NATIONAL RADIO ASTRONOMY OBSERVATORY
VERY LARGE ARRAY
Socorro, New Mexico

VLA TEST MEMORANDUM NO. 142

DISCUSSION OF VLA POINTING

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February, 1983

PRESENT STATUS OF VLA POINTING AND ASSOCIATED PROBLEMS

1. Pointing Parameters and Performance Monitoring

Current procedures for maintaining on-line antenna pointing parameters (under the capable guidance of P. Hicks and B. Ross) appear to be viable and effective, with exception of data archiving. The large line printer outputs from the PEEK program (which are used to determine pointing parameters) are too bulky to be permanently stored. These outputs are currently being stored on microfiche (a rather tedious and expensive process). Experience has shown that it is seldom necessary to have more than the last few outputs on hand for any purpose. It is suggested that only the six most recent PEEK outputs be kept in the operations area and that archiving of pointing data be accomplished via saving of the INPNT outputs (.PNT files) on magnetic tape. This would allow the most time consuming step in pointing data processing (running INPNT) to be done only once, and the archived data would be in its most compact currently existing format (.PNT files). Such tapes could be permanently assigned to the new user POINTING[13,714] (password POINT). It is further suggested that archived .PNT files be properly edited such that only valid pointing error measurements are saved. New features for listing and editing would have to be added to the INPNT program to accomplish this.

2. Long Term Pointing Performance

An analysis of pointing errors from nighttime SYSPOINT runs during 1981-82 has been conducted. Results for all antennas are shown in the following table:

Elevation Range (degrees)	8-90	55-90	90-125
RMS Azimuth Error (arcsec)	12.8	12.1	12.1
RMS Elevation Error (arcsec)	14.4	12.4	12.8
Number of Points	~50000	~7000	~5000

These results indicate that there is no significant degradation in pointing at over-the-top elevations (at least at 6 cm, the most commonly used band in the SYSPOINT observing program). The table also indicates that elevation pointing is significantly worse for lower elevations. Two suggestions for the cause of this are: 1) errors in atmospheric refraction corrections and 2) subreflector shifting caused by loose quadripod guy rods. The latter could be readily tested by repeating the analysis using only lower numbered antennas which have been through overhaul and have properly tensioned guy rods.

3. Antenna Thermal Insulation

Polyurethane foam insulation, which has proven to be effective in precluding large (~1 arcmin) tilt deviations caused by daytime thermal deformation (cf. VLA Test Memorandum 138), is currently installed on Antennas 14 and 22. It is now being installed on Antenna 15 which is in overhaul. The current plan will require approximately 2.5 years to complete foam installation on 28 antennas.

There has been some concern over the existence of rather high (~3°C) measured temperature differences between the insulated yoke faces in Antenna 22. S. von Hoerner has suggested that these differences are caused by thermal conduction into the back yoke face from the large, platform attached to the face. Eight additional sensors were placed in the Antenna 22 yoke in August 1982 to assist in studying this effect. The new sensors measure temperature differences between the narrow yoke arm faces as well as the broad faces at the base of the yoke. Tests were conducted in which the sun was tracked for an entire day with one yoke face (or the other). In these tests, the broad yoke face with the platform became warmer during the day regardless of which face was tracking the sun. Also, the platform face consistently gets colder at night than the front face. These results indicate that conduction from air into the platform is significant but that thermal input to the platform from the sun is not. This would indicate that shading the platform would not be effective in reducing these thermal differences. These same tests showed that smaller (~1.5°C) differences developed between the faces in the slender yoke arms (which are somewhat removed from the platform attachment points) as opposed to the larger (~3°C) differences observed in the broad faces. Since thermal differences in the slender arms will produce more significant yoke deformation than differences in the broad faces, it is suggested that deformation caused by the observed differences might be acceptably small. More sun tracking tests using the Antenna 22 yoke temperature sensors as well as new thermal deformation calculations (or measurements) are needed to verify this suggestion.

4. New Focus/Rotation System (Antenna 12)

The new focus/rotation (F/R) system installed on Antenna 12 incorporates an improved mechanical design which includes a locking pin to minimize subreflector movement at a given band setting. Special pointing tests were conducted using all antennas at the four VLA bands. Calculations of RMS average pointing errors showed Antenna 12 to be superior at 2 and 1.3 cm, average at 6 cm, and poor at 20 cm. However, comparison of these RMS values for Antenna 12 to those from SYSOFFSET runs made prior to the F/R modification indicate that pointing performance is about the same at 20 cm and 6 cm with small (~10%) improvement at 2 and 1.3 cm. Analysis of other four frequency pointing tests is needed to better quantify this improvement, but it is expected that it will not be large. A decision on incorporation of the F/R modification in all antennas should be made on the basis of improved reliability, maintainability, operability, and cost.

