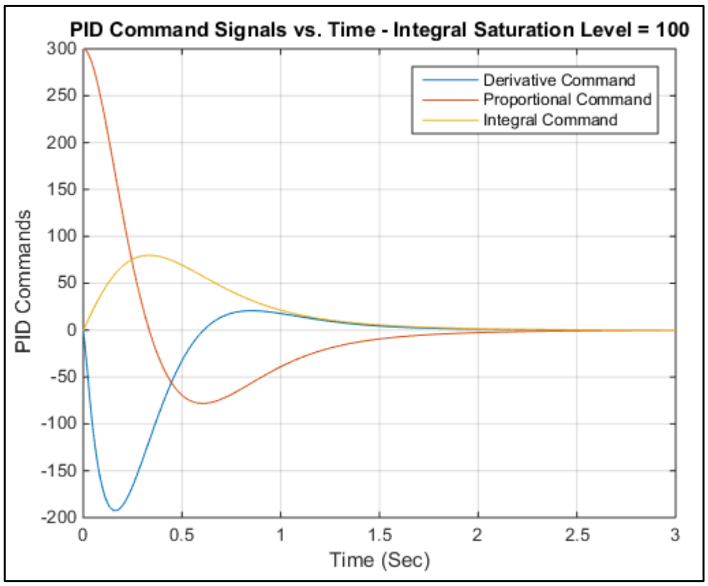


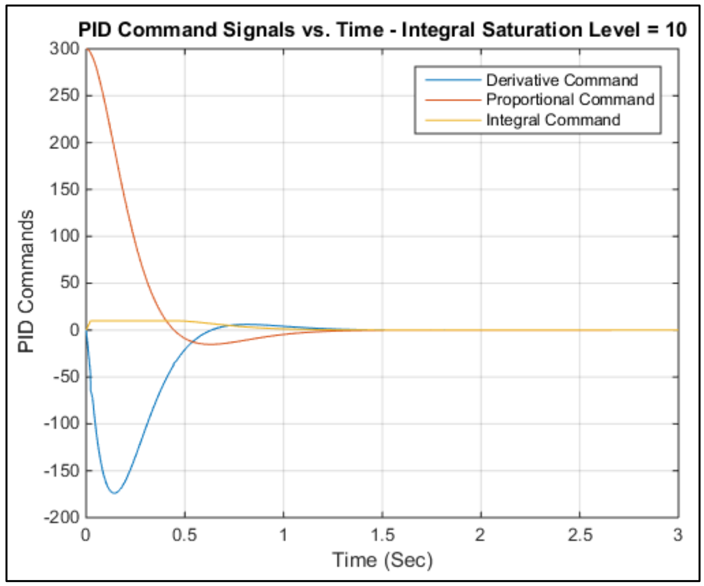
The results shown below are for the system responding to a ***step position command*** of magnitude 10. The PID command saturation level has been set so that ***no saturation*** of the combined PID command signal occurs. The model was then executed for ***two different limits*** on the integral command. The limit of ± 100 has ***no effect*** on the limit of the integral command, so those results show how the system responds with ***no saturation limits***. Conversely, the integral saturation level of ± 10 clearly ***lowers*** the ***integral part*** of the PID command and ***changes*** the system's response.

