GBT MEMO 104

NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, WV

MEMORANDUM April 23, 1993

To: Jay Lockman
From: R. Lacasse, T. Weadon
Subj: GBT Dynamics

Introduction

A recent report from RSi/PCD, "Final Analysis Report for the Green Bank Telescope Control System", has prompted several questions from members of the NRAO staff. The questions all deal with the time required to move the telescope using the AZ/EL servo system. There are apparent contradictions in the report in this area. This memo attempts to shed some light on this question and raises several questions which need to be answered to allow NRAO to make optimum use of the telescope.

Linear and Non-linear Regions of Operation of the Servo

A key concept in understanding the settling time is the regions of operation of the servo. There are two regions, a linear one and a non-linear one. In the linear region the full compensation of the servo loops is employed to get smooth settling. This region is typically small; RSi/PCD usually uses +/- 158 arcsec. It is centered about the commanded position. In this region, the position step response is linear; this means that *for any step size that is completely within the linear region, settling time to a given percentage of the step size is a constant*. A graphic representation of this is shown in Figure 4.1-7 from the above mentioned report, and reproduced on page 4 of this memo: the vertical axis is unitless and can be scaled for any step smaller than 158 arcsec.

In the non-linear region, some of the loop compensation is disabled, again to optimize overall settling time. In this region, time from point A to point B is determined by acceleration and velocity limits and certain algorithms of the control system; it is roughly proportional to the distance from A to B.

Settling Time Examples

When the GBT is commanded to move, the servo system looks at the size of the commanded step. If the size of the step is greater than the linear region, the move initially uses the "non-linear" algorithm. When the linear region is reached, the linear algorithms come into play. When the telescope arrives within a desired tolerance of the commanded position, it is considered ON SOURCE and observing may begin.

One example worth considering is the AZ and EL step responses, Figures 4.1-7 and 4.2-7 in the report, reproduced on pages 4 and 5 of this memo. Five percent settling time on both of these is approximately 8 seconds, and 2.5% settling is approximately 10 seconds. For a step of 100 arc sec (within the linear range), settling to 5 arc sec will take 8 sec. Similarly, for a step of 50 arcsec, settling to 2.5 arcsec will also take 8 seconds. For steps larger than 158 arcsec this curve does not tell the whole story.

A second example to consider is a 10 x 10 grid map on page 76 of the report, reproduced on page 6 of this memo. Step size in this example is 10 arcmin, and settling to 15 arcsec (2.5%) is required. A settling time of 3.8 seconds is achieved. This seems to contradict the above example. However it was really achieved with the same telescope dynamic model by changing several parameters to optimize the settling time for this size step. In particular the size of the linear region was set to 15 arc seconds, and the acceleration and deceleration limits were chosen so that the telescope would not overshoot the linear region, i.e. so that it would stay within 15 arcsec once it got that close.