5. Azimuth Bearing Deformations

After tiltmeters were installed on Antenna 6 in connection with thermal deformation studies, measurements of tilt as a function of antenna azimuth consistently showed significant tilt deviations up to about 30 arcsec over a particular azimuth range. Measurements of azimuth bearing runout (radial motion of the moving race with respect to the fixed race at a specific point on the fixed race) and tilt (axial motion of the moving race with respect to the fixed race at a specific point) showed a direct correspondence with the tiltmeter deviations. A search for this sort of discrepancy in other antennas was made by plotting elevation error measurements from the data discussed in Paragraph 2 (above) versus true azimuth for each antenna (with the exception of Antenna 9 which had changed arms during the two year period). About eight of the 27 antennas seemed to show significant elevation errors over specific azimuth ranges (including Antenna 6). It will be necessary to measure the azimuth bearings in these antennas to determine if these errors are related to bearing deformations as in the case of Antenna 6.

L. Temple has suggested that the Antenna 6 bearing deformations are likely to have been caused by imperfections in the substructures into which the bearing races are bolted, and that replacement of the bearing (a rather formidable task) would likely not improve the elevation pointing. It therefore seems most reasonable to deal with the problem by some sort of compensation technique such as additional parameters in the MODCOMP's Antennas Files (B. Clark thinks that this would be feasible for a few antennas).

6. Tiltmeters and Real-Time Corrections

The use of tiltmeters to measure angular deformations of the antenna structure below the elevation axis is currently being investigated. The ultimate purpose of such measurements is to allow real-time compensation for pointing errors caused by such deformations. With the success of thermal insulation in reducing thermal deformations of this type, the dominant effect for which real-time compensation is desired are wind-induced deformations (up to 1 arcmin pointing errors have been observed in 30-35 mph winds). In view of this, it is critical that the fraction of wind-induced pointing error caused by deformations below the elevation axis (as opposed to dish, backup structure, or quadripod deformations) be determined in order to assess the feasibility of the technique. One way this might be done is to make simultaneous tilt and pointing error measurements during windy conditions. This was attempted in the Spring of 1982, but was not successful due to tiltmeter related problems as discussed in the following paragraph.

Deformations of the antenna structure below the elevation axis can affect pointing in five independent terms. These are: 1) E-W tilt of the azimuth rotation axis, 2) N-S tilt of this axis, 3) parallel displacement of the elevation axis in the azimuth rotation plane (elevation offset), 4) angular displacement of the elevation axis in the azimuth rotation plane (azimuth offset), and 5) angular displacement of the elevation axis out of the azimuth rotation plane (azimuth-elevation perpendicularity). Effects 1) and 2) must be measured in the vicinity of the azimuth bearing. In the current instrumentation configuration (Antennas 6 and 22), such tiltmeters are mounted on the yoke baseplate near the azimuth axis. Tests have shown that this baseplate is subject to considerable nonplanar distortion (~30 arcsec at the tiltmeter mounting location) as the instrumented radius passes over the hard points in the top of the pedestal structure. These deformations make it extremely difficult to determine the two tilt terms for the azimuth axis from tilt measurements made at a single azimuth. Further, it is necessary to determine the azimuth axis tilt terms before any of the other three terms can be determined from tilt measurements made near the elevation axis (where the remaining tiltmeters are currently mounted) since these measurements include the effects of changes in azimuth axis tilt. Thus, it is concluded that it is not feasible to determine below-elevation-axis pointing error terms by tilt measurements in the current tiltmeter configuration.

The tiltmeters mounted on the yoke arm just below the elevation axis appear to be adequate for measuring tilts due to the combination of yoke deformations and tilt of the azimuth axis. However, measurement of deformation of one yoke arm provides only part of the information on deviations of the elevation axis which affect the elevation offset, azimuth offset, and axis perpendicularity terms. It is necessary to measure deformations of the other yoke arm to completely determine the elevation axis deviations. An additional instrument package containing two orthogonal tiltmeters placed on the other yoke arm in the same position below the elevation axis should be sufficient for this.

