Submillimeter Array Technical Memorandum

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Measurements of friction in the elevation drive of antenna-1

Introduction

An excessive amount of friction in the elevation drive of antenna-1 has become a major impediment in our efforts towards achieving the required sub-arcsecond tracking accuracy. Considering that some amount of friction is inevitable in all mechanical systems, the PMAC does provide a facility to counteract friction, via the I variable x68 which adds or subtracts a specified amount of torque according to the direction of commanded motion. In our application however, this does not help because the static friction (stiction) appears to be about 3 times greater than the running friction. In addition to this problem, stiction varies significantly with elevation due to the unbalanced load.

Accurate measurements of stiction are important for a better understanding and implementation of the servo and for assessing the quality of the mechanical components and their assembly. In this memo, I present the measurements of stiction and running friction in the elevation drive of antenna-1. In a subsequent memo, similar measurements on the azimuth drives of antennas 1 & 2 will be presented.

Measurement procedure

The stiction torque is estimated by measuring the motor current required to start moving the antenna from rest at a given elevation and converting the current to torque using the torque constant of the motor, 12 ft-lb/A. The current can also be determined using the digital output of PMAC (DAC output), converting the voltage to current using the known constants of the Glentek amplifier. In these experiments, the elevation encoder reading is simultaneously recorded along with the motor current and commanded DAC output. The data are sampled every servo cycle (0.442 msec) so that we can unambiguously identify the peak torque at the moment the antenna starts to move.

The torque applied to just start moving the antenna up in elevation, is given by $T = T_g + T_s$ and similarly, $-T = T_g - T_s$ to move down in elevation. The stiction torque, T_s opposes the direction of commanded motion. T_g is the torque due to gravity, as the antenna is unbalanced in elevation. T is the applied torque. Note that the current measured from glentek does not change sign whereas the commanded DAC is a signed quantity (± 10 volts). Moreover, the glentek current has an offset that appears when the amplifier is powered on. Therefore, when comparing the results obtained from the current measurements, one has to "fold" the current readings from the point where the DAC crosses zero instead of just reversing the polarity of the peak current reading. From the two measurements of current required to just start moving the antenna in both directions, one can obtain the values of stiction and load balancing current. I will discuss the latter in a separate memo.

Sources of errors

The peak current and DAC values were identified visually after plotting the raw data (e.g., Figures 1& 2). The error in the estimation of these peak values is expected to be well below $\sim$0.5A. A major source of systematic error in the stiction measurement can come from an error in the torque constant of the motor. Unfortunately, Carlsbad Magnetics have not specified any error estimates on their measurements of the torque constants for our motors. The specified values for different motors vary between 11.8 to 12.1 ft-lb/A. For a given motor, the torque constant can be reduced substantially by an incorrect commutation. Ideally, the "zero-phase" angle of the motor shaft (when the poles are aligned), should be determined under no load conditions. On antenna-1, however, this was done after the motors were mounted. Thus one would expect commutation to be somewhat imperfect. A direct way of assessing the consequence of this on the stiction measurements is to compare the current measurements with manual measurements using a torque-wrench on the end of the elevation screw. On antenna-1, a few such measurements were made at an elevation of about 7 degrees, close to the lower hard-stop. The manually measured stiction torque was about 260 ft-lb which agrees reasonably well with the electronic measurement of about 240 ft-lb at that elevation.

The error in the elevation encoder measurement is about 0.3" which corresponds to the noise in the least significant bit of the 22-bit encoder. The commanded DAC that is recorded, is not the input voltage to the amplifiers but the output counts resulting from the servo calculation. The PMAC has a 16 bit DAC with an output of $\pm$10V going to the amplifiers. The conversion factor at the amplifier input (differential) is 14A/V. Thus, 1 bit of DAC error corresponds to about 4mA of error on current, or about 5×10^{-2} ft-lb of error in torque. The error in the DAC output (which is more relevant for our experiment) is not yet measured. The motor current is measured as a voltage across pins 7 and 8 on the Glentek amplifier's control card, with a conversion factor of 20A/V. This voltage is measured through an A/D (PMAC accessory ACC-28) which does not meet its specification of 16 bit resolution but is effectively a 13-bit A/D [1] Thus, the minimum sampling step of current is about 24 mA and the rms error in the torque measurement of about 8.4×10^{-2} ft-lb, relatively insignificant.

