Tracking and Slewing the Azimuth Axis with the LM628 Servo
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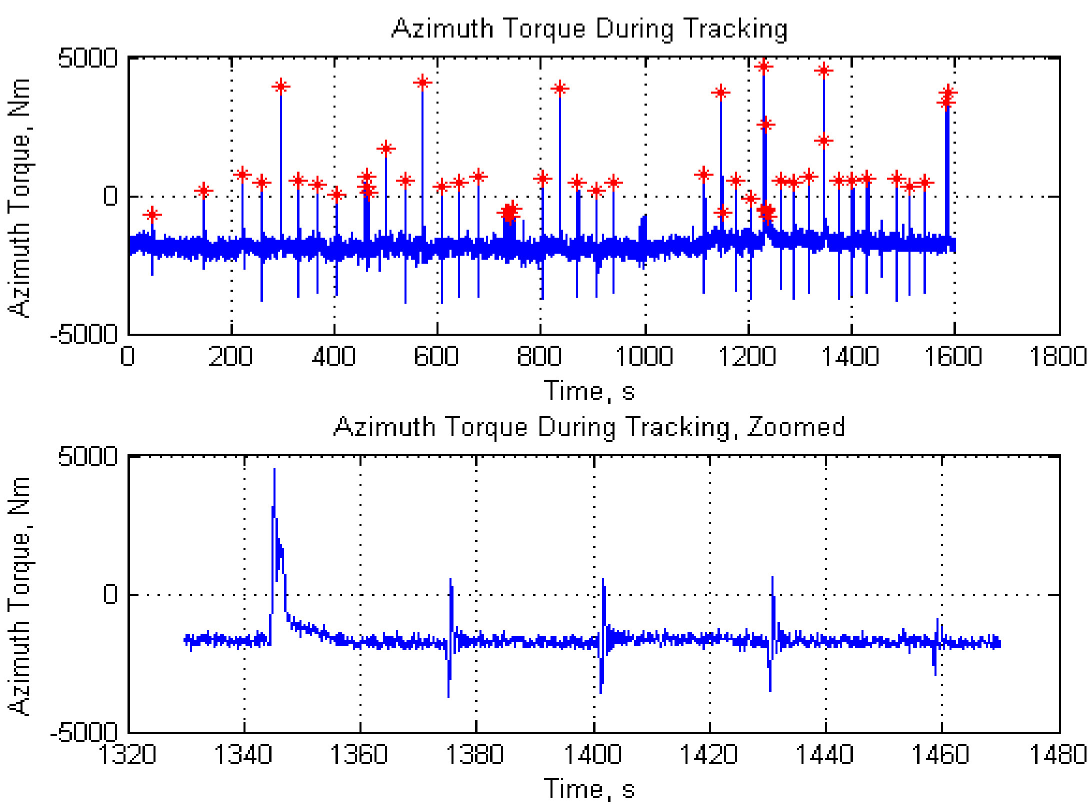
Introduction

During the data collection campaign of last June, data were collected on the closed-loop response of the LM628 servo (described in the previous report), as well as tracking and slewing data to help document the operational behavior of the LM628 controller. In this report, the focus is on data collected during tracking and slewing the telescope. For the tests described here, the elevation axis was fixed at 45° with the brakes set.

Tracking Motor Currents

Each of the 4 azimuth drive current-source amplifiers have an output monitor BNC that was connected to the xPC Target analog inputs. An object track was commanded at -25° Azimuth, 61° Elevation, and 1600s of data were collected from the 4 analog input channels at 10Hz. The azimuth tracking rate was thus about 13”/s. With this, direct measurement of the running torque on the azimuth drivetrain, and the time response of the servo during tracking is available.

