# Servo Project Report #9
**August 28, 2008**
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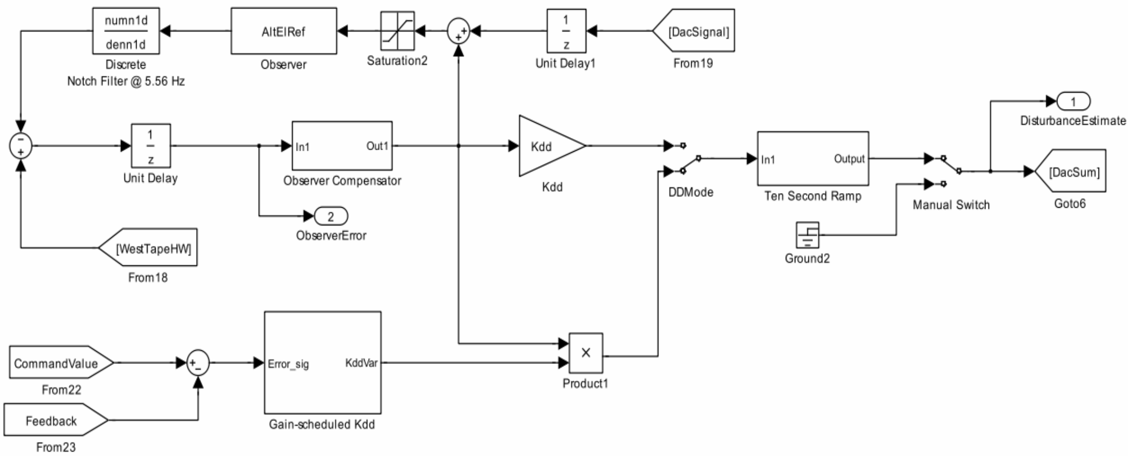
## Summary

Reports of difficulties with the controller properly handling multiple slew commands, and unsafe behavior near motion limits, resulted in the email report, linked at: http://www.mmto.org/~dclark/Reports/El%20collision%2073108%20servo.pdf for those interested.

The data from limited slew testing in May 2008 confirms that there was a difficulty in the servo loop that created the corner case of large controller outputs winding up from both the main PID control loop and the disturbance decoupling loop. We also had confirmed that the re-aligned east elevation tape head resulted in 65Hz oscillation when the position loop was closed on that head. This report documents several changes to the controller to a) mitigate the windup issue, and b) regain the ability to close the servo loop on either tape encoder.

## Disturbance Decoupling Loop Windup

First, the windup in the disturbance decoupling signal path. Below is reproduced the Luenberger Observer loop and resultant estimated disturbance output that is applied to the output DAC signal for cancellation of disturbance torques for the previous version of the controller.



The observer loop is fed by the torque demand signal from the output of the main position PID loop, and the resulting real encoder position is compared to the model's output to form an estimation error, which is compensated via PID and fed back to drive the observer model and real telescope into agreement. In this version of the observer loop, the torque signal that is the sum of the compensator output and position PID torque demand is limited by a saturation block. This is the source of our windup difficulties.

Consider the case of a DC error between the true encoder position and the observer's predicted position: the compensator PID will of course wind up due to the Integrator gain and attempt to drive the observer model back into agreement with the true encoder position – but this signal is saturated! The model simply cannot respond instantaneously, and so the observer error remains for a considerable time. The compensator output passes through a gain fade that is intended to turn off the decoupling signal during slews, but is not otherwise limited. The large, woundup value of the compensator goes directly to the DAC signal path. The primary position loop must then overcome this signal in order to maintain the loop closure. Hence, we have windups from both the observer compensation loop and the primary position PID loop.

In addition to this problem, the gain fade on the disturbance decoupling signal, which is intended to only operate during tracking, was scaled to be on during slews, leaving the observer loop in the game when it truly should not be. This was rescaled to only operate over a position error of ~ ±2 arcminutes.

The fix for this windup issue is as follows:

1. Move the saturation block outside of the observer's compensation path.
2. Saturate the position PID loop output before it goes to the observer loop.
3. Correct the gain fade authority to operate over the proper range of position error.

Since the encoder output is by definition bounded, having all the inputs and outputs of the observer loop bounded means that the observer compensator can go to any necessary large value to zero out the observer error, while limiting the authority of the decoupling signal that goes to the DAC.

The decoupling signal saturation level has been set to a value less than 50% of the available swing to ±2.25V, while the primary PID loop is clipped at ±5V. This ensures that the primary position PID loop can always overcome any output from the observer loop. A final clip at the same level is applied just before the DAC block to ensure no test signals, or summation of the PID loop's torque demand and decoupling signal can exceed the maximum.