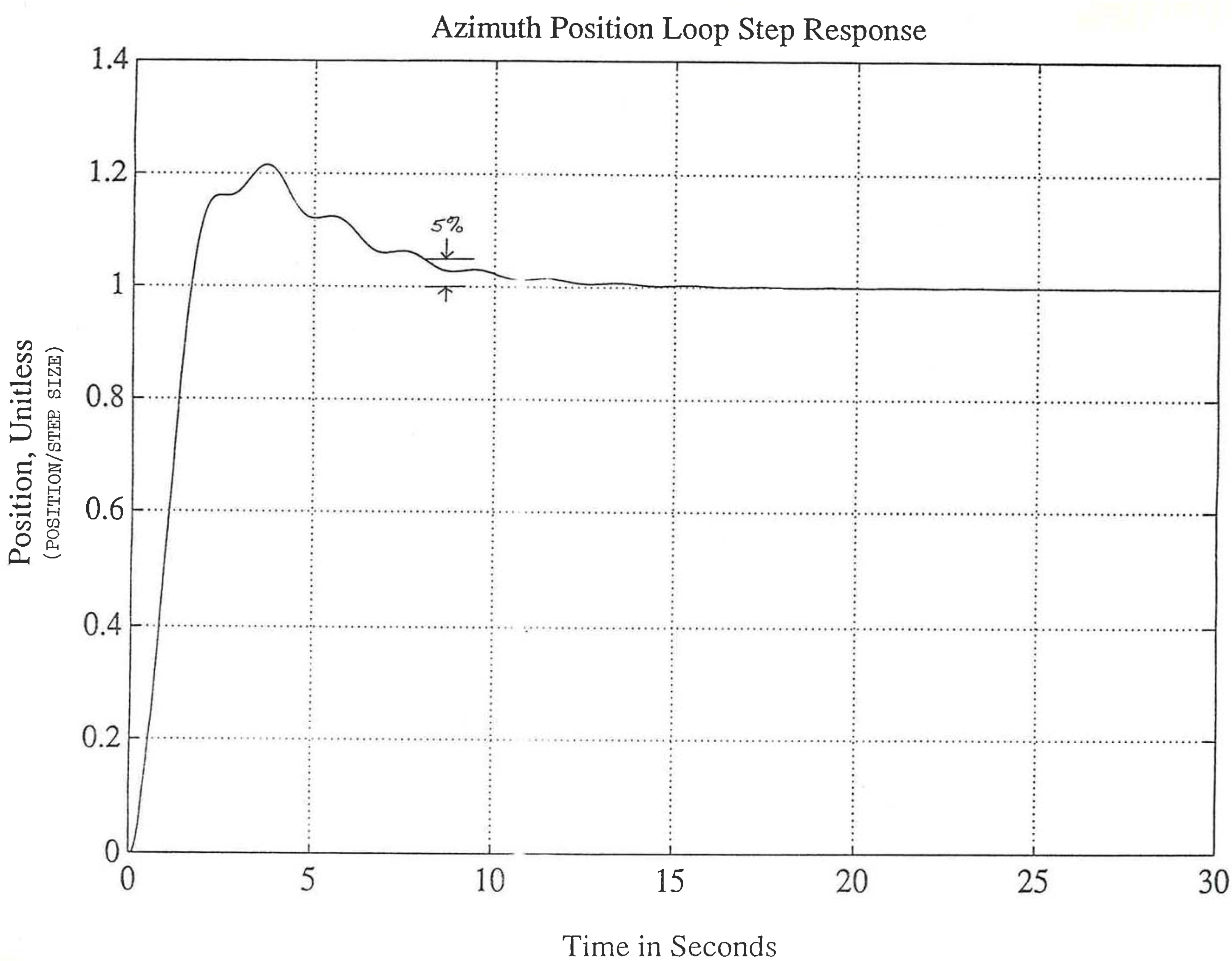
A third example prompted by Phil Jewell illustrates a worst case scenario where the linear region and accel/decel parameters are left at factory default values. Suppose we are observing at 1.3cm and are position switching by 1800 arcsec. The beamwidth of the GBT will be ~33 arcsec at this wavelength. If you require that the dish be within 1/10 of a beam before beginning to take data that corresponds to a fractional step of 0.002, i.e. settling to 0.2%. How long does this take? The move exceeds 158 arcsec, so the initial 1642 arcsec of the move will be in the non-linear region. Scaling from various plots in the report, it appears that we would spend approximately 5 seconds in the non-linear region. We still have to settle to 3.3 arcsec out of 158 or 2.4%. This takes approximately 10 seconds. So the total settling time would be 15 seconds.

Discussion

Although it achieves impressive settling times in the 10 X 10 grid test, the desirability of tuning the structure is not all that clear. See the memo by Jeff Mellstrom of JPL, included as pages 7 through 9 of this memo for a good discussion of this topic. Additionally, the same memo by Mellstrom points out that JPL is working on next generation servo concepts. These, as well as others being developed around the world, may be of great benefit to the GBT.

