

Servo Project Progress Report
Dates covered: 12/22/2006 to 1/12/2007
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Prior to the holiday break, we had successfully tested the deployment and operation of the new elevation controller on the telescope, and wished to begin final testing, debugging, and deployment early in January. The complete list of activities from the last report was:

1. Bring Tom's Matlab installation up to that required for controller design and simulation from open-loop data.
2. Create a list of commissioning tests to be performed on the new controller before releasing it for science observing.
3. Make changes to the mount code infrastructure to automate loading the controller code and getting it ready to run so it behaves similarly to the existing code suite.
4. Develop telemetry from the existing mount code to gather tracking error data. This data should be fast enough to capture modal frequencies on the telescope axis.
5. Quantify the new controller closed-loop bandwidth with a frequency-response test for comparison to that predicted in Simulink and the existing servo loop. The frequency-response test should be in the command signal path and as a disturbance to the motor torque signal to fully characterize the command response and disturbance rejection.
6. Perform a series of commissioning tests based on the list in (2) above.

Item 1 on the list is not really on the critical path for getting the controller running, so we choose to defer it until more pressing tasks are completed. For Item 2, Clark wrote a commissioning checklist to be performed in order to fully test and verify the new controller's proper operation. This commissioning checklist can be found at:

<http://www.mmt.org/~dclark/Reports/MMT%20elevation%20commissioning%20checkout.pdf> for the interested reader. Item 3 has been completed; changes were made to allow the realtime code to load and run in the mount code startup script. Item 4 is somewhat more problematic. We were able to add a logging variable to the mount network logging suite that continuously captures the RMS position error in the mount, but this does not necessarily give enough high-speed data flow to take the time-domain data and convert to frequency-domain plots for analysis of the modal response of the telescope during science object tracking.

Discussion at the servo meeting on 1/4/07 regarding verification of the tracking performance centered on deciding what tracking specification over a specified time period should apply, and how to capture this data for analysis and verification purposes. It was decided that 1kHz data collection for a 2-minute period would be sufficient for verifying an initial tracking-error specification of 0.1 arcseconds (peak-to-peak? RMS? peak?) over a 1-minute period. We would like to have on-the-fly reduction of the time data to frequency-domain information for capturing the modal response of the telescope,

but so long as the raw time-domain data collection and archiving remains tractable, we can afford to use disk and memory space for this data. Collection of this data before permanently moving to the new controller would be of use in comparing the controllers' performance in an empirical manner.

Trebisky arrived on the mountain 1/8/07 to begin the process of final debugging and checkout of the controller prior to beginning the commissioning checkout procedure. A bug in the software that improperly added the value of the absolute encoder output to the tape encoder counter value at the first drive startup, and then didn't perform this initialization at subsequent startups was corrected; the absolute encoder value now always gets added to the tape encoder counter when the drives start, so absolute positioning and tracking now properly works with the tape encoder. Clark had another encoder interface cable made and checked it out – this allows the use of a dedicated pair of encoder signal cables for the 50X encoder interpolator boxes so that the existing suite of interpolator cables can remain undisturbed while testing the new controller, speeding up setup/teardown of the testing hardware, as well as making the rotator and elevation axis interpolator cables identical to one another.

The night of 1/9/07 was dedicated to Red Channel Spectrograph checkout and “elcoll” data collection, so Clark used the time to complete the process of bringing the engineering laptop and xPC Target machine up to the latest Matlab versions to bring them into sync with the version used by Trebisky. Next day, Trebisky arrived on the mountain. Clark and Trebisky then got busy going through the commissioning checklist.

Problems were encountered early in the process – we experienced intermittent startup oscillations in the elevation drives, especially after the drives were shut down by an interlock ready chain interrupt. Turning the drives on and off via the GUI did not produce the problem. Since the controller needs to be utterly reliable under all possible startup conditions, this was something of a show-stopper. It turned out that the drive on/off status was not being passed to the servo loop properly, so the control loop remained closed on elevation when the drives were off, so the loop integrators wound up against the un-moving telescope. When next they were turned off, the windup was present on the servo loop output, driving the system into oscillation. Trebisky then made a number of changes to the code for both the mount and interlock computers to better handle failure conditions and make safe system startup possible.

Once that hurdle was overcome, we moved on to testing items in the checklist. We succeeded in passing all of the safety-related items in the list, such as handling ready chain interrupts, emergency stops, and startup of other portions of the mount control system and ancillary systems.

