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MMT Observatory

Smithsonian Institution &
The University of Arizona®

Primary Mirror Actuators Test Report

D. Clark

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Abstract: *The MMT primary mirror support system has been experiencing difficulties supporting the mirror weight when elevation slew velocities exceed 0.5° per second. Since all the primary mirror actuators were removed in preparation for 2005 Aluminizing, an excellent opportunity for test and evaluation of the actuators is at hand. In order to better understand the operational characteristics of the actuators, a series of tests were performed on a spare actuator and an actuator that had reported problems. This allows for development of a performance baseline for comparison and detection of electromechanical issues that cause actuators to fail in use. The following report documents the test results.*

Test Procedure

The MMT primary mirror support actuators were in the process of being removed from the primary mirror cell during the week of July 25 – 29, 2005. Prior to beginning testing and calibration of all units on the MMT actuator test stand, it was decided to evaluate the behavior of the actuator(s) in order to validate the current test procedure, and develop efficient means of detecting an actuator that does not meet its performance requirements.

With this in mind, two dual-axis actuators were selected for testing. One, unit #19, was a spare in the storage rack tagged “good”. This unit is considered the baseline. The other, unit #40, was identified by T. Trebisky as a suspect unit after testing before Summer 2005 Shutdown. A single-axis unit, #162, was also tested in a less rigorous manner; careful inspection revealed problems with its mounting on the test stand, so the data from #162 are not used for this report.

Each actuator had both axes tested two ways: with the force control loop open, and with the force control loop in operation. The force loop was also tested with and without the integrator turned on. In this way, separation of the behavior of the electromechanical portion of the actuator (air transducers, cylinder, load cell) from the purely electronic nature of the force servo card is possible.

For open loop testing, the force servo card was removed from the actuator, and a simple test circuit was inserted to drive the air transducers and measure the force response of the load cell. A signal generator was used to apply both sine waves and square waves to the actuator to test its slew rate response and output signal characteristics. A Hewlett-Packard HP35670A Dynamic Signal Analyzer (DSA) was then used to drive the test circuit and capture the frequency response of the actuator.

Once the actuator open-loop measurements were completed, the servo card was replaced and the signal generator was again used, this time to capture the closed-loop sine and step response signals. The DSA was next used to gather the closed-loop frequency response of the servo card.

The following figure shows the test circuit used for the open-loop measurements:

