GBT MEMO 176

GBT Subreflector Motions and Servo Properties

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Abstract

Five types of GBT subreflector motions needed for astronomical observations are discussed, and estimates of their amplitudes and frequencies are given. These estimates are translated into velocity and acceleration requirements, which are compared with the specifications of the existing servo implementation.

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1 Introduction

On Wednesday 1997-10-22, five NRAO staff members had a teleconference with four CRSi Precision Controls Division engineers and with Ben Parvin, NRAO's servo consultant from JPL, regarding recent performance measurements on the subreflector actuator servos. During the course of the meeting, Ralph White of PCD asked NRAO to describe the types of motions which we anticipate commanding the servos to perform. This memo has been prepared in response to that request. The two NRAO action items agreed to in that meeting are:

- NRAO to compute the tilts of the subreflector required to compensate for that swaying of the structure due to wind.
- NRAO to work backwards from the list of 5 subreflector requirements to requirements on the individual actuators.

2 Five Types of Subreflector Motions

NRAO anticipates that five classes of subreflector motions will be used in astronomical operations. These are itemized below.

The nominal capabilities of the subreflector actuators are $V_{max} = 1$ in/s and $A_{max} = 0.4$ in/s^2. These can be transformed into equivalent displacement motions by using the partial derivatives given in Tables 3 through 8 of [Wel98].

2.1 Focus Tracking

The GBT structure distorts under gravity as a function of elevation. In particular, the feedarm tip moves with respect to the prime focal point of the paraboloid. The subreflector must be moved in a focus tracking trajectory in order to maintain the gain and avoid pointing errors. The total travel needed is of order 10 inches for 90° elevation change, and the elevation slew rate is only 0.33 deg/s, so the focus tracking rate needed while slewing elevation is only about 0.04 in/s (the sidereal tracking rate is *much* smaller, of course). This slew translation rate is mainly in the subreflector Y and X axes. There is an additional small translation motion required to track the sideways motion of the feedarm due to the "elevator assymetry"; this Z displacement is given as ±0.83 inch in [Zai92]. Tilt motions of a few milliradians about all three axes will also be needed over the 90° elevation range.

A more interesting requirement will be tracking thermal- and wind-induced displacements of the feedarm. Distortions of the structure due to differential temperature will change very slowly, but the wind-induced displacements will change on a timescale of seconds. The probable magnitude of typical wind displacements is about an inch for timescales of ten seconds or more. The implied translation requirement is of order 0.1 in/s.

2.2 Beam Switching

In general, GBT receivers will have two horns, so that a source and the sky may be observed simultaneously. The source must be moved from one horn to the other periodically; this will be a step motion for the subreflector actuators. The maximum horn separation at the Gregorian focal plane is about 14 inches (see Figure 3 of [BNS91], 8-12 GHz case); this is an angular displacement of the prime-focal-point to feedhorn line of about 1.8 degrees. It will probably also be necessary to translate the subreflector by several inches (roughly half the feedhorn separation) in order to maintain optimum gain (minimum sidelobes). The velocity specifications (both angle and translation) of the subreflector imply that it will take some seconds to make this worst-case beam switching movement, for the 8-12 GHz horns. The separations of the high frequency horns are several times smaller: about 3.8 inches for the 40-50 GHz horns. The optimum beam switching recipes have not yet been determined, but it appears that beam switching speed will be significantly limited by the subreflector actuator servos.

2.3 Vibration Compensation

In addition to the bending of the GBT structure caused by the average wind speed over timescales longer than 5-10 seconds, which is mentioned in Section 2.1 above, the wind turbulence noise will excite vibrations at the modal frequencies of the GBT: "the worst case.. is for wind gusting along the elevation axis.. at.. 7 m/s (steady state and gusting).. rms pointing error of 13.3 arcsecond in cross-elevation.." [GP95, p.2]. This beam vibration amplitude will probably vary with the square of the wind speed, and so the amplitude of beam displacement in cross-elevation will be a significant fraction of the high frequency beam width much of the time, and this is likely to be a serious operational problem for the GBT [Wel96]. The first mode of the GBT is primarily a beam motion in cross-elevation, at a frequency of 0.66 Hz.

For "on-the-fly" mapping operations this beam motion will not be particularly important, because if we know the beam trajectory as a function of time we can co-add the data samples at the correct grid locations. For point source spectroscopy we have a choice: we can let the beam wander and regard it as on-the-fly mapping with a small number of pixels, or we can try to stop the motion of the beam with the subreflector.[1] There are two subreflector motions which can displace the beam on the sky: translation and rotation.

Beam deflection by translation is achieved by moving the first focal point of the ellipsoid in the prime focal plane. For sinusoidal motion we have

$$x'' = -A\omega^2 \sin \omega t$$

with $\omega = 2\pi f$, so

$$x''_{\rm max} = 39.5 A f^2.$$

Therefore, the $x''_{\rm max} = 0.4 \frac{\rm in}{\rm s^2}$ translation capability of the subreflector actuators implies a translation amplitude of 0.58 mm at 0.66 Hz. The subreflector translation pointing coefficient in cross-elevation is 0.624 arcmin/cm (3.74 arcsec/mm) [Sri90, p.2], so we can track a beam motion amplitude of only about 2 arcsec at 0.66 Hz by using translation, about five times smaller than the amplitude we need. Probably we will not use translation to track wind-induced vibrations.

