APF Telescope Tracking Accuracy Tests Results Updated Summary

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Abstract

This memo summarizes the results of tracking accuracy tests carried out with the APF Telescope during August and September 2010. The tests were conducted according to the test procedure documented in test 2.4, Tracking Accuracy, as specified in the Site Acceptance Test document ATP-134838-1. These tests were all performed with the same pointing model installed; that model was generated using TPOINT. The model was based on a set of pointing observations of 163 targets spaced evenly across the sky and observed on August 10, 2010; the model yielded an all-sky RMS pointing error of 2.35 arcsec. Unless otherwise noted, these tracking tests were conducted during periods of light winds, clear weather, and reasonably good seeing; the dome shutters were not operating in wind-screen mode.

10-MINUTE TRACKING ACCURACY TESTS

The following set of tests lasted for 10 minutes each. The contract requirement is that the total RMS tracking error be less than or equal to 0.5 arcsec RMS over 10 minutes (Reference Appendix B Section 3.10). Results in bold fail to meet that requirement. Results marked with a * indicate that bad wind-shake occurred during the test, and those tests should be repeated.

Tests started with target object acquired towards North

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
20	2010-09-01	4833F	0.179”	0.324”	0.369”
45	2010-09-02	5749F	0.189”	0.259”	0.320”
70	2010-09-01	5793F	0.235”	0.318”	0.394”
85	2010-09-02	5842F	0.386”	0.358”	**0.527”**

Tests started with target object acquired towards South

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
20	2010-08-19	5751F	0.227”	0.243”	0.332”
45	2010-08-25	5691F	0.140”	0.206”	0.249”
70	2010-09-02	5984F	0.127”	**0.507” ***	**0.522” ***
85	2010-08-11	5800F	0.133”	0.211”	0.249”

Tests started with target object acquired towards East

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
20	2010-09-13	4199F	0.205”	0.225”	0.304”
45	2010-09-12	6110F	0.095”	0.160”	0.186”
70	2010-08-31	5994F	0.224”	0.317”	0.391”

Tests started with target object acquired towards West

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
20	2010-09-13	5545F	0.191”	0.304”	0.359”
45	2010-09-12	5397F	0.140”	0.242”	0.280”
70	2010-09-12	5765F	0.136”	0.178”	0.224”

It was decided to the skip the tests at Elevation 85 for an object acquired towards the West and East since these would not be significantly different than the tests at Elevation 85 with an object acquired towards the North or South.

Pole star test (tracking an object near Polaris but not Polaris)

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
88.5	2010-09-13	3954F	0.155”	0.168”	0.228”

60-MINUTE TRACKING ACCURACY TESTS

The following set of tests lasted for 60 minutes each. The contract requirement is that the total RMS tracking error be less than or equal to 2.5 arcsec RMS over 60 minutes (Reference Appendix B Section 3.10). Results in bold fail to meet that requirement. Results marked with a * indicate that bad wind-shake occurred during the test, and those tests should be repeated.

Tests started with target object acquired towards North

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
20	2010-09-01	4833F	0.350”	0.926”	0.993”
45	2010-09-02	5749F	0.240”	0.724”	0.762”
70	2010-09-01	5793F	0.649”	0.708”	0.960”
85	2010-09-02	5842F	0.772”	2.155”	2.289”

Tests started with target object acquired towards South

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
20	2010-08-19	5751F	0.192”	0.171”	0.257”
45	2010-08-25	5691F	0.145”	0.517”	0.537”
70	2010-09-02	5984F	0.600”	0.659”	0.891”
85	2010-08-11	5800F	0.889”	1.324”	1.594”

Tests started with target object acquired towards East

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
20	2010-09-13	4199F	0.822”	1.365”	1.593”
45	2010-09-12	6110F	0.129”	0.264”	0.294”
70	2010-08-31	5994F	0.481”	0.428”	0.646”

Tests started with target object acquired towards West

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
20	2010-09-13	5545F	1.524”	3.079” **	3.436” **
45	2010-09-12	5397F	0.178”	0.413”	0.449”
70	2010-09-12	5765F	0.157”	0.674”	0.692”

Note: The results of the test with the star acquired in the West near 20 degrees elevation (marked with ** in the table above) technically exceed the 2.5 arcsec RMS track error specification. However, this test tracks the star to a very low elevation angle (< 10 degrees) which is outside of the range of the specification, and most of this error is due to the very large atmospheric refraction at such a low elevation angle. Note that at 50 minutes into this test, the RMS tracking error was still within the specification, with total RMS tracking error at 2.401”. Accordingly, this test is deemed to have passed.

It was decided to the skip the tests at Elevation 85 for an object acquired towards the West and East since these would not be significantly different than the tests at Elevation 85 with an object acquired towards the North or South.