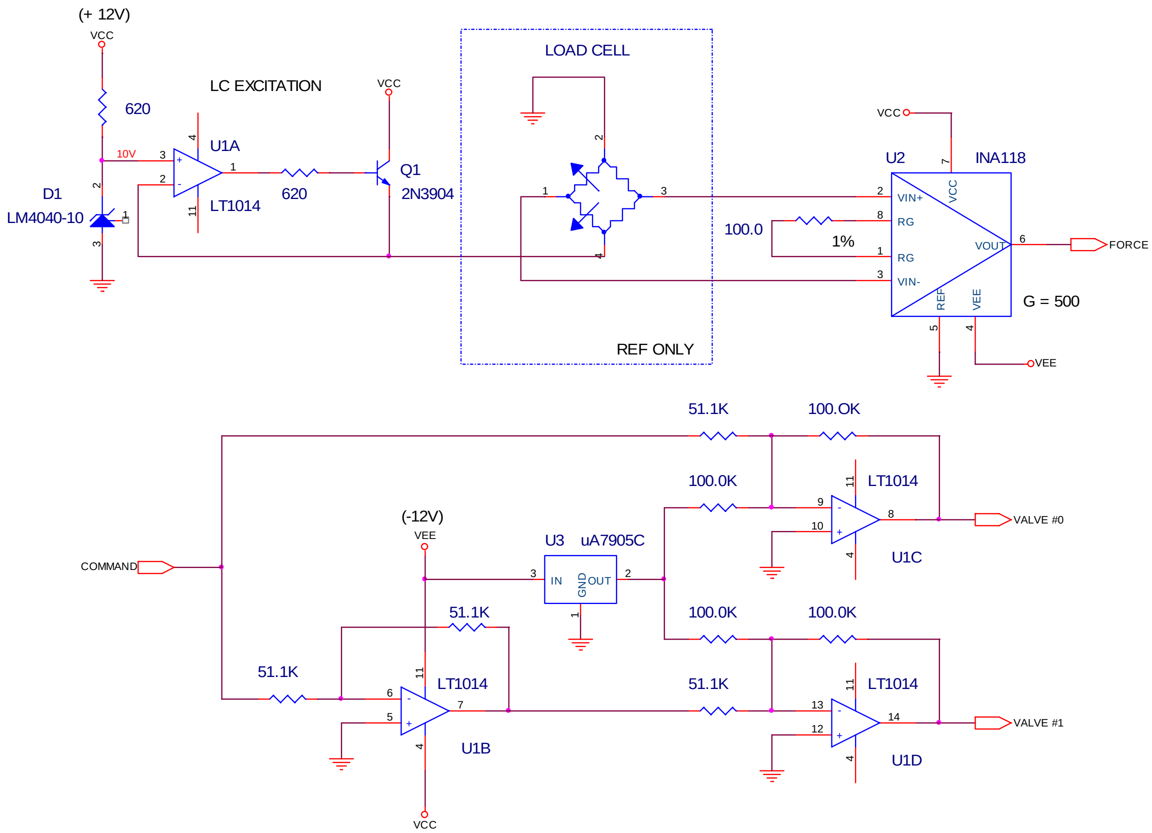

Figure 1. Open Loop Test Circuit

As can be seen, the load cell scaling is the same as that provided by the servo card, and the op-amp circuit provides the necessary algebraic manipulations to drive the air transducers in tandem with the appropriate half-scale offset, again just like the existing servo card. This circuit is designed to perform the output relationship:

$$y = \pm 2x + b$$

where *x* is the input signal, and *b* the offset voltage, just as the real servo board does.

Open Loop Testing

For gathering the open-loop time response of the actuators, a Tektronix 4-channel digital oscilloscope was used to measure both the input signal from the signal generator, and the output signal from the INA118 load cell amplifier. These signals were then saved to floppy as Excel comma-separated value files.

Each actuator axis had both sine and square waves applied. The following figure shows the sine wave responses of units #19 and #40. “Main” refers to the z-axis actuator, while “Aux” refers to the y-axis (diagonal) actuator. I have tiled the plots, instead of overlaying them as there appears to have been a problem with the oscilloscope triggering, which may have been inadvertently changed in the hours between the two tests. Changing the triggering will offset the plots in the x-direction, making overlays of no use. Each plot shows the saved input signal in blue, and the load cell output signal in red. The x-axis is seconds, and the y-axis is volts.