We had a period of confusion late in the evening of 1/10, where we became unsure of the feedback signs and indeed, *which* tape encoder was being used for feedback. This was because the signs of the two tape encoder counters are in opposition (the drive arcs mirror one another), so Trebisky entered a sign flip on the “unused” encoder channel to make them track each other for convenience's sake in the data collection. Since we were (at the

time) convinced the other tape was in use for encoder feedback, this should have made no difference at all to the servo loop. Unfortunately, this change introduced some strange behavior in the controller, where it appeared that it was indeed getting positive feedback and going unstable. After much troubleshooting, we changed the sign flip back to the original state, and the servo loop was again operational. Some investigation will be necessary to ensure we have correct feedback and that the proper signs are observed.

Once all the safety and system-startup checks were completed, we moved on to formally testing motions based on the checklist. All the slew-motion tests passed, but with some issues that need additional engineering:

1. Windup is indeed present on the motor outputs when the servo is running with the brakes engaged. Some logic needs to be added to the controller to reset the loop integrators when the brakes are engaged to avoid overheating the motors. Even the existing controller code could use this change.
2. The tape encoder position and the absolute encoder position are not in agreement, as expected. We see a 19.7 arcsecond delta when slewing from 75 to 45 degrees. We will need to fully analyze the data collected during the run to develop a strategy for dealing with this mismatch (i.e. LUTs, cubic spline corrections, etc), if the data show that is not completely correctable with TPOINT coefficients.
3. Using the temporary linear amplifiers for driving the telescope limits the available torque output to ~10A, or just half the output of the Copley PWM amplifiers. We were able to drive the telescope out of balance enough to overcome the available motor torque, so care **must** be exercised to ensure that no unsafe unbalance condition exists when trying to drive elevation. The good news is that the servo loop was able to tolerate an unbalanced condition, as required in the checklist, so long as the unbalance (or torque demand while in motion) was not more than the aforementioned 10A. This problem is alleviated when we bring the Copley amplifiers online for use in the servo loop, but will always be a safety issue with the MMT.
4. At high elevations ($> 87^\circ$), the servo output has an audible oscillation that the telemetry data show is 20Hz. We also appear to have some other intermittent oscillations when tracking at other elevations. There is some anecdotal evidence that suggests this was a problem with loading the servo parameter values, as we noticed a reduced amplitude when Trebisky rebuilt the controller code on Thursday, not running the controller as had been built on Monday.

For the sake of getting as much testing done as possible in the limited time available, we chose to defer tracking down the oscillations on the night of 1/10 in favor of testing some of the pointing and tracking-related tests in the checklist. We were able to do all of the target-acquisition and position offset tests successfully.

As a dry run for target acquisition, we acquired a couple of nearby stars (one directly to the S, one to the SE), and Saturn (low in the E) with the shutters closed. We had rain and fog, so doing any work on the sky was out of the question. We were also unable to collect any closed-loop bandwidth and disturbance-rejection measurements, as we had planned.

Trebisky did some additional work on the morning of 1/11 to again verify safe startup and operation of the elevation axis. He also collected some additional data on tracking so we can get more insight into the oscillations, which again, we observed to be a different amplitude than seen in the previous 2 days of testing.

After all of this testing, the most problematic and important problem we have at this point is the oscillation in the servo. Why it appears to worsen at high elevation, and indeed is present at all, is cause for concern. No audible oscillations or modal frequencies have been heretofore observed on the xPC Target version of the controller. To track this down, and verify the controller operation, Clark started building a version of the xPC Target controller that includes the ability to command absolute positions, freeze motion, and track at a given rate. Since the basic controller is “known good”, we can safely drive it up to near the final zenith limit to verify/disprove the 20Hz oscillation, and put it into a tracking mode to get full-bandwidth realtime telemetry for troubleshooting this servo stability problem. Collection of open-loop data for comparison and archival purposes will be part of this effort.

If this controller has the same problems as the VxWorks mount PC, we can eliminate code generation and deployment as suspects, and concentrate on servo design or tuning errors as the culprits. Clark will get the variable-mode controller running over the period 1/11 to 1/15/2007, and will test this controller at the MMT during Director time, if possible, 1/16 or 1/17/2007.

Activities for the next reporting period:

1. Develop and test an xPC Target controller for verifying controller operation and discovering the source of the 20Hz oscillation, and correct it.
2. Measure open-loop telescope response.
3. Complete documentation and code changes as necessary to ensure the proper feedback signal flow and signs in the mount PC.
4. Complete data analysis for the differential positions reported by the absolute and tape encoders. Plan a strategy for dealing with measured position errors from the drive arc encoder(s).
5. Test the new mount controller on the sky (weather and Director permitting).
6. Collect closed-loop and disturbance rejection data for documentation of the new controller performance.
7. Install telemetry in the mount controller for collection of high-speed tracking error data to verify tracking performance and measure modal responses.