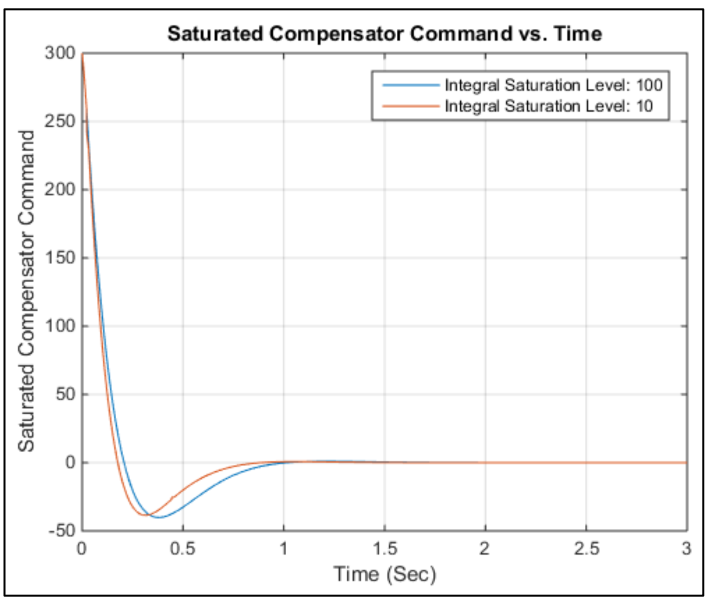
The two plots in the ***top row*** show the ***individual PID command signals*** at the ***two integral saturation limits***. The plot on the ***upper left*** clearly shows that the integral command signal is ***not limited*** when the integral limit is ± 100, and the plot on the ***upper right*** shows a ***limited integral command*** and the corresponding proportional and derivative commands.

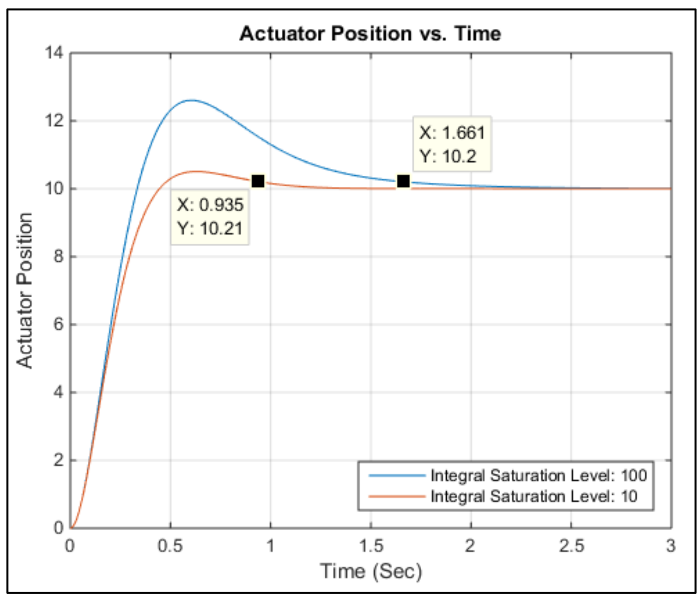
The plots in the ***bottom row*** show the ***saturated PID command signal*** and the ***actuator position response*** at the ***two integral saturation limits***. The plot on the ***lower left*** shows the total PID command signal is ***not limited***. The plot on the ***lower right*** shows the ***improvement*** to the ***step response*** achieved by ***limiting*** the magnitude of the integral command. The system has ***less overshoot*** and a ***lower settling time***. The locations of the approximate two-percent settling times are indicated on the plot.

If left unchecked, the integral command builds until the actuator reaches its final position, and then its takes time for the PID command level to decrease. This effect is known as ***integrator wind-up***.