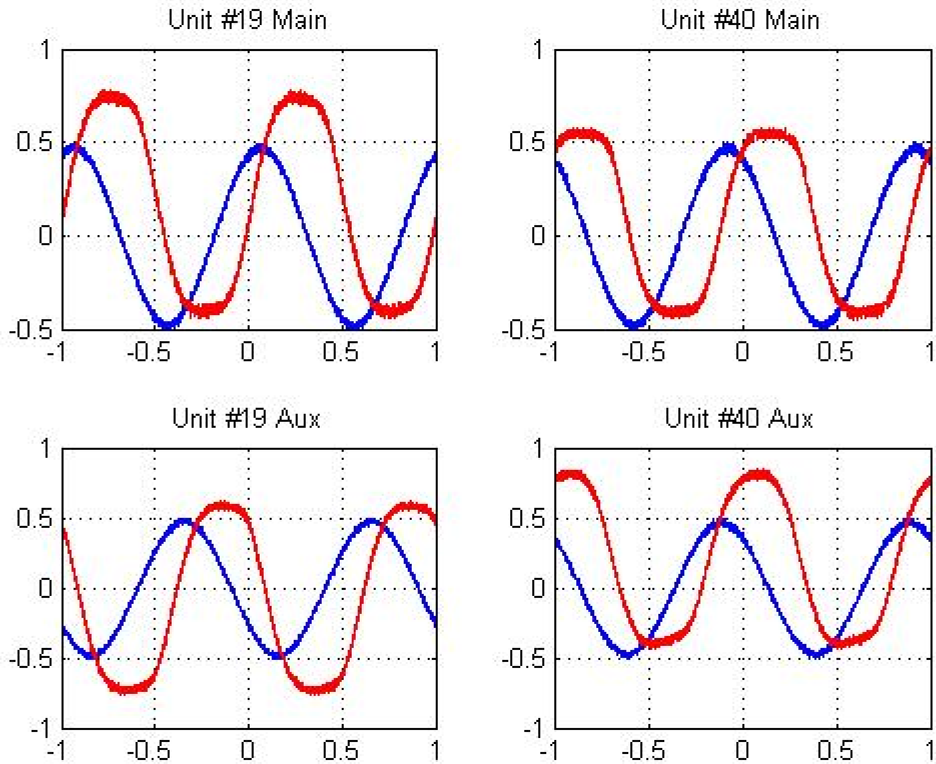

Figure 2. Sinewave Responses

The shapes of the waveforms are very similar. The main axis of #19 shows significant offset, as does the aux axis of #40. This may be due to misalignments in mounting the two units in the test stand fixture, or it may be indicative of some mechanical problem with the load cell hardware. The main axis signal swing is 1.22V for #19, and 1.03V for #40. The aux axis signal swing for #19 is 1.38V, and for #40, 1.28V. The simplest explanation for the output swing differential is probably adjustment drift of the air pressure transducers.

Moving on to measuring the time response, next we have the squarewave outputs. The frequency and amplitude remained the same for this test. Again, we had some sort of problem with signal triggering, as can be seen on the plot for unit #19's main axis. This will require a little investigation; I suspect pilot error using the test equipment, not the fault of the actuator.