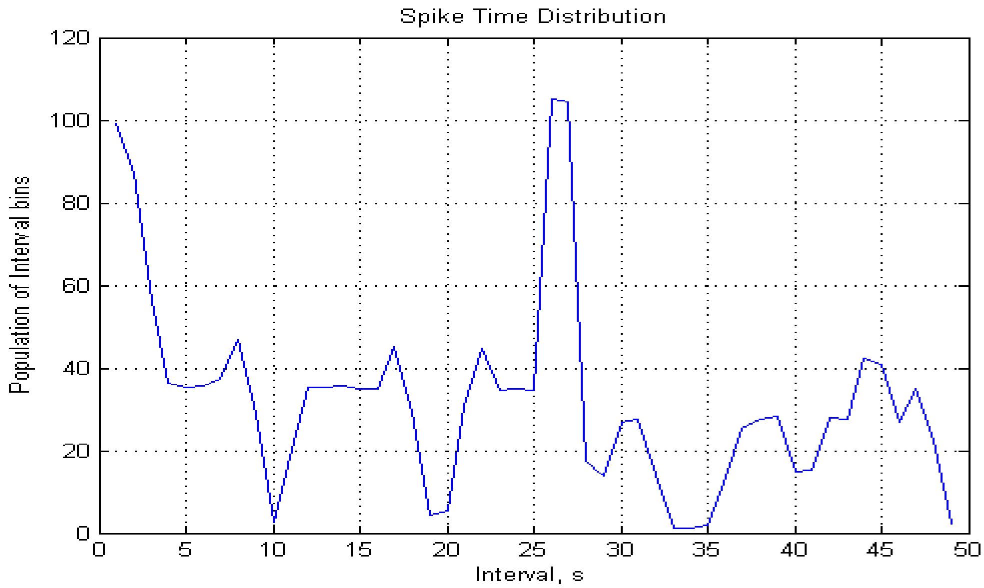
The total torque on the azimuth axis is the sum of the motor currents, multiplied by the mechanical advantage of the gearboxes. In the figure below, we have the torque in Nm over time, along with a zoomed section of the data.



Here, we see that the mean torque during the track is about 1700Nm, and regular torque “spikes” are seen at roughly 30s intervals, highlighted with red markers. In the zoomed section, the regular character of the "spikes" seems to be a positive spike followed by several oscillatory events. The torque spike is large, about 3000Nm. With a roughly 30s interval at 13"/s, this corresponds to about 3115 cycles per telescope revolution. I can think of no mechanical source in the drive train that would result in this particular mechanical rate. Some of the Usual Suspects are:

- Azimuth bull gear 944 teeth, or 944 cycles/rev
- Pinion gear with 45 teeth, or about 21 cycles/rev
- Motor brush commutator rings with 190 bars, or 18960 cycles/rev

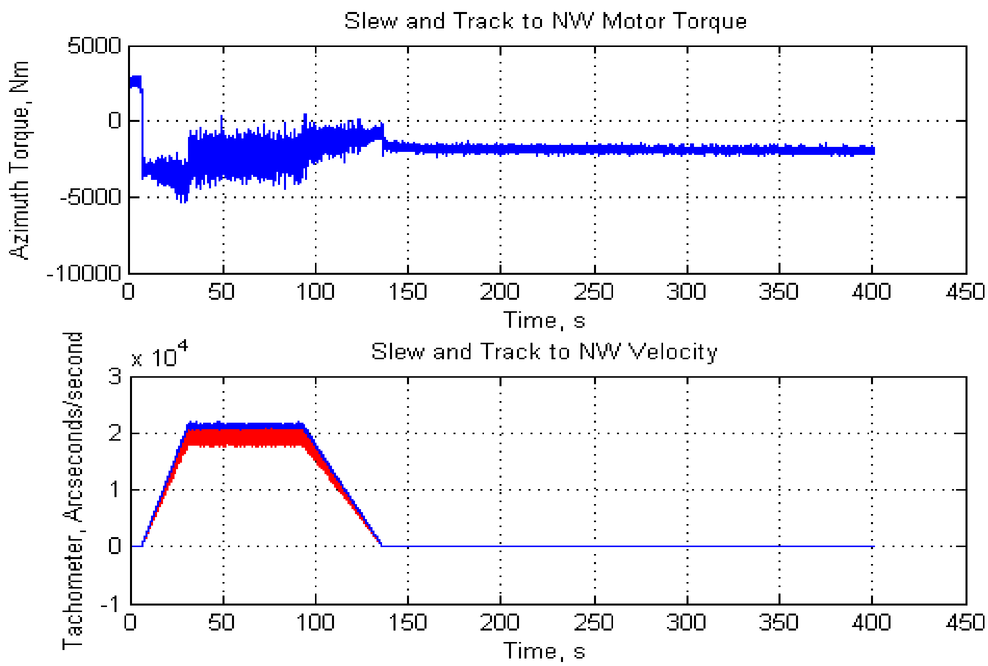
I don't currently have information about the number of rolling elements in the motor bearings, gearboxes, and azimuth bearings; there may be some closer mechanical frequencies from them due to bearing wear.