The tiltmeter instrument package design (mounting hardware, electronics, thermal control, etc.) appears to be adequate with the exception that no simple means for introducing a calibration tilt deflection is incorporated. Currently, the best method for calibrating tiltmeter gains involves placing a shim between one of the antenna mounting piers and the antenna and comparing the tiltmeter readings with those of the unshimmed antenna. This procedure requires an antenna transporter and crew for several hours and is certainly not satisfactory for periodic tiltmeter calibrations on all antennas.

One very important question involving tiltmeter instrumentation which has not been satisfactorily resolved is that of type of tilt transducer to be used. The current instrument packages (which have been installed in Antennas 6 and 22 for about 20 months) contain bobweight type sensors (Shaevitz) and electrolytic spirit level type sensors (bubble). It was intended that the rather expensive (~$1K) Shaevitz tiltmeters which were known to meet VLA requirements be used to evaluate the performance characteristics of the inexpensive (~$20) bubble tiltmeters. It is known that these bubbles are capable of ~1 arcsec sensitivities, but they are poorly documented devices and little is known about their characteristics in dynamic environments. A substantial amount of difficulty was encountered in initially getting the bubbles to function properly. This was largely due to erroneous information obtained from the manufacturer regarding operating parameters. Once these problems were solved it was determined that bubbles were unsatisfactory for use in windy conditions because of long settling times. However, I now feel that this determination may have been somewhat premature and that further (and more quantitative) testing be done before the bubbles are abandoned. This suggestion is based on qualitative examination of tiltmeter data taken over many months and a variety of wind conditions which indicates very close correspondence between Shaevitz and bubble tiltmeters in nearly all cases. There is no doubt that the bubbles are substantially more difficult to deal with in terms of installation, adjustment, interfacing, and reliability, but the sizable cost reduction obtained when installing several tiltmeters on each of 28 antennas may prove to be a sufficient tradeoff. A proper quantitative analysis of the wealth of existing tilt data taken simultaneously from both types of transducers over a broad range of conditions should allow the correct decision to be made.

In conclusion, I feel that the following steps should be taken (in order) to determine the feasibility of using tiltmeter measurements for real-time pointing error compensation:

A. Find tiltmeter mounting locations which will adequately determine the azimuth axis tilt (N-S and E-W) with the antenna positioned at any arbitrary azimuth. W. Horne's Tally Vel tiltmeters might be helpful in this endeavor. The main difficulty in accomplishing this is the nonplanar distortion of the structure in the region of the azimuth bearing. It is suggested that the best placement might be over one or more of the hard points in the "pedestal plates" area just below the yoke. Three sets of two orthogonal tiltmeters (one for each hard point) would most accurately determine azimuth axis tilt. With four tiltmeters on the yoke near the elevation axis (as suggested above) this would require a total of ten tiltmeters per antenna. The VLA currently owns six Shaevitz tiltmeters. Four more would be have to be procured to test this configuration on a single antenna. Instrumentation packages produced for this effort should incorporate a mechanical device for input of a known tilt displacement (calibration signal) to the tiltmeters.

B. Once it is known that accurate measurements of tilt of the azimuth axis can be made for all azimuth positions, the next step is to determine the fraction of wind-induced pointing errors caused by deformation below the elevation axis. This can be done by simultaneous pointing error and tiltmeter measurements during windy conditions. This critical question must be answered before any real-time compensation system design is considered.

C. Once it is proven that tiltmeter measurements can be used to adequately compensate for wind-induced pointing errors, a choice of tilt transducer must be made. The cost difference between the types currently under consideration (Shaevitz and bubble) is quite significant and will certainly be a large tradeoff consideration in this decision. Other transducers should also be considered at this point (a suggestion has even been made to use Inertial Navigation Systems!).

7. Half-Power Pointing Tests

P. Napier instituted a weekly test program (PN3DB) which tracks point sources at the antenna half power points (displaced in azimuth and elevation). These tests have been useful in showing the existence of miscellaneous hardware faults (antenna control units, position encoders, servo-systems, etc.) which have not been indicated by any other means, and they should be continued.

8. High Frequency Over-the-Top Pointing

The current system default allows over-the-top pointing (to minimize antenna move time) at observing wavelengths of 20 and 6 cm, but precludes it for higher frequencies (2 and 1.3 cm). Over-the-top pointing tests at 2 cm have shown that RMS pointing errors are not affected at over-the-top elevations. On this basis, observers are advised to override the system default in cases where significant move time savings can be achieved. However, the 2 cm over-the-top tests have also shown that the best fit pointing parameters change in a way which is currently not understood. Changing of the system default to allow high frequency over-the-top is awaiting achievement of this understanding.