[1] For the purposes of this discussion, we will ignore the possibility of active damping with a driven mass [PSS96] or with magnetorheological fluid dampers [Per97, Cor98].

Beam deflection in cross-elevation can also be achieved by rotating about the X_n axis.[2] The actuator acceleration limit is 0.4 in/s^2, and $\partial l_j/\partial\theta_{x_n} = 0.717$ at the "home" ($E = 44°$) position (from Table 6 of [Wel98]), so the X_n rotation acceleration capability of the subreflector is $x''_{\rm max} = 0.56\frac{\rm deg}{\rm s^2}$. This implies a sinusoidal angular amplitude

$$A = \frac{x''_{\rm max}}{39.5f^2}$$

of $A = \pm 0.032°$ at 0.66 Hz. The pointing coefficient for X_n is approximately 0.13 arcmin/arcmin (468 arcsec/deg) [Sri90, p.2], and so this acceleration will move the beam in cross-elevation with sinusoidal amplitude about 15 arcsec, about the amount that we expect to need in order to track vibration with wind 6 m/s (15 mph) [GP95].

2.4 Mapping

In principle we will be able to do "On-The-Fly" mapping with the subreflector rather than with the main Az-El drives. It appears that this possibility has not been discussed or studied in the GBT project. The author conjectures that fields of view of a few minutes of arc scanned at approximately 0.1 Hz might be practical and of scientific interest.

2.5 Focussing

The servos will need to move the Y_i actuators to move the second focal point of the subreflector along the axis of a Gregorian feedhorn The full range of this motion will take some seconds to accomplish, probably at maximum velocity.

References

[BNS91] M. Balister, R. Norrod, and S. Srikanth. Gregorian receivers for the GBT. GBT Memo 66, NRAO, September 1991.

[Cor98] Lord Corp. Model MRD-9000 magnetorheological damper. *IEEE Spectrum*, 152:74, January 1998. Footnote: "with a mass of only about 250 kg, the.. damper.. can withstand loads as high as 200000 N and be continuously adjusted for smaller yield stresses. Its only moving part is the piston..".

[GP95] Wodek Gawronski and Ben Parvin. Modeling and analysis of the Green Bank Telescope control system. GBT Memo 129, National Radio Astronomy Observatory, April 1995. 'The servo system of the Green Bank Telescope is modeled and analyzed. The model includes the finite element structural model 95B (in modal coordinates), gearboxes and drives, PI and feedforward controllers and wind disturbance models.. lowest.. resonance.. 0.68 Hz, ..settling for one degree step.. 12 seconds for elevation.. 15 seconds for cross-elevation.. for wind.. along elevation axis.. 7 m/s.. rms pointing error of 13.3 arcsecond..'.

[2] Note that this "nutation" axis is orthogonal to the axis of the primary mirror – it is *not* the same as the X_s translation axis of the subreflector!

[Per97] Sid Perkins. Calming bad vibes—from microscopes to skyscrapers, smart structures help control vibration. *Science News*, 152:328–329, November 22 1997. p.329: "Prototype dampers filled with the [magnetorheological] fluids can generate reactive forces of up to 20 tons with as little as 50 watts of power..".

[PSS96] J.M. Payne, D. Schiebel, and F.R. Schwab. Dynamic tests on the GBT. GBT Memo 159, NRAO, October 1996. "A means of applying a force of variable amplitude and frequency to a large structure such as the GBT is described. A simple hydraulic servo-mechanism positions a mass in accordance with an electronic command signal, and the resulting reaction force is applied to the structure of interest. The mechanism may have application in the future for damping out vibration in crucial areas of the GBT..".

[Sri90] S. Srikanth. GBT pointing coefficients. GBT Memo 53, NRAO, May 1990. "..pointing coefficients [have been] calculated using some analysis programs that are available at NRAO..; .. [they are] different in the symmetric and the asymmetric planes of the clear aperture antenna..; ..positioning requirements for the feed and subreflector for the purposes of tracking stability and registration are calculated..".

[Wel96] Don Wells. Approaches to the GBT vibration problem. GBT Memo 161, NRAO, December 1996. 'The primary GBT vibration problem is that vibrations caused by wind turbulence are likely to be the major technical limitation for high frequency work throughout the life of the telescope'.

[Wel98] Don Wells. GBT subreflector actuator functions in C. GBT Memo 175, NRAO, January 1998. Two ANSI-C functions are described: `srDisplacementToLength()`, which accepts displacements (three linear, three angular) from the "home" position of the subreflector and computes six actuator lengths, and `srLengthToDisplacement()`, which performs an iterative numerical inversion of function `srDisplacementToLength()` (i.e., it accepts actuator lengths and produces displacements). These two functions will be used in the GBT Monitor and Control software to transform Gregorian focus tracking outputs into actuator commands. Partial derivatives of the actuator lengths *wrt* translation and tilt are tabulated.

[Zai92] J. Zaine. Mechanical analysis S/R positioner. Loral GBT Technical Memo 46, Loral Western Development Labs, October 1992. This comprehensive report discusses operational, peak operational and survival loadings, required motor torques, lost motion (backlash) of the U-joints and possible structural interference and U-joint angle problems of the subreflector actuators. Portions of Loral Interoffice Memorandum 3WL110-DLE-107, titled "NRAO 100m GBT Prime Focus Feed & Subreflector Positioner Gravity Correction Travel Requirements" are included as Appendix A (pp.A1-A13). The asymmetric structural model which was used enabled calculation of the required out-of-plane Z_s translation ± 0.83in.