Pole star test (tracking an object near Polaris but not Polaris)

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
88.5	2010-09-13	3954F	0.224”	0.210”	0.307”

CONCLUSION

With two exceptions, all of the results tabulated above in this preliminary summary meet the contract requirements. The two exceptions both involve 10-minute tracking accuracy tests, and the first test probably failed due to bad wind-shake and should be repeated. The second tests suggests that the pointing model needs further refinement to better handle high-elevation targets near the meridian.

Tests started with target object acquired towards South

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
70	2010-09-02	5984F	0.127”	**0.507” ***	**0.522” ***

Tests started with target object acquired towards North

Elevation	Date of Obs.	Target ID	RMS Error Az	RMS Error El	Total RMS Error
85	2010-09-02	5842F	0.386”	0.358”	**0.527”**

As noted earlier, TPOINT was used to generate the pointing model that was installed during the period of time when these tracking performance tests were conducted. At that time, we were unable to import our pointing observations into StarCAL for analysis, because we used a more time-efficient, automated procedure (rather than StarCAL's manual procedure) for carrying out those observations. Because of uncertainties regarding the sign conventions that TPOINT uses for certain pointing terms versus those that StarCAL (and hence the EOST telescope control system) uses for those same terms, we were unable to include in that model various pointing terms that normally would have been included and which we believe would have improved both the performance of that model as well as the tracking accuracy performance of the telescope in some regions of the sky.

On October 1, 2010, EOST made available to us a new MMTool utility program that enables us to convert our sets of pointing observations into a file format that can be read by StarCAL; we are extremely grateful to EOST for providing this program to us. Using that program, we converted our August 10 pointing observation data set into that format and used StarCAL to generate a new pointing model that includes a more complete set of pointing model terms. That new model yields an RMS pointing error of 1.74”, as compared to 2.35” in the current model. We plan to install and test that new model whenever we are next able to observe with the APF Telescope; that will depend on the weather and how quickly the failing gearbox for the dome front shutter drive can be repaired.

Assuming that verification of the new pointing model is successful, we are reasonably confident that when the two tracking performance tests that did not quite meet specifications are repeated with that new model in place and on a night without high winds, that satisfactory results will be obtained for both tests. Once those tests are repeated, and assuming both pass, then I will recommend to those that have signature authority that the telescope pointing and tracking accuracy tests specified in the SAT document be signed off as having been successfully completed.

Appendix 1 – Currently-installed telescope pointing model generated with TPOINT

This model was based on a set of 163 pointing observations collected with the APF Telescope on the night of August 10, 2010. As noted earlier, some pointing model terms were not included in this model because of uncertainties regarding the sign conventions that TPOINT uses for those terms versus the conventions used by StarCAL and the EOST telescope control software. Omission of those terms resulted in a less than optimal model. This is the pointing model that was installed during the period of time when the tracking performance tests tabulated previously were conducted.

The model terms are first listed in TPOINT format, followed by the transcription of those terms (with appropriate sign adjustments as needed) into the format used for the mount model file (TelescopeMountModel.dmx) read by the EOST Telescope control software.

TPOINT model terms:

```
     coeff         value      sigma
  1    IA      -32104.855     0.472
  2    IE       -1072.239     0.614
  3    AW          +8.884     0.212
  4    AN          -2.344     0.220
  5    NPAE       +44.744     0.489
  6    HECE       -23.646     0.852
  7    HASA2       +1.648     0.375
  8    HACA2       -5.365     0.355

Sky RMS =   2.35
Popn SD =   2.41
```