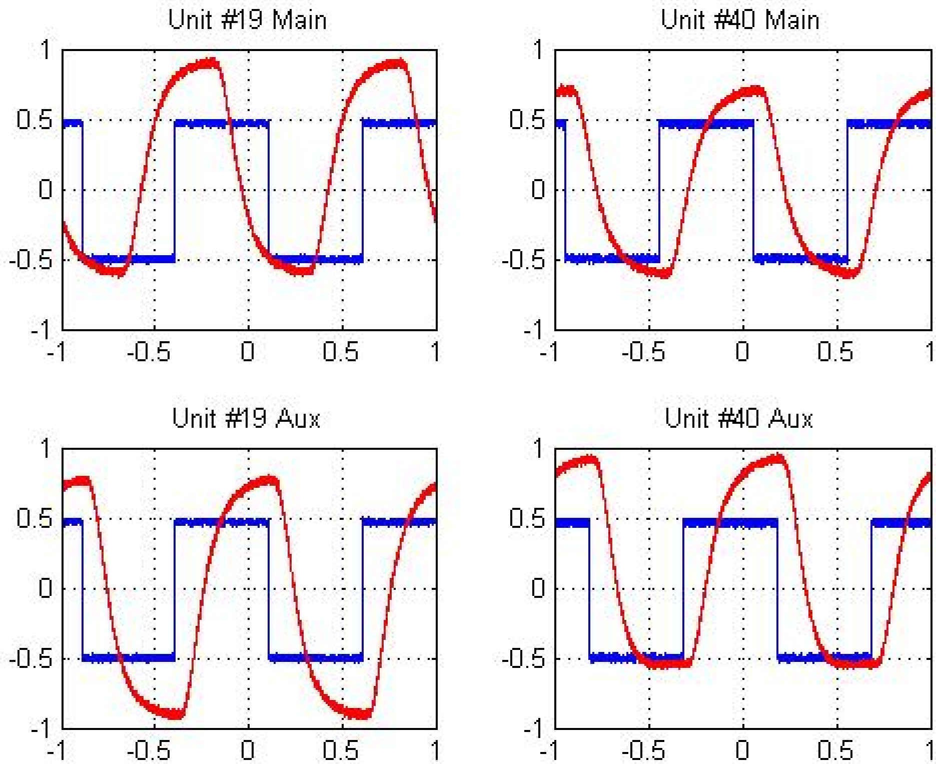

Figure 3. Squarewave Responses

Here we see again the differential offset and swing between the two actuators. However, using 60 lbf/V as our nominal force to voltage conversion factor, we see that the actuator can slew ±50 lbf in roughly 0.5 seconds, or 100 lbf/second. This is well above the ~10 lbf/second required at 1.5º/second elevation slew velocity.

To complete the measurement of the open-loop actuator, we then attached the DSA to the drive circuit and used a 0.25Vpk 0.1Hz to 10Hz chirp signal to acquire the frequency response of the two actuators, shown in the next figure:

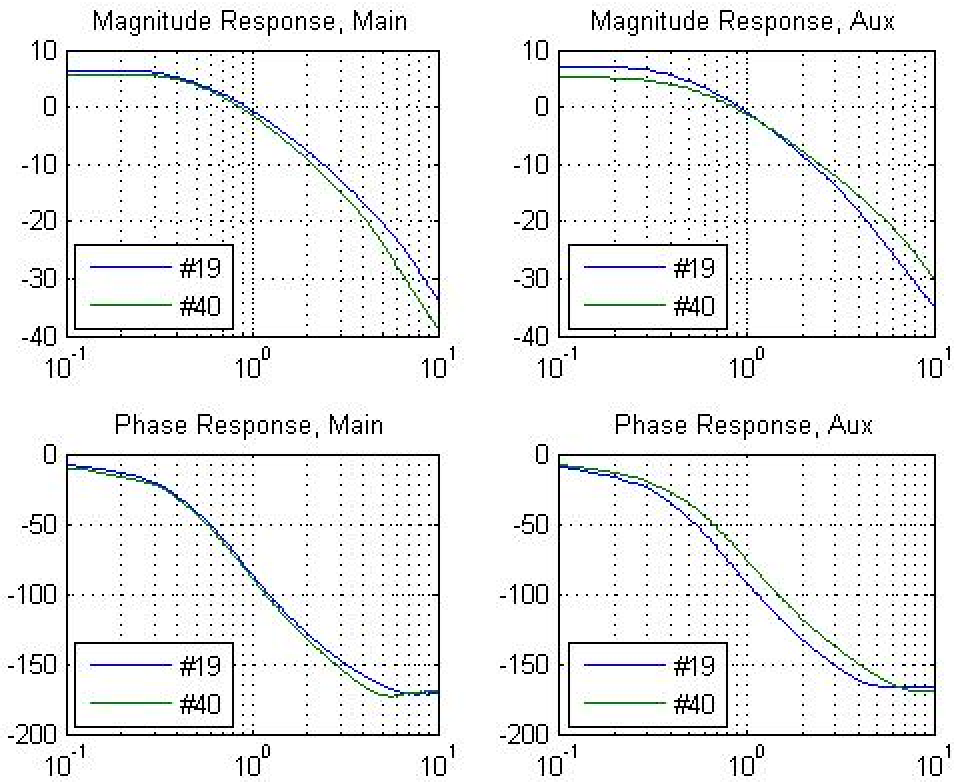

Figure 4. Open Loop Frequency Responses

The aux axis response of #40 is about 2db lower than that of #19, up until about 1 Hz, then the two cross over. The phase responses are also different. This again may be due to gain and offset adjustment differences between the two units, or perhaps an air leak in the cylinder. Component variations between the two servo boards can also be suspected.

This completes the testing of the electromechanical portion of the two units. So far, there appears to be no insurmountable difficulty for the actuator to follow force commands at the necessary rate in closed-loop operation.

Closed Loop Tests

In doing the closed-loop tests, the actuator servo board was installed and driven by either the signal generator for time responses, or the DSA for frequency responses. Data was collected with the servo loop integrator on and off for comparison.