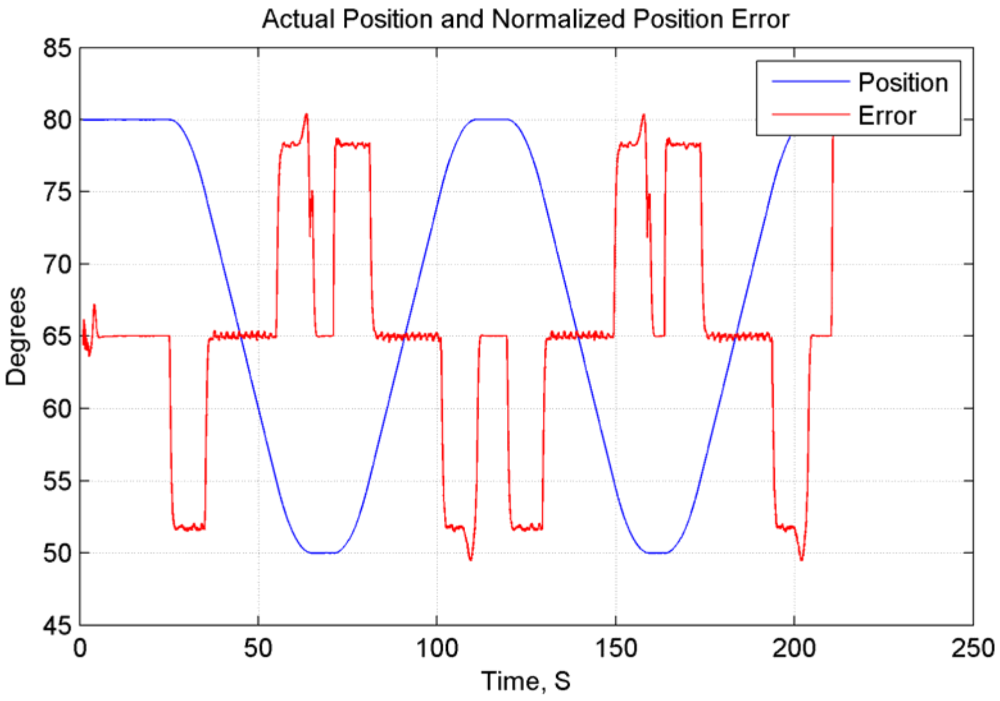
The current version of the model is stored at: http://mmto.org/~dclark/Keith%20Powell/MMTAug08/testElServo_vxmount12.mdl and includes these changes, and others to support filtering of the tape encoder signals.