In summary, the overall scale factor in converting current to torque was checked by comparing the low elevation electronic measurements with manual measurements of

[1] As found by Paul Peterson and Tony Stark.

torque required to move up the antenna. The variations in the peak current readings plotted in figures 5-8 are most likely due to the statistical variation in stiction itself.

Results

Figures 1-4 present examples of the raw data at low and high elevations. In Figure 1, the antenna is commanded to move up. The servo builds up the current until at about 2.6 seconds, when it reaches a value required to overcome stiction. The derived stiction values are plotted in Figures 5 & 6. Three sets of measurements were made on 11 September 1996. A somewhat less accurate set of measurements was made on 26 August 1996 (sampling rate was every 50 servo cycles instead of every servo cycle; current was not recorded). The latter data set is indicated by dashed line in Figure 6, Figures 7 & 8 show the variation of running friction as a function of elevation. The full set of raw and reduced data is available on a web page at *(http://smanap.harvard.edu/pmac_data.html)* which allows one to take a closer look at the data by zooming interactively.

Conclusions

A practical and accurate method is established to measure the stiction in the elevation drive of the SMA antennas. Measurements on antenna-1 reveal the following:

1. Stiction varies between 120 ft-lb, near zenith, to about 240 ft-lb, near horizon, as measured on the motor-shaft.

2. The smallest value of stiction measured on the assembled drive system, appears to be at least twice as high as the value of stiction measured on the worm gear including the ball-nut on the bench.

3. Stiction appears to be about 3 times greater than running friction.

4. The sum of the stiction and load currents required to raise the antenna from the lower hard-stop ($\sim 4.7^o$) exceeds the rms current limit of 45A on the Glentek amplifier.

Acknowledgements

I am grateful to Paul Peterson, Bob Wilson and Bill Bruckman for their help and advice.

Figure 1: Raw data showing elevation encoder counts (right axis), current and DAC counts (left axis) as a function of time. The lighter curve is DAC and darker curve, current. The elevation readings show a fluctuation in the least significant bit (0.3”).