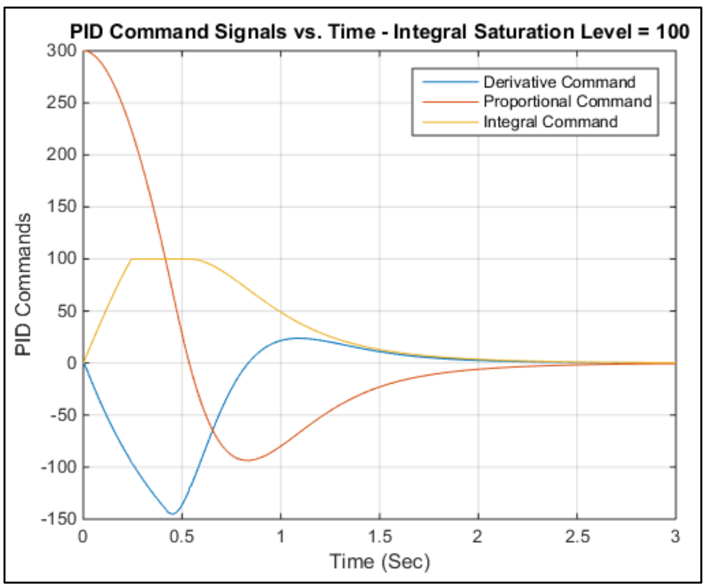


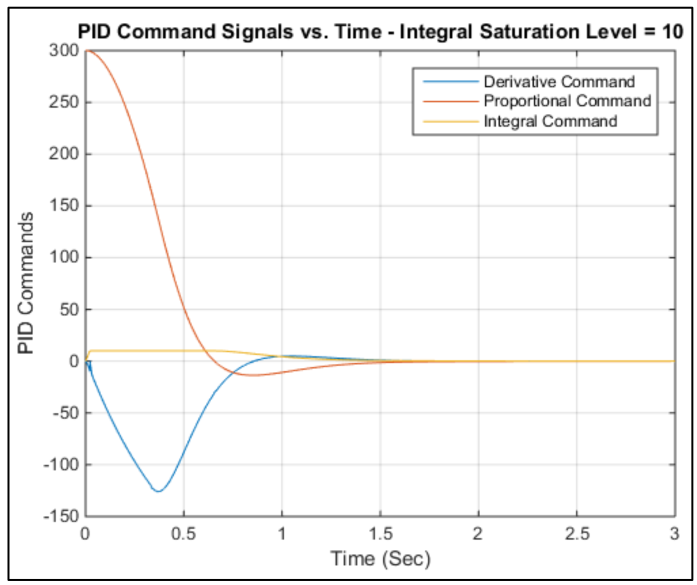


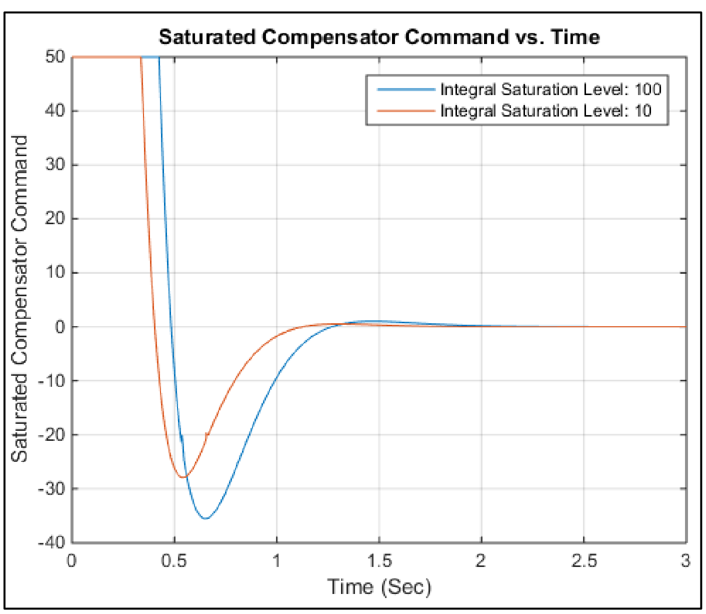


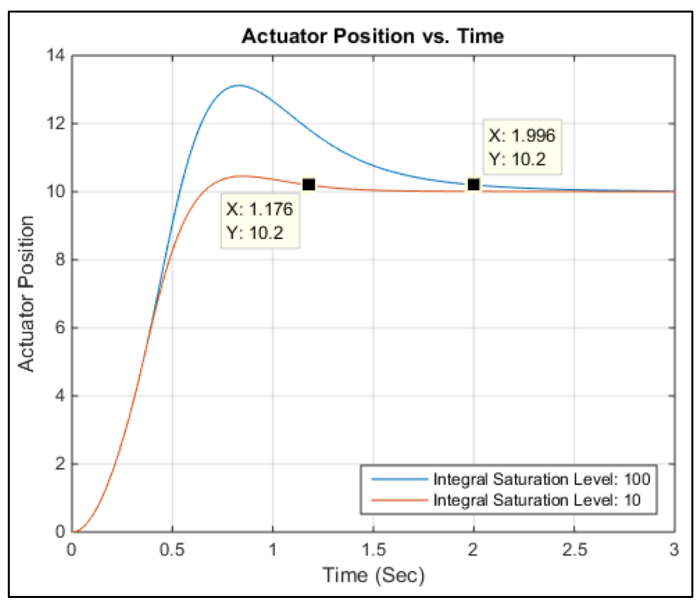
The ***effects*** of ***integrator wind-up*** can be ***worsened*** when the actuator itself experiences ***saturation***. A ***second set*** of results is shown below for ***integrator saturation levels*** of ± 100 and ± 10 and a ***PID compensator signal saturation*** limit of ± 50. As shown in the figure on the ***top left***, the integrator signal now experiences saturation when the limit is set at ± 100. So, the ***integrator command*** has ***increased*** due to the ***actuator saturation***. The ***saturated compensator command*** is shown in the figure on the ***bottom left***.

The ***step response*** of the system is shown on the ***bottom right***. Note that ***actuator saturation*** has ***increased*** the ***settling times*** of the system at ***both*** integrator saturation levels. It also ***significantly increased*** the ***overshoot*** at the ***higher integral saturation level***.