For the time response measurements, the driving signal was either a square wave or a sinusoid, both at 1 Hz, 1Vpp, as before.

Late in the testing, I stopped saving the input signals in an effort to save disk space on the dwindling supply of floppy disks available; this is why the input signal is offset on the integrator-on data in time.

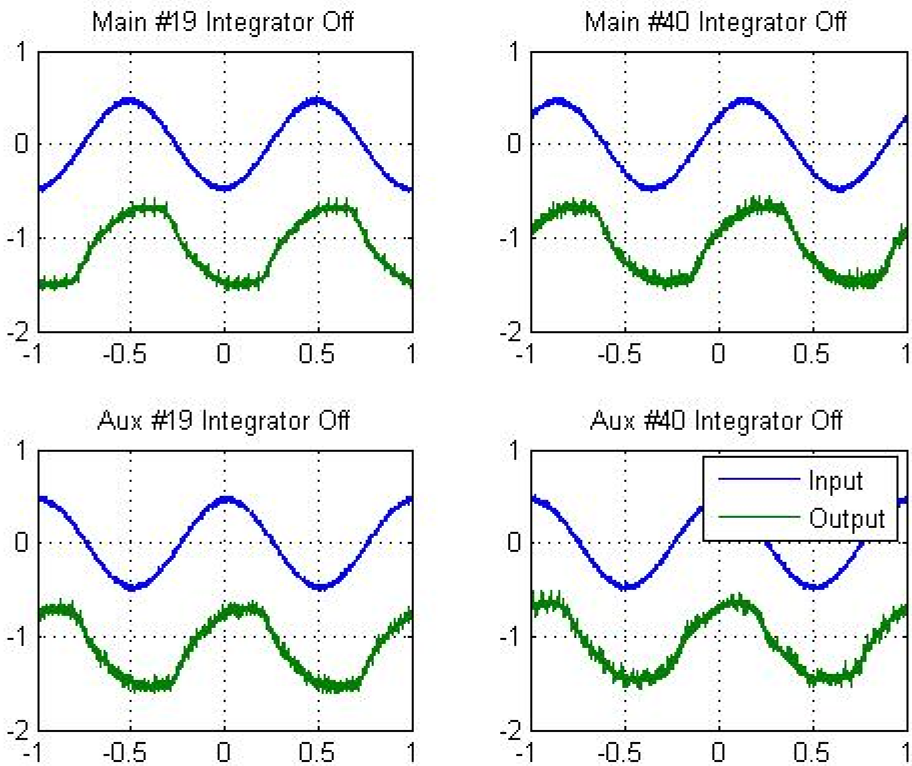

Figure 5. Closed-loop Sinewave Responses

The actuators exhibit a "pull-back" feature when the integrator is off, easily seen here. This is a historical leftover from the early SO design that worried (perhaps excessively) about having positive contact with the mirror hardware, and tried to ensure the mirror was fully engaged on its static supports when not raised into operating position.

Next, we applied the same sinewave signal with the integrator on, shown on the next page:

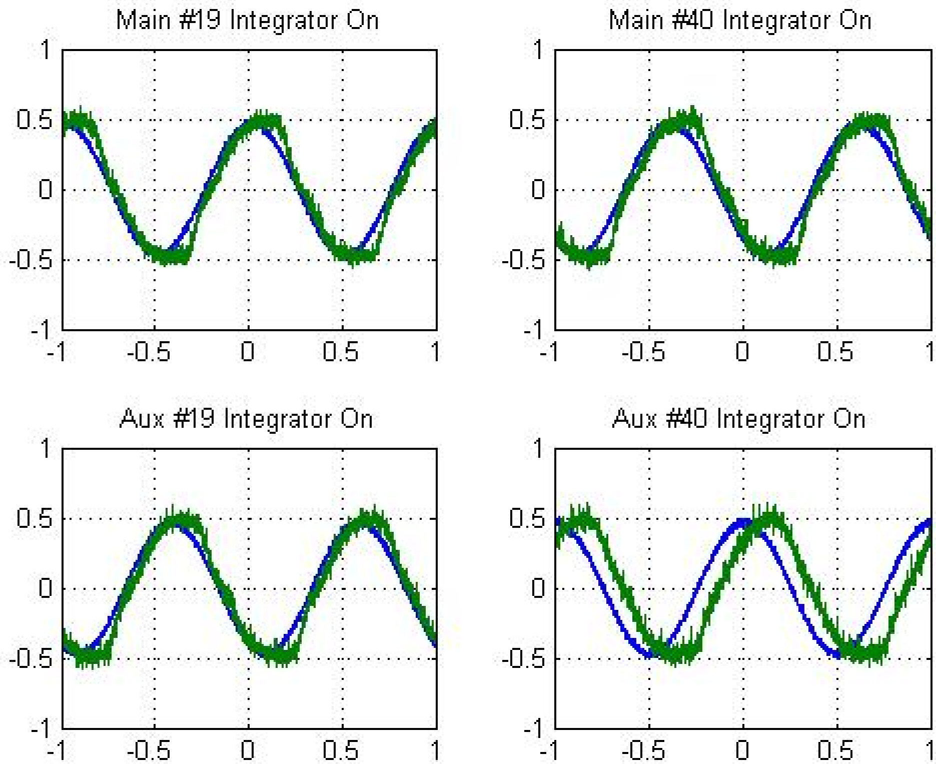

Figure 6. Closed-loop Sinewave Responses

The response shapes are again very similar in appearance. Square waves were also applied, as shown in the following page, with and without the integrator:

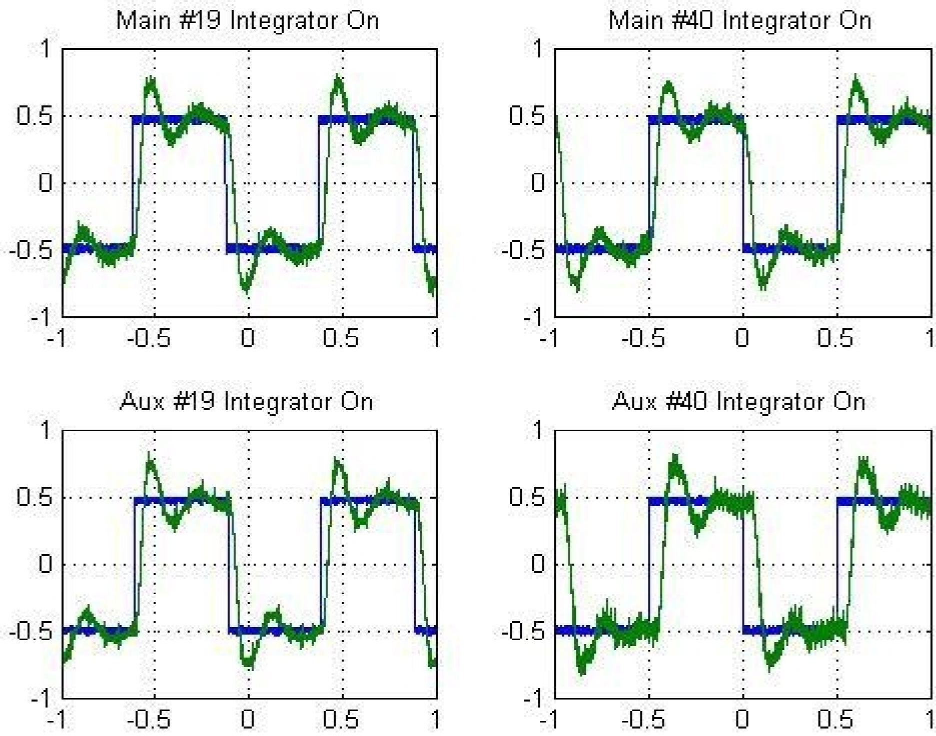

Figure 7. Closed-loop Squarewave Responses

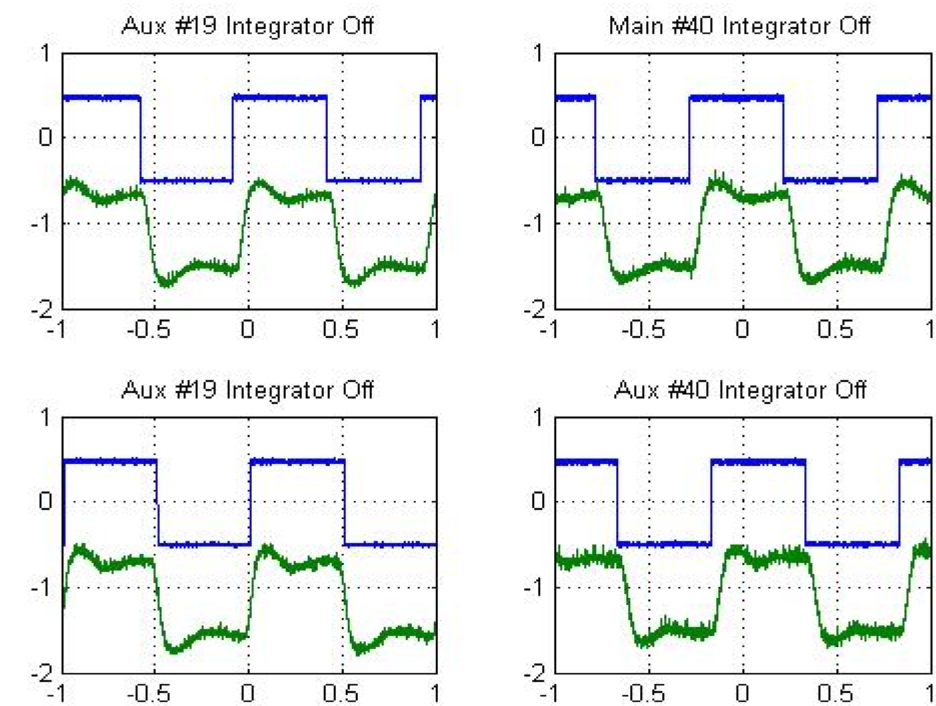

Figure 8. Closed-loop Squarewave Responses

Once again, in a misguided attempt to save floppy disk space, we don't have the actual input signal for the aux channel. Given the waveshape, however, we can conclude that it works more or less like every other channel.

We conclude with measurements of the closed-loop frequency response, with and without the integrator:

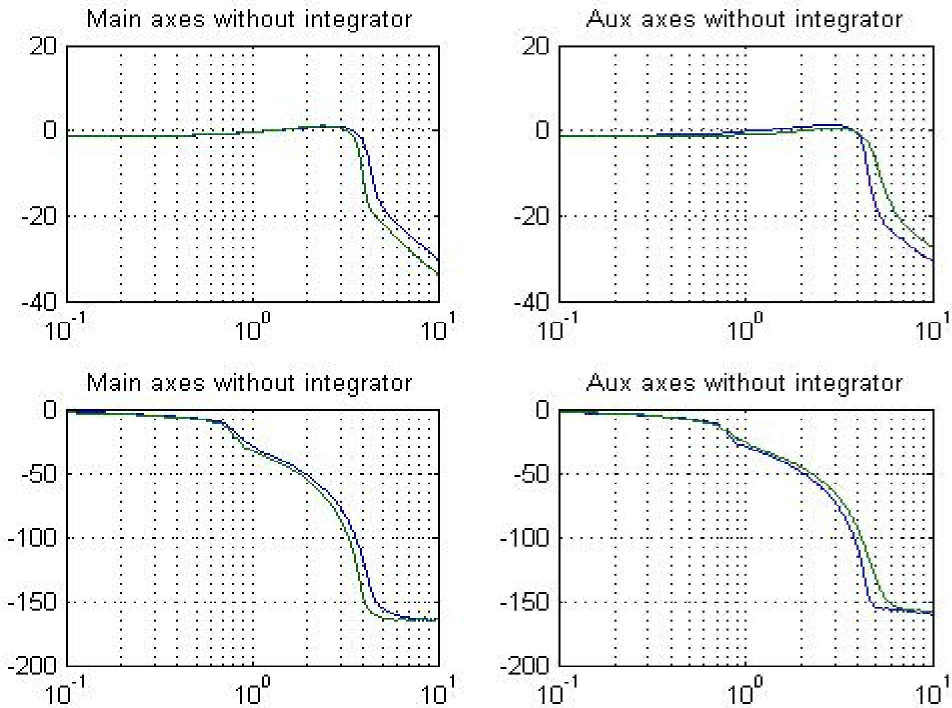

Figure 9. Closed-loop Frequency Responses

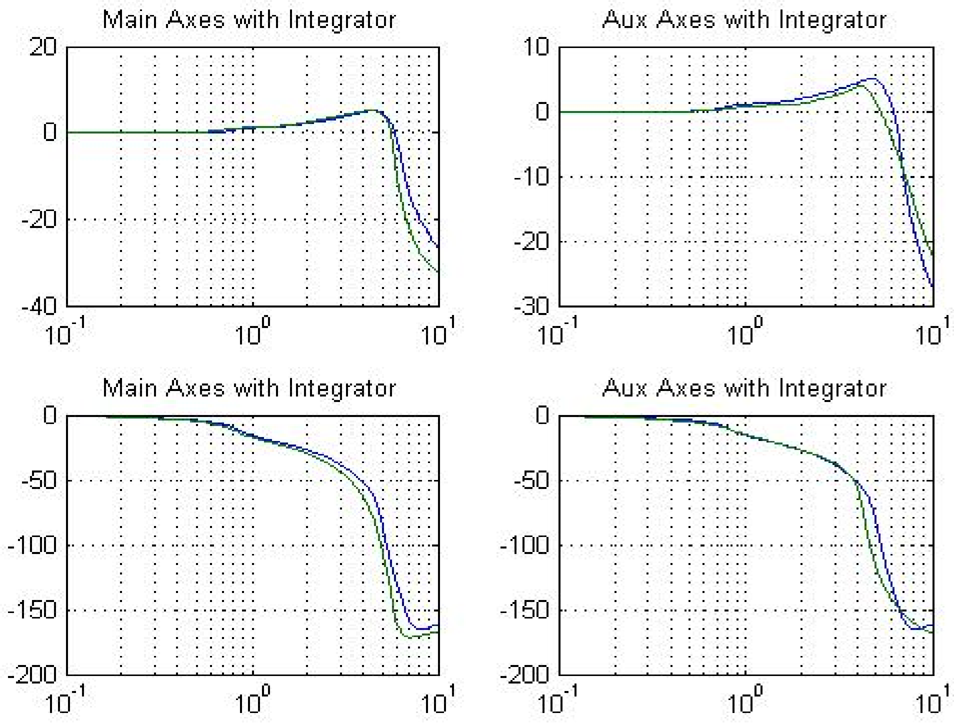

Figure 10. Closed-loop Frequency Responses

Conclusion

The MMT primary mirror actuator dynamic behavior is now well understood. The data presented here has been used to develop Simulink models of the actuators for later use as a design tool to determine changes to the servo response if deemed necessary.

This type of dynamic testing is unfortunately not possible to do with the present test stand electronics due to the presence of a low-pass filter at the analog-to-digital converter with a time constant of seconds. Reconstituting the test stand electronics to improve noise levels and bandwidth is therefore a worthwhile project.

For the servo cards, the large amount of force overshoot and the pullback force are two items of particular concern. In addition, no safeguards are in place to prevent rapid force demands from being applied to the actuator. We may want to put some work into:

1. Filter the command signal path to prevent fast force commands from putting excessive rapid force demands on the mirror (i.e. a command pre-processor).
2. Eliminate the pullback force to reduce stray forces on the mirror and pucks when the cell computer is not running or in its boot process.
3. Redesign the servo components to reduce the overshoot and ringing and concomitant stresses on the support system components.