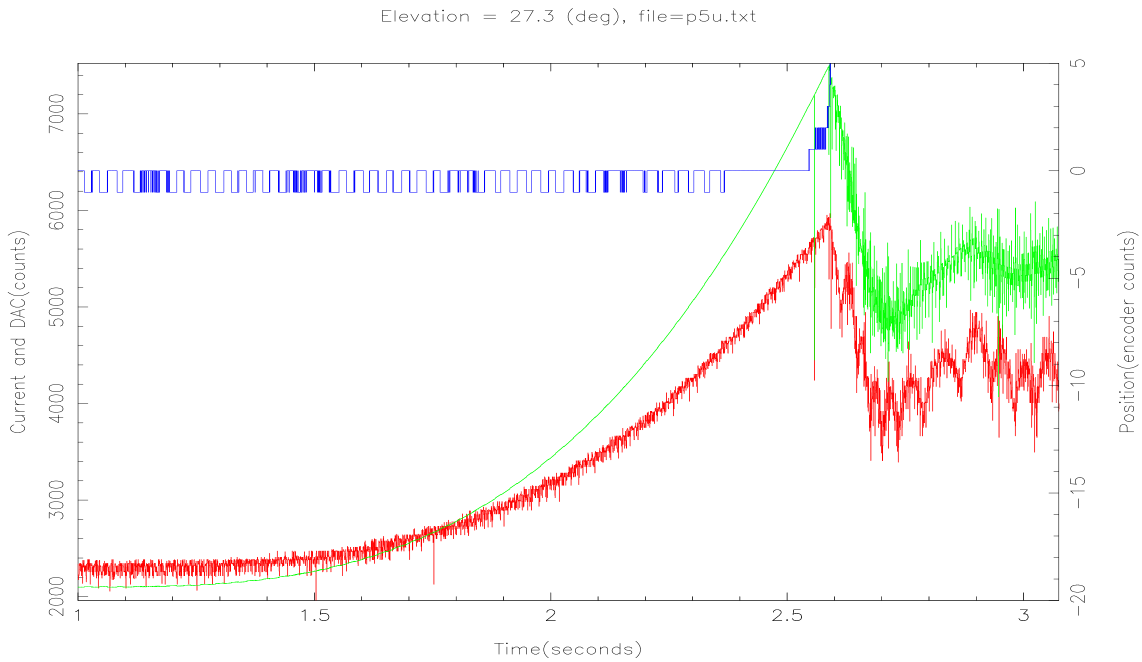

Figure 2: Same as above for command to go down in elevation

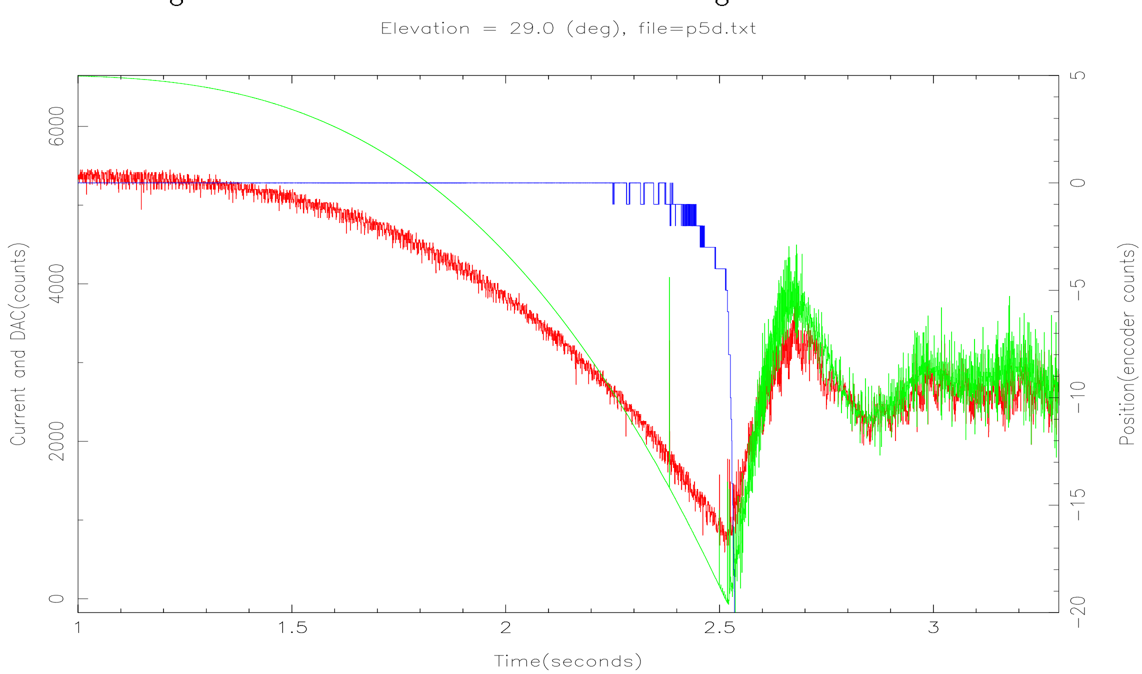

Figure 3: Same as in Figure 6, for command: Up, at a high elevation