9. Pointing Files and Data Awaiting Analysis

Due to the recent departure of R. Newell from the VLA, most of the special test work and analysis pertaining to VLA pointing problems has temporarily stopped. It is planned that this work will resume when a replacement is obtained. In the meantime, all appropriate files, data, and information are in the custody of C. Wade. Currently existing data which has yet to be analyzed includes:

A. Several 2 cm over-the-top pointing tests.

B. Several four frequency pointing tests involving Antenna 12 (modified F/R system).

C. Quidripod thermal deformation test.

D. Several months of on-line tiltmeter data (Shaevitz versus bubble tiltmeter performance).

Details of these test data and required analyses are contained in the appropriate files.

SUGGESTED FUTURE WORK

The specific tests and developments mentioned in the preceeding section which have not yet been accomplished are summarized below:

1. Determine cause of high RMS elevation errors at low elevations (suggested possibilities are refraction and loose guy rods).

2. Determine long term day time RMS pointing errors.

3. Continue to monitor performance of the first thermally insulated antenna (no. 22) to determine long term effects on daytime RMS pointing.

4. Perform additional tests to determine the cause of temperature differences between lower yoke faces in insulated antennas and its effect on pointing.

5. Measure azimuth bearings (radial and axial motion of one race with respect to the other at a fixed point on the stationary race) of those antennas which show long term systematic elevation errors over specific azimuth ranges. This will determine if the cause of the errors is due to bearing deformation (as in the case of Antenna 6). Investigate techniques (such as on-line correction) for compensating for such elevation errors.

6. Find tiltmeter mounting locations which will allow measurement of azimuth axis tilt (N-S and E-W) with the antenna positioned at any arbitrary azimuth. Incorporate a calibration feature in tiltmeter instrumentation packages.

7. Determine that fraction of wind-induced pointing errors caused by structural deformation below the elevation axis.

8. Determine the capability of bubble type tiltmeters to meet VLA tilt measurement requirements.

COMPUTER SOFTWARE AND DOCUMENTATION

All applicable programs are contained in DEC-10 user area [13,714] (password POINT). The area also contains documentation files for the monitor data programs. The two major pointing data programs (INTPNT and PEEK) which are used routinely by VLA operators for maintenance of antenna pointing parameters are also contained in P. Hicks area [21,172]. He is the current resident expert on the use of these programs. A list of [13,714] programs follows:

1. INTPNT

Reads interferometric pointing data from a MODCOMP data tape and creates a pointing database for use by the PEEK and AZPEEK programs.

2. PEEK

Reads a pointing database, computes pointing errors, and calculates antenna pointing parameters by least squares fitting. Displays pointing errors and other data.

3. AZPEEK

Reads a pointing database and computes pointing errors with statistical analyses. Displays pointing errors and statistical results. Creates files of pointing errors as functions of time, azimuth, and elevation. These files can be used by some of the monitor data programs described below.

4. MONMAK

Makes data files from monitor databases for use by other MON??? programs.

5. MONAVG

Averages monitor data in a variety of ways.

6. MONDIF

Subtracts (or adds) monitor data points.

7. MONLIS

Lists monitor data files.

8. MONPLO

Plots monitor data files.

9. MONBIN

Bins monitor data for histograms.

10. MONTLT

Processes tiltmeter data in a variety of ways. Its most important use is to determine the five pointing error terms from measured tilts.

POINTING INSTRUMENTATION HARDWARE

Documentation for antenna mounted pointing instrumentation is maintained by D. Weber (some is duplicated in the files held by C. Wade). Documentation for environmental parameter measurement instrumentation is maintained by J. Spargo. Documentation for the theodolite (used for relative translational and rotational deformation measurements) and pointing servo-system equipment is maintained by L. Temple. A list of hardware follows:

1. Antenna Mounted Instrumentation

   A. Installed in Antennas 6 and 22 (cf. VLA Test Memo. 138)

      1) Shaevitz Tiltmeters (6)

      2) Bubble Tiltmeters (8)

      3) Temperature Sensors (16)

   B. Tally Vel Tiltmeters (2) (currently in Antenna 17)

   C. Additional Yoke Temperature Sensors (8) in Antenna 22

2. Environmental Instrumentation

   A. Weather Stations

      1) Array Center

      2) Last Antenna on SW Arm

   B. Solar Flux Balls (array center)

3. Autocollimating Theodolite