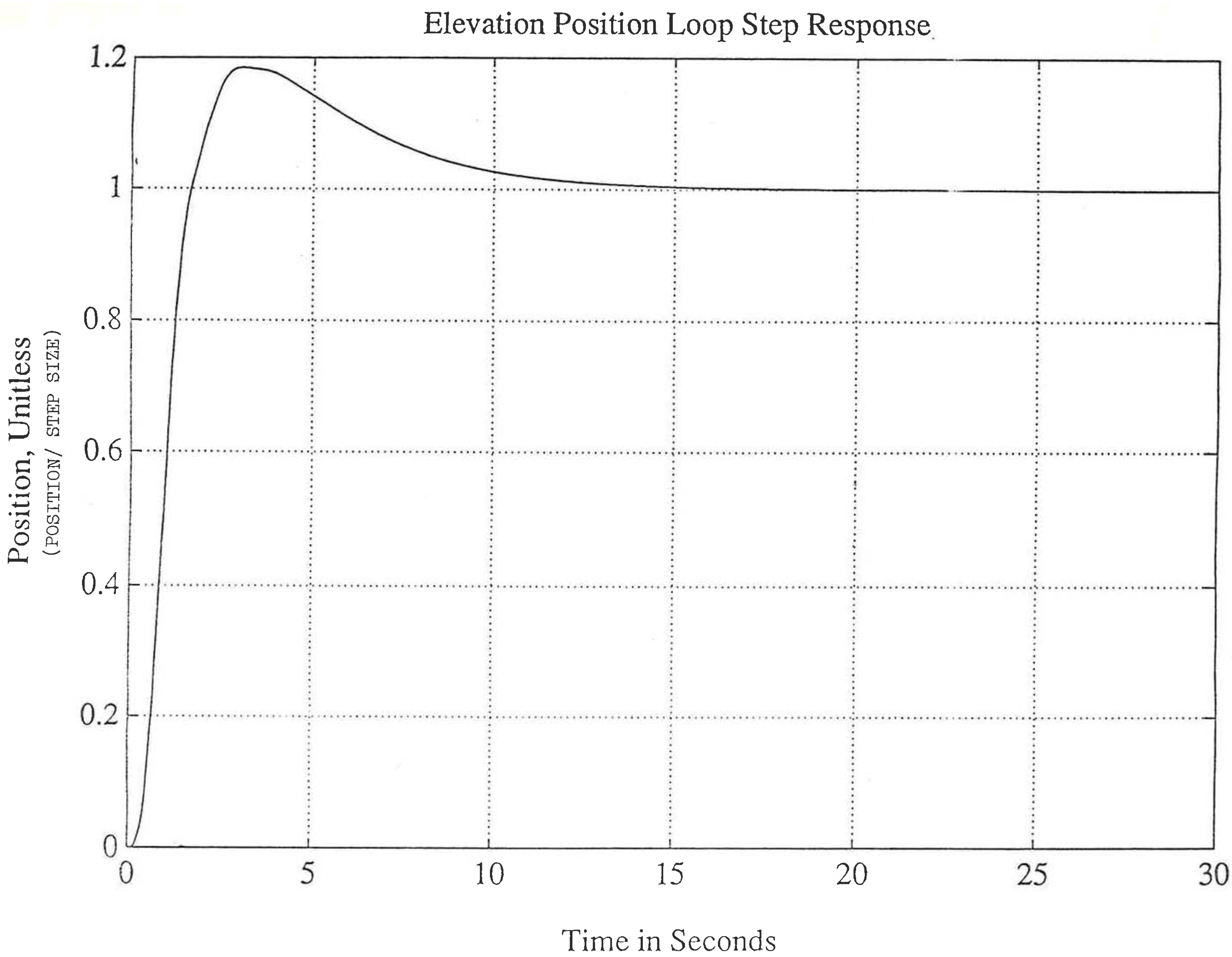
Conclusions

Improvements on the system delivered by RSi/PCD will no doubt be possible. However, moving 16 million pounds of steel with high accuracy is going to take a bit more time than people are used to. New modes of observing may need to be investigated to make optimum use of this instrument. At this point, we have rudimentary information on tuning the structure for optimum performance, as RSi/PCD did in the 10 x 10 grid test. "Hooks" are available in the software to do the tuning performed in the 10 X 10 test. Software tools are available (at a price) to investigate the effect of parameter changes on beam settling time and structural stability. This would be essential if it is decided that tuning the structure is a viable option. Finally, it is in NRAO's best interest to stay current with developments in the servo field to make optimum use of the GBT.



