EOS

TECHNOLOGIES, INC.

LICK

2.4m Telescope

Factory Acceptance Test

ATP-10609-2 R

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DOCUMENT CONTROL

Issue: 2

Prepared:	D. Shelby Stubbe		Date: 2/27/2009
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Configured:	Edith Hatch		Date: 2/27/2009

Document Revisions

Issue	Date	Description	Prep	Chk	Appr
1	9/20/2006	Initial Release	DSS	KRH	KRH
2	2/27/2009	Updated formatting, removed unnecessary inspection items, revised test procedures.	DSS	BC	DSS

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2.4 Meter Alt-Azimuth Telescope

Factory and Site Acceptance Test

1 INTRODUCTION

This document describes the inspection, test procedures and equipment used to perform the pre-shipment Factory Acceptance Test (FAT) of the 2.4 m Telescope in accordance with the contract, the technical specifications, attachments and annexes between the University of California Observatory/Lick (UCO/Lick) and EOS Technologies Inc. (EOST).

The reference numbering system used in this Acceptance Test document corresponds to the numbering system used in Contract Appendix C: 2.4m Telescope Specification for The Lick Observatory APF Telescope.

1.1 SCOPE

This document outlines the test methods to be used to test or inspect the listed contract requirements or specifications. Where appropriate, high level tests of pointing, tracking and wavefront error are performed on-sky to validate the full system functionality. It should be noted that no test will be performed unless prior agreement is reached by the parties and the tests are entered into this document.

1.2 CONFIGURATION

This document has been configured as ATP-10609-2 and is a designated controlled document under the EOST Quality System.

1.3 REFERENCES

The following source documents may be used as reference materials for this document:

- Contract Agreement Number CTR-4875-1

1.4 DEFINITIONS AND ACRONYMS

- COTS – Commercial off the Shelf
- CTR – Contract document
- EOST – EOS Technologies, Inc.
- FAT – Factory Acceptance Test
- RMS – Root Mean Square
- SAT – Site Acceptance Test
- TCC – Telescope Control Computer
- UCO – University of California Observatory

1.5 GENERAL

Factory Acceptance Tests (FAT) in the University of California Observatory/Lick (UCO/Lick) contract Agreement Number CTR-4875-1 dated 30 July 2003. These tests are required to satisfy clause 2.1 and clause 10.

1.6 DELIVERABLE ITEM

The 2.4 Meter Alt-Azimuth Telescope acceptance test documentation is deliverable as per Appendix B of the Contract.

1.7 RECORDS TO BE KEPT

All inspection and test results are to be recorded in this document and stored with the 2.4 Meter Alt-Azimuth Telescope documentation. Refer to Quality Procedure QIPT-T2973-3 Document and Data Control.

1.8 LIFETIME DISCUSSION

The telescope has been designed using components that will last indefinitely under the calculated loads assuming routine maintenance has been performed. No Lifetime or destructive Test to Failure testing is required or planned. The design life of the telescope is 20 years, meaning that all components and designs are based on established technologies and products.

1.9 ENVIRONMENTAL DISCUSSION

The telescope has been designed for operation in varying temperatures. All component materials have been matched to eliminate or minimize expansion and contraction problems caused by large temperature changes.

As the EOST Tucson site has no capacity for testing large assemblies over extremes of temperature and/or humidity, there is no special environmental testing planned. The telescope will be tested at the EOST Assembly and Test facility in Tucson, Arizona under ambient conditions which include a humidity range of 20% to 95% and temperatures from 10 °C to 30 °C. During the winter months, the temperature may fall as low as 0 °C.

The test facilities and equipment used in the various categories of tests include:

1. Initial testing performed at EOST Assembly and Test facility using EOST equipment.
2. Image quality testing performed on-sky with Shack-Hartmann wavefront sensor.
3. Tracking tests also performed on-sky.
4. Final testing performed on-site.

1.10 TEST EQUIPMENT AND CALIBRATION

EOST maintains all inspection measuring and test equipment calibration according to the current revision of Quality Procedure QIPT-T2920. This procedure complies with the ISO-9001-2000 standard. Documentation and compliance reports are available upon request.

2 INSPECTIONS

This section describes all inspections to be undertaken during the factory acceptance phase.

In general inspections take the following forms:

- The inspection of commercial off the shelf (COTS) manufacturer's data and or test reports.
- The physical inspection of a part or sub-assembly in order to verify its existence and or performance.
- The inspection of a manufacturing drawing or optical design to verify design meets functional specification.

No procedures are required or provided for the purpose of inspection.

2.1 SYSTEM DESCRIPTION

2.1.1 Inspection Objective and Scope

The purpose of this inspection is to verify that the telescope complies with the referenced specifications.

2.1.2 Safety Requirements

General safety procedures should be observed.

2.1.3 Test Equipment

- There is no test equipment associated with this inspection.

2.1.4 Inspection Results

Record any documents referenced in support of the requirements.