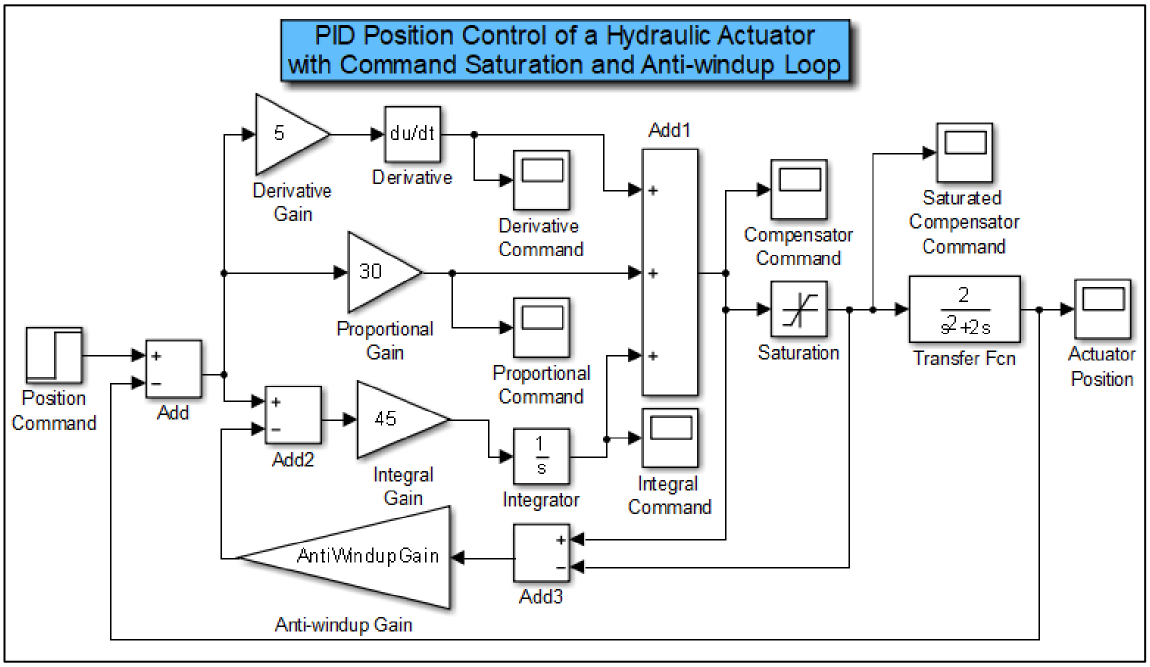






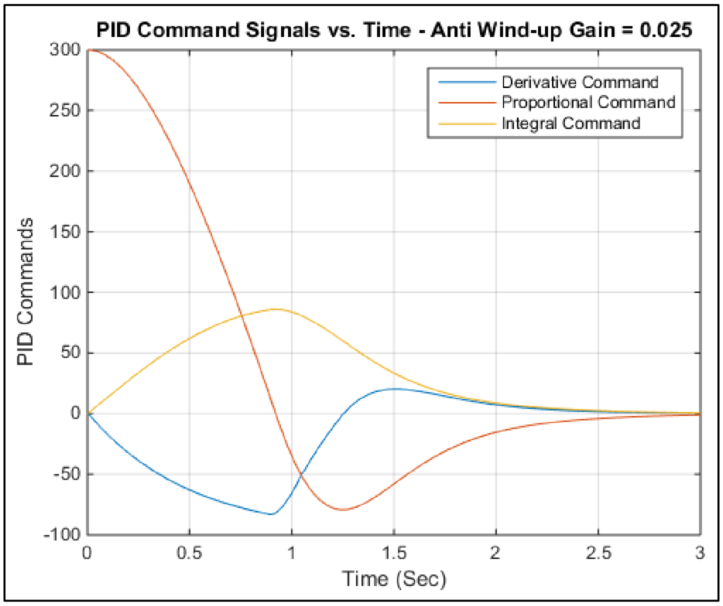


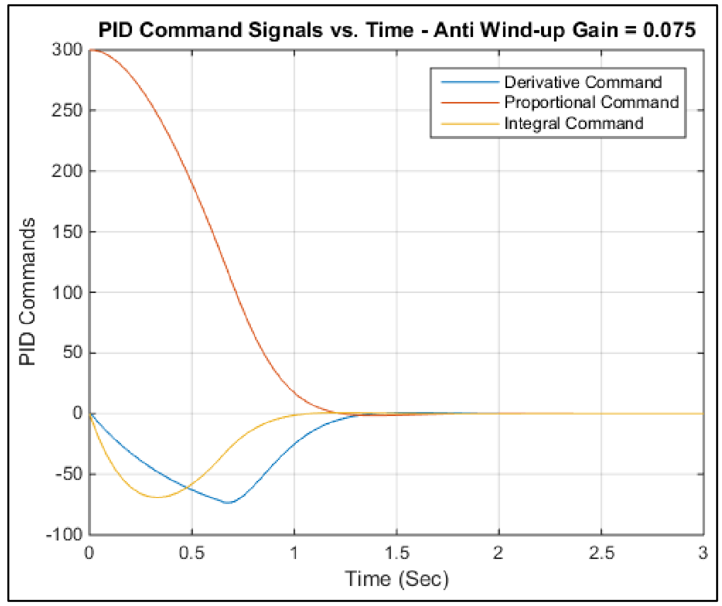
A ***second solution*** to integrator wind-up is to ***add*** a ***feedback loop*** to the ***compensator*** that is ***activated*** when saturation occurs. In the model shown below, the amount of ***PID command signal saturation*** is calculated by taking the ***difference*** between the compensator command and the saturated compensator command. That difference is multiplied by the anti-wind-up gain and then subtracted from the actuator position error to lower the input to the integrator, and hence, lower the integral command. For good performance, the anti-windup gain should be ***large enough*** to ***limit*** the size of the integral command signal and can be found by trial-and-error.