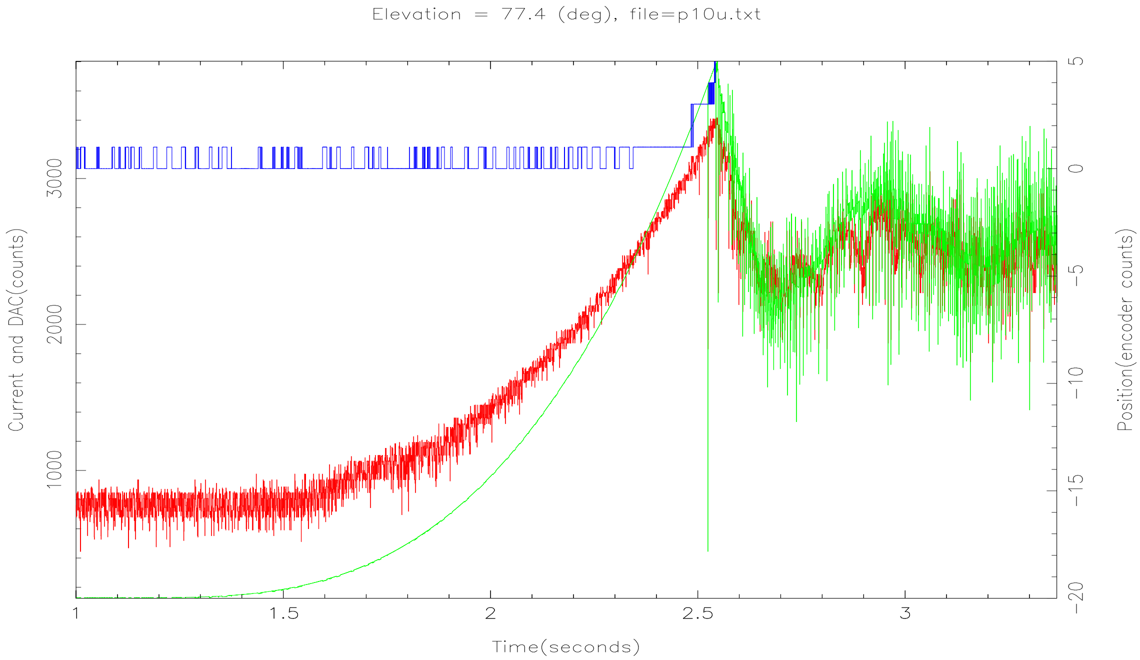

Figure 4: Same as above for command to go down in elevation

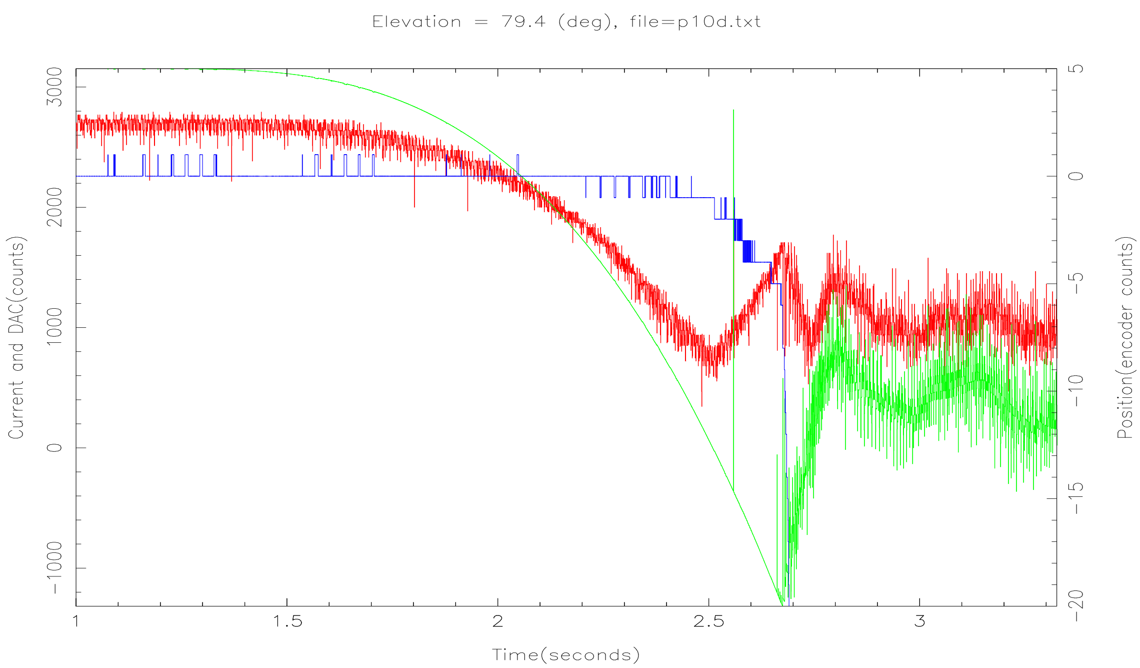

Figure 5: Stiction current as a function of elevation. Current is estimated from Glentek