Above, the time difference between peaks highlighted in the first plot is plotted in terms of their distribution. Clearly, there is a strong population bin at about 27s. This regular torque spiking is rarely seen in the normal tracking data logs due to their 120s duration. At most, we would see about 4 excursions. More long data collection at higher sample rates should be done to confirm this behavior, and help find its source.

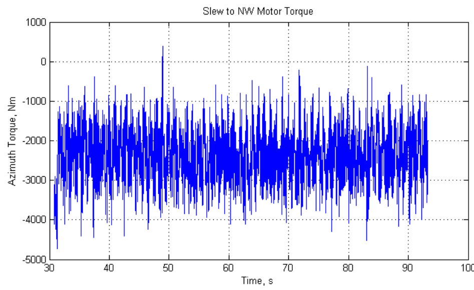
Slewing and Tracking

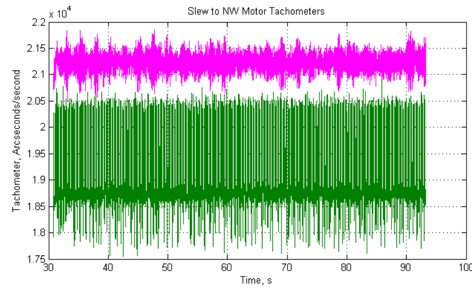
Three different slews and tracks were performed while collecting data at 500Hz from two of the motor amplifier current monitor signals, and the two working motor shaft tachometers. A bug with the old IP-16ADC xPC Target driver prevented it from working properly under the latest version of Matlab and the xPC Target kernel, so only 4 channels of data collection with the IP-16ADC are available. Also, the single-ended ADC front end ended up picking up large amounts of 60Hz noise on the tachometer signals. I plan to update the hardware and software on the xPC Target test computer to fix these problems before collecting more azimuth system data.

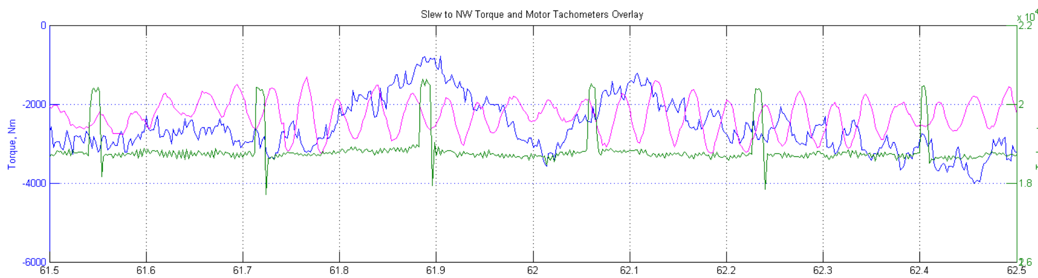


In the interest of time and space, only the data from slewing to the NW and tracking there for ~200s is shown here. Above, we have the azimuth drive torque in Nm and the two tachometer outputs in arcseconds/second. The data begin with a slew from zero velocity, accelerating up to slew velocity, then ramping down and tracking.