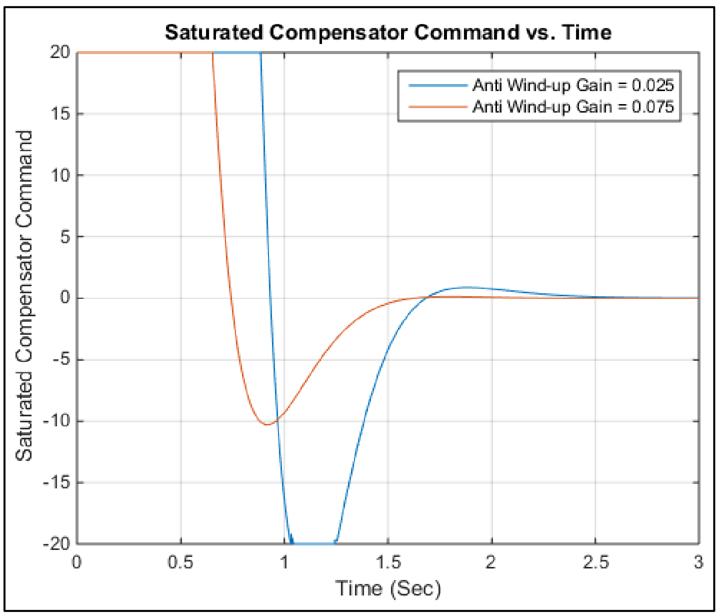


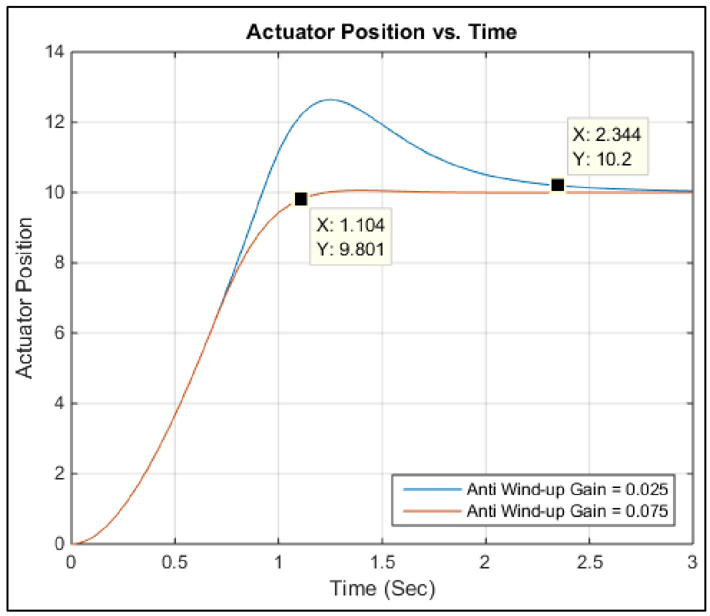
Model results are shown below for ***two anti-wind-up gains*** and a ***PID command signal saturation level*** of 20. The ***top two plots*** show the ***PID command signals*** for anti-wind-up gains of 0.025 and 0.075. The ***bottom two plots*** show the ***saturated command signals*** and the ***actuator position response*** associated with the two anti-wind-up gains.

The ***lower anti-wind-up gain*** is ***not large enough*** to stop integrator wind-up. At this gain, the actuator position ***significantly overshoots*** the position command of 10 and takes over 2 seconds to settle within two-percent of the command. The ***higher anti-wind-up gain*** reduces the integral command significantly, ***reduces*** the ***overshoot*** to almost zero, and ***reduces*** the ***two-percent settling time*** to just over 1 second.


PID Command Signals vs. Time - Anti Wind-up Gain = 0.025
Derivative Command
Proportional Command
Integral Command
PID Commands
Time (Sec)


PID Command Signals vs. Time - Anti Wind-up Gain = 0.075
Derivative Command
Proportional Command
Integral Command
PID Commands
Time (Sec)


Saturated Compensator Command vs. Time
Anti Wind-up Gain = 0.025
Anti Wind-up Gain = 0.075
Saturated Compensator Command
Time (Sec)


Actuator Position vs. Time
X: 2.344
Y: 10.2
X: 1.104
Y: 9.801
Anti Wind-up Gain = 0.025
Anti Wind-up Gain = 0.075
Actuator Position
Time (Sec)