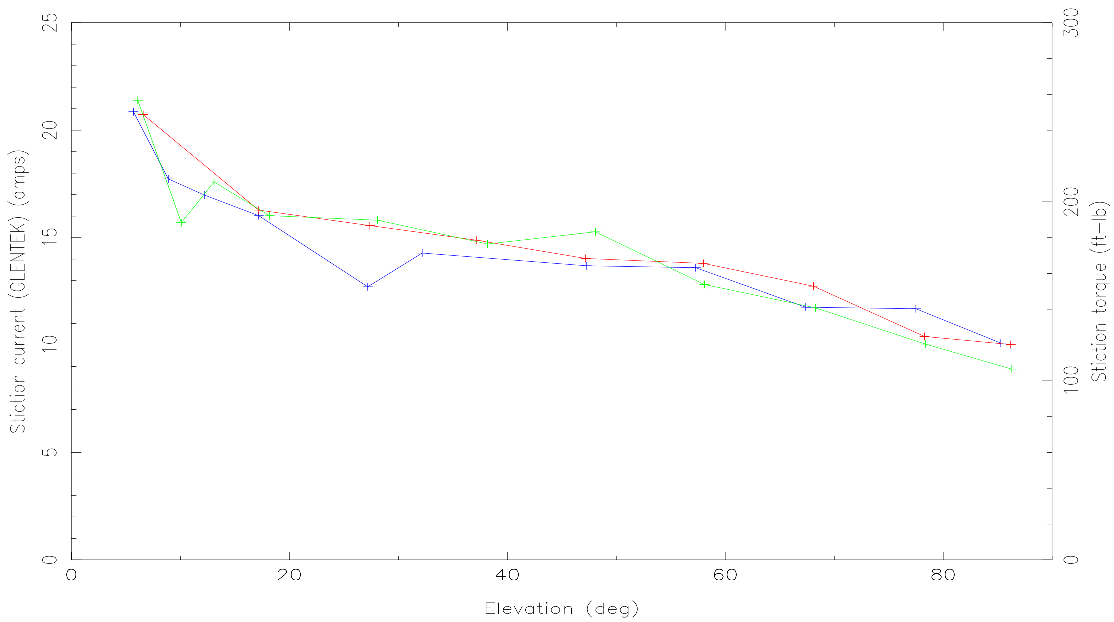

Figure 6: Same as above with current obtained from DAC counts

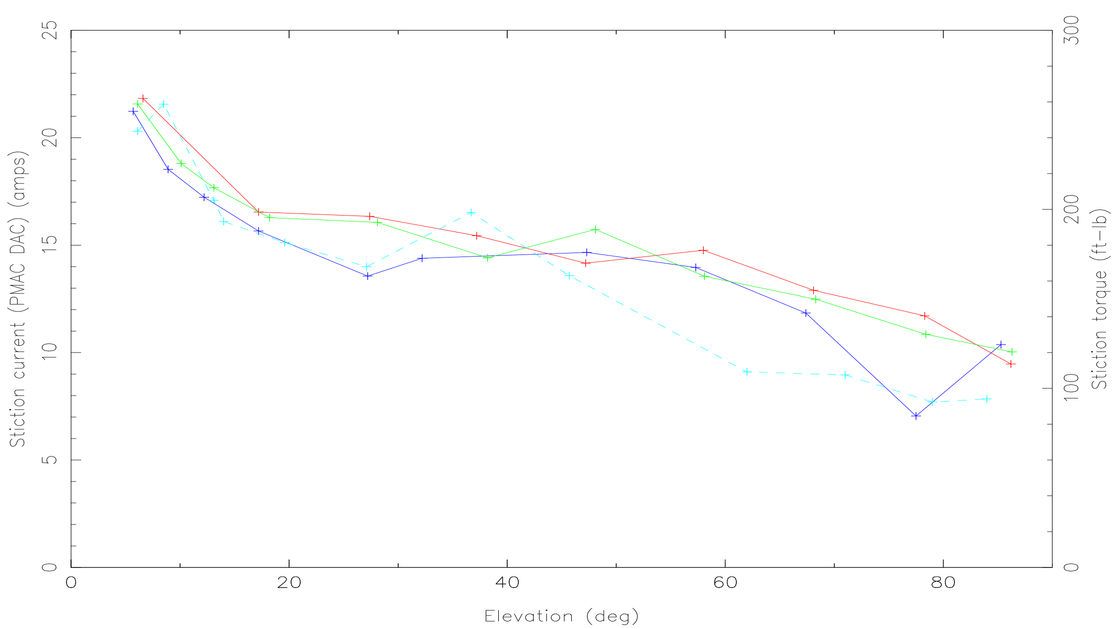