Contents of TelescopeMountModel.dmx:

```
__Schema_Version__
{
  __Schema_Version_Major__2 INTEGER
  __Schema_Version_Minor__0 INTEGER
}
MountModelLimits
{
  MaxLimit FLOAT
  MinLimit FLOAT
}
MountModelTerm
{
  Formula STRING
  Name STRING
  Value FLOAT
}
MountModelConfig
{
  AzLimits STRUCTURE MountModelLimits
  Date STRING
  ElLimits STRUCTURE MountModelLimits
  Name STRING
```

```
   Terms ARRAY STRUCTURE MountModelTerm
}
Configuration
{
   MountModel ARRAY STRUCTURE MountModelConfig
}

@

Configuration
{
   MountModel
   [

      {
         AzLimits
         {
            MaxLimit 10.000000000000000
            MinLimit -10.000000000000000
         }
         Date "2010/08/11 00:12:14"
         ElLimits
         {
            MaxLimit 2.000000000000000
            MinLimit -2.000000000000000
         }
         Name "Default"
         Terms
         [
                    {
            Formula "A=1"
            Name "Azimuth Encoder Offset"
            Value -32104.855000000000000
         }

         {
            Formula "E=1"
            Name "Elevation Encoder Offset"
            Value 1072.239000000000000
         }

         {
            Formula "A=tEcA;E=-sA"
            Name "X Axis Tilt"
            Value 8.884000000000000
         }

         {
            Formula "A=tEsA;E=cA"
            Name "Y Axis Tilt"
            Value -2.344000000000000
         }
```

```
{
   Formula "S=1"
   Name "Transverse Misalignment"
   Value  0.000000000000000
}

{
   Formula "A=tE"
   Name "Az-El Non-Orthogonality"
   Value 44.744000000000000
}

{
   Formula "A=sA"
   Name "Sin(Azimuth) in Azimuth"
   Value 0.000000000000000
}

{
   Formula "A=cA"
   Name "Cos(Azimuth) in Azimuth"
   Value 0.000000000000000
}

{
   Formula "E=sE"
   Name "Sin(Elevation) in Elevation"
   Value 0.000000000000000
}

{
   Formula "E=cE"
   Name "Cos(Elevation) in Elevation"
   Value 23.646000000000000
}

{
   Formula "E=1/tE"
   Name "Flexure"
   Value 0.000000000000000
}

{
   Formula "A=A/r360"
   Name "Azimuth Encoder Scale"
   Value 0.000000000000000
}

{
   Formula "E=E/r360"
   Name "Elevation Encoder Scale"
```

```
Value 0.000000000000000
}

{
Formula "A=s(2A)"
Name "Sin(2*Azimuth) in Azimuth"
Value -1.648000000000000
}

{
Formula "A=c(2A)"
Name "Cos(2*Azimuth) in Azimuth"
Value -5.365000000000000
}

{
Formula "E=sA"
Name "Sin(Azimuth) in Elevation"
Value 0.000000000000000
}

{
Formula "E=cA"
Name "Cos(Azimuth) in Elevation"
Value 0.000000000000000
}

{
Formula "E=EsA"
Name "El Sin(Az) in Elevation"
Value 0.000000000000000
}

{
Formula "E=EcA"
Name "El Cos(Az) in Elevation"
Value 0.000000000000000
}

{
Formula "A=cE"
Name "X1"
Value 0.000000000000000
}
]
}
]
```

Appendix 2 – New (and as yet untested) pointing model generated with StarCAL

This new model was based on a set of 163 pointing observations collected with the APF Telescope on the night of August 10, 2010; this is the identical set of observations as was used for the TPOINT generated model documented in Appendix 1. This new model includes all of the pointing model terms that we found to be significant.

```
Mount Model Terms
=================

       Std Dev     Value
Term   arc sec    arc sec   Name                              Formula
----   -------    -------   ----                              -------
 01       0.56  -32112.75   Azimuth Encoder Offset            A=1
 02       1.31    1053.41   Elevation Encoder Offset          E=1
 03       0.08       9.02   X Axis Tilt                       A=tEcA;E=-sA
 04       0.08      -2.30   Y Axis Tilt                       A=tEsA;E=cA
 05       0.94      11.36   Transverse Misalignment           S=1
 06       0.86      35.55   Az-El Non-Orthogonality           A=tE
 07       ----       ----   Sin(Azimuth) in Azimuth           A=sA
 08       ----       ----   Cos(Azimuth) in Azimuth           A=cA
 09       ----       ----   Sin(Elevation) in Elevation       E=sE
 10       1.95      51.58   Cos(Elevation) in Elevation       E=cE
 11       ----       ----   Flexure                           E=1/tE
 12       ----       ----   Azimuth Encoder Scale             A=A/r360
 13       ----       ----   Elevation Encoder Scale           E=E/r360
 14       0.15      -1.78   Sin(2*Azimuth) in Azimuth         A=s(2A)
 15       0.14      -5.43   Cos(2*Azimuth) in Azimuth         A=c(2A)
 16       ----       ----   Sin(Azimuth) in Elevation         E=sA
 17       ----       ----   Cos(Azimuth) in Elevation         E=cA
 18       ----       ----   El Sin(Az) in Elevation           E=EsA
 19       ----       ----   El Cos(Az) in Elevation           E=EcA
 20       ----       ----   X1                                A=cE
 21       0.82     -11.95   Cos(2*Elevation) in Elevation     E=c(2E)
 22       0.12      -0.80   Cos(2*Azimuth) in Elevation       E=c(2A)
 23       0.13      -0.90   Sin(2*Azimuth) in Elevation       E=s(2A)
 24       0.12      -0.49   Cos(4*Azimuth) in Elevation       E=c(4A)



             Prefit Residuals            Postfit Residuals
                 arc sec                      arc sec
          Azim      Elev      Error      Azim      Elev      Error
          ----      ----      -----      ----      ----      -----
RMS:  23076.39   1089.57   23044.41      1.57      0.74       1.74
```