Clearly, there is a lot of noise in the data during the slewing (constant-velocity) period. It's instructive to look at it a little more closely (next page):



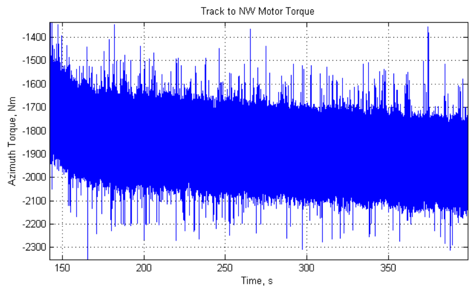


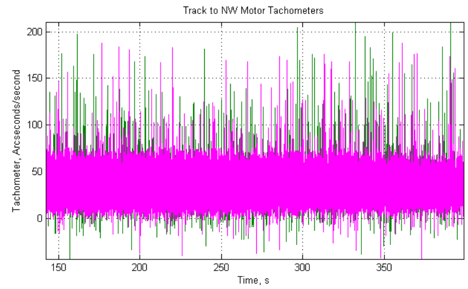


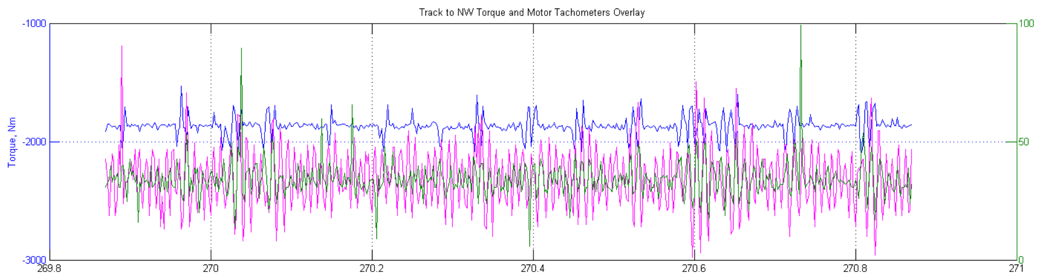
In the zoomed lower section, we can see that one tachometer (green line) has large commutation spikes and probably should be discounted, an unfortunate thing: it means that 3 of the 4 motor shaft tachometers are inoperable – two failed during the 1980s and were never repaired, and the third apparently has gone the same way. This may be yet another piece of evidence that the motors should be removed and serviced, given their ~35 years of operation with virtually no attention.

The other tachometer shows a clear sinusoidal character (magenta line) that doesn't seem to correlate well with the torque signal (blue line). However, it's clear that there are large variations in torque of order 3000Nm during constant-velocity slewing. The torque variations may account in part for the occasional rough building motion during slews, in my opinion.

On the following page, we have the same kind of graph for the tracking portion of this data:







Above, we see that the azimuth torque signal changing as the slew ends and tracking begins. We still have large torque variations that don't seem to correlate with the tachometer outputs. The one tachometer's commutation spikes are less of an issue at this low velocity (about 35"/s). However, the motor shaft velocity is clearly oscillatory in character (if the tachs can be believed). I suspect that any motor torque oscillations are "absorbed" in part in the gearbox compliance and largely low-pass filtered by the telescope inertia. But this scenario does not explain how the torque signal oscillations are only semi-periodic.

It would be more illuminating to have data like this with the motor shaft RON905 encoder and absolute encoder outputs to really track down whether the torque variation is mechanical or coming from the LM628 control loop – it may well be a combination of the two.

Conclusion

More data need to be collected on the motor shaft and gearbox interaction with the telescope position. Careful measurements of the azimuth drivetrain friction and gear noise are needed to fully characterize the drivetrain smoothness; the focus should be on detection of any mechanical issues that will make achievement of smooth tracking difficult (e.g. worn bearings, stick-slip in gear tooth interfaces). I am very concerned about the torque spiking, as this has a direct effect on the tracking quality.

Another campaign of data collection is planned. I need to upgrade the hardware and software for acquiring analog data. The next data collection setup needs to include all the encoders, motor torques, and any working tachometer outputs. I have data from this earlier collection effort on open-loop responses and a (fairly) crude friction-measurement setup; this all needs to be repeated with a better testing method, which I still have to work out. The results from these measurements will be outlined in my next report.