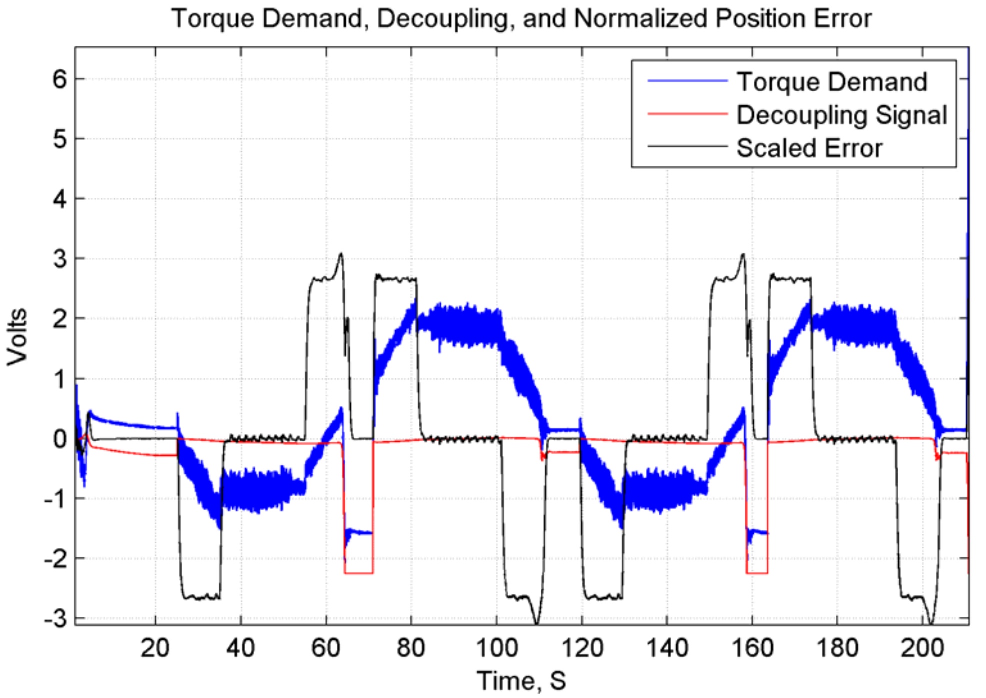
## New Notch Filter

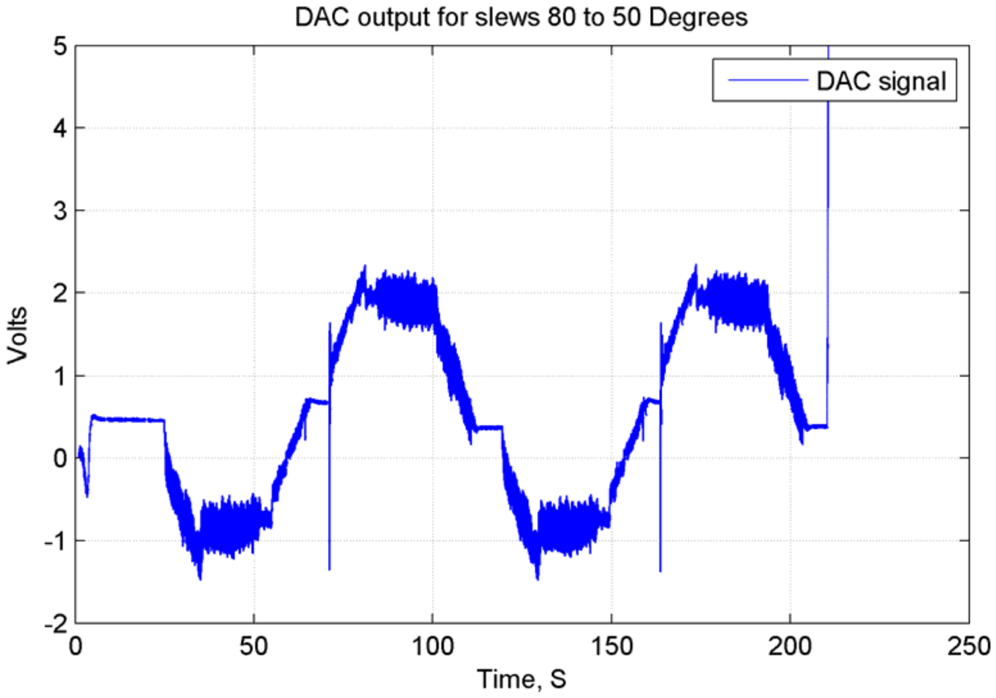
A new 2nd-order notch filter centered at 65.4Hz was implemented and tested on the feedback from both encoders. With the filter in place, the servo loop can be closed once again on the east tape head. However, the attenuation of the filter is compromised by the forward gain of the servo loop and 65Hz oscillation appears on the DAC output, though the controller is not unstable. The notch filter was then moved out to the chain of notch filters used on the position PID loop's output, where it has sufficient attenuation to successfully close the servo loop on either head without stability issues.

Tracking (with a simulated wind source) and slewing was then performed using both heads successfully. Some study of the tracking data is necessary, but is not the focus of this report.

Several long back-to-back slews were performed to confirm proper operation of the loops on both heads. The following were the east encoder head with the new filter. I have normalized the position error to the signal superposed on the plots for clarity; the raw position error was over the range ±30 arcseconds for all the motions. Slews were commanded from 80° to 50° and back several times over the course of testing. Since the *f/9* secondary was installed without any topbox or instrument weight, the telescope balance was considerably off. This serves as a handy test of an un-encoded torque "disturbing" the telescope (e.g. a DC error). So if windup is at issue, you would expect to see the position PID and observer loop again winding up against each other. This is not the case:




Torque Demand, Decoupling, and Normalized Position Error


DAC output for slews 80 to 50 Degrees

These plots show, first, that the position error remains zero whenever the commanded position has been reached. Second, the torque demand (from the position PID loop) and decoupling signal (from the observer loop) remain constant at that commanded position. Finally, the DAC signal remains a constant to overcome whatever unbalance torque is present, and does not wind up to intolerable levels. Note also that the decoupling signal switches to zero at the beginning of the motion, and only comes in when the slew is nearly complete, as it should. This confirms the rescaling of the gain fade for tracking-only disturbance decoupling operation.

These changes should be implemented on the Vxworks version of the controller, and tested. An inventory of the changes, again:

1. The observer loop topology now has a saturation limit on the decoupling signal, with a concomitant variable *DecupLim* in the model workspace archive. Experience will show us if this authority level is sufficient for wind torques in operation.
2. The torque demand signal likewise has a new saturation block that is a copy of the final DAC output limit that has always been present.
3. A new 65Hz notch filter is in the flexible-mode filter chain on the torque demand signal path.

I have more analysis to do on the tracking data collected, but these simple changes will cure the unsafe windup behavior, and should be confirmed on that implementation.