Azimuth Position Loop Step Response
Position, Unitless
(POSITION/STEP SIZE)
Time in Seconds
5%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
5
10
15
20
25
30

FIGURE 4.1-7



Elevation Position Loop Step Response
Position, Unitless
(POSITION/ STEP SIZE)
Time in Seconds
0
0.2
0.4
0.6
0.8
1
1.2
5
10
15
20
25
30

FIGURE 4.2-7

Table 6-2 10 x 10 GRID Test Summary

- linear region

AZIMUTH - 10 ARC Minute Step	time (sec), to settle within 15 arc seconds	Figure
Step only	3.8	6.3-1
sidereal rate with positive offset	4.84	6.3-2
sidereal rate with negative offset	3.78	6.3-3

ELEVATION - 10 ARC Minute Step

Step only	3.8	6.3-4
sidereal rate with positive offset	4.7	6.3-5
sidereal rate with negative offset	3.78	6.3-6

TOTAL TIME, 10 x 10 Grid with 10 seconds of observation per point static sidereal

STATIC: 1376 seconds or 23 minutes
SIDEREAL: 1422 seconds or 24 minutes

Theoretical minimum, static 1090 or 18 minutes

JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**

3324-93-040
April 6, 1993

TO: Ben Parvin

FROM: Jeff Mellstrom

SUBJECT: **Comments on R. Lacasse Memorandum**

In general, nonlinear system behavior is governed by:

- Nonlinearity (acceleration limits, velocity limits, etc.)
- Inputs
- Initial conditions
- Linear subsystem frequency response

The 10x10 GRID results reported by RSI were achieved by adjusting the switching rules and the nonlinearity (acceleration limit) to optimize the system response for that specific set of inputs and initial conditions (with the linear subsystem unchanged). These adjusted values are not globally applicable, and may not even be "stable" for certain sets of inputs, initial conditions, and linear subsystem frequency responses. I put stable in quotes because the system may be theoretically stable, but the output may not be desirable (example of a plot is attached that shows terrible performance of a DSN antenna). The DSN uses a similar type of linear/nonlinear system switching as RSI. The plot shows a 400 mdeg limit cycle. This was caused by an acceleration limit that was set too low. This acceleration limit was fine for some inputs, but bad for others. Another DSN example is the SETI scan. This scan is continuous in position but discontinuous in velocity. (Velocity drops discontinuously from 200 mdeg/sec to 0 mdeg/sec). Since DSN switching rules are position based, and don't consider velocity, the antenna doesn't behave well at these points. The servo rails against one (i.e. negative) acceleration limit to stop, overshoots, rails at the other limit (positive) to return then finally starts to settle out.

Lacasse suggests installing the "hooks" to fine tune the system. I agree that the hooks should be there. However, the fine tuning process is trial and error. It is time consuming and risky unless done through simulation. Ultimately, I don't feel that fine tuning for a specific experiment is worthwhile because values that work well for one experiment under a given set of operating conditions may cause problems if those conditions change, or for another experiment. I feel that a set of widely applicable parameters should be chosen, and changed only if there is a problem

Finally, JPL has developed a new concept for dealing with this scenario. It is a trajectory preprocessor that modifies the trajectory whenever acceleration or velocity limits would be invoked (i.e. steps, SETI scans). This trajectory preprocessor modifies the antenna commanded position such that the servo system always operates in a linear regime. Since the system is linear, global stability is assured, and performance is easily quantifiable. I suggest that in the future, NRAO may want to use a similar algorithm.

JM:rrg

Acceleration Limit Results in 400 mdeg p-p Limit Cycle

DSS15 Response to a 0.7 Degree Move Command