Figure 7: Running friction as a function of elevation (glentek current)

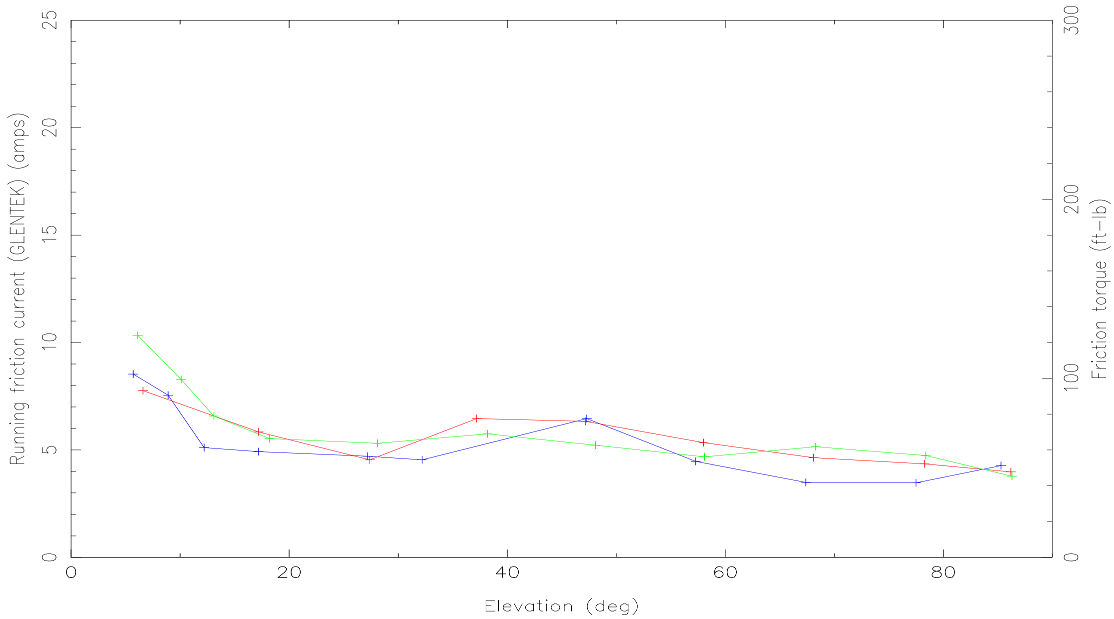

Figure 8: Same as above with current obtained from DAC counts