Item #	Description	Ref.	Contract Requirement	Notes	Pass/ Fail
1	Azimuth Encoders	1	minimum 2 read heads	Same as 1.8 m but with minimum 2 read heads instead of 4	P
2	Elevation Encoders	1	minimum 2 read heads	Same as 1.8 m but with minimum 2 read heads instead of 4	P
3	Active Collimation	1.3	The telescope uses a computer controlled, articulated secondary mirror to maintain the primary and secondary mirror alignment through tip and tilt of the secondary.	Same quasi-static actuator as 1.8 m, without fast tip/tilt. Existing actuators can accommodate the larger secondary mirror for the 2.4 m telescope	P
4	Active Collimation	1.3	The control system provides features that include compensation for misalignments due to gravity flexure		P

MK

	Name	Signature
Inspection Conducted By:	D. Shelby Stubbe	
Inspection Accepted By:	Matthew Radovan	
	Test Date	3-2-09

2.2 PRIMARY MIRROR SUPPORT

2.2.1 Inspection Objective and Scope

The purpose of this inspection is to verify that the telescope complies with the referenced specifications.

2.2.2 Safety Requirements

General safety procedures should be observed.

2.2.3 Test Equipment

- There is no test equipment associated with this inspection.

2.2.4 Inspection Results

Record any documents referenced in support of the requirements.

Item #	Description	Ref.	Contract Requirement	Notes	Pass/ Fail
1	M1 Support Type	4.6	Passive		P
2	M1 Axial Support	4.6	27 point whiffle tree		P
3	M1 Lateral Support	4.6	12 point counterweight		P

	Name	Signature
Inspection Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Inspection Accepted By:	Matthew Radovan	Matthew Radovan
	Test Date	3-2-09

2.3 PRIMARY MIRROR COVER

2.3.1 Inspection Objective and Scope

The purpose of this inspection is to verify that the telescope complies with the referenced specifications.

2.3.2 Safety Requirements

General safety procedures should be observed.

2.3.3 Test Equipment

- There is no test equipment associated with this inspection.

2.3.4 Inspection Results

Record any documents referenced in support of the requirements.

Item #	Description	Ref.	Contract Requirement	Notes	Pass/ Fail
1	M1 Cover	4.7	Protect primary mirror against settling dust when closed Protect against blunt impacts from above of < 20 kg-m/s Present minimal cross section for wind shake	See videos and images of test panel impacts.	P

	Name	Signature
Inspection Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Inspection Accepted By:	Matthew Radavan	Matth Radavan
	Test Date	3-2-09

2.4 TELESCOPE EQUIPMENT

2.4.1 Inspection Objective and Scope

The purpose of this inspection is to verify that the telescope complies with the referenced specifications.

2.4.2 Safety Requirements

General safety procedures should be observed.

2.4.3 Test Equipment

- There is no test equipment associated with this inspection.

2.4.4 Inspection Results

Record any documents referenced in support of the requirements.

Item #	Description	Ref.	Contract Requirement	Notes	Pass/ Fail
1	Horizon Stay Bar	7.1	1 supplied (For maintenance, e.g. mirror cell removal)	Stay bar replaced with locking pins	P
2	Zenith Stay Bar	7.1	1 supplied (combined with horizon stay bar)	Stay bar replaced with locking pins	P
3	Azimuth Rotation Lock	7.1	For protection of maintenance personnel (supplied)	Not necessary due to design of co-rotating dome.	N/A
4	Cable Ways and Wraps	7.2	Expandable cable paths are provided through the elevation and azimuth axes Custom wraps can be provided for the instrument rotators, if fitted The actual cable routing is customized for the specific application and is dependent on the choice of enclosure (That is, the azimuth cable wrap is not required in a co-rotating enclosure)	No azimuth wrap is required with the co-rotating dome	P

	Name	Signature
Inspection Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Inspection Accepted By:	Matthew Radovan	Matth Radvan
	Test Date	3-2-09

3 TESTS

The following sections describe items to be tested by EOST in order to verify telescope system function against the contract statement of work.

Where required test procedures are described. These test procedures are provided to the customer in this document. Each test will be witnessed by the customer at their discretion. Each test will be signed by both EOST and the customer and a pass or fail status will be assigned. Tests that failed will be assessed and the reason for failure will be corrected if applicable and the test repeated. If it is found that the test procedure is not valid it will be revised. The revised test procedure will be in agreed upon with the customer prior to re-testing.

3.1 TELESCOPE AXIS CONTROL: AZIMUTH AND ELEVATION AXES RANGE OF MOTION

3.1.1 Test Objective and Scope

The objective of this test is to verify that the motion range of azimuth rotation is +/- 270 ° from the center reference and that the range of altitude motion is 0 ° to 90 ° from zenith.

3.1.2 Reference Documents

- 2.4 Meter Alt-Azimuth Telescope Contract Number CTR-4875-1

3.1.3 Safety Requirements

- Remain a safe distance from the telescope as it rotates.

3.1.4 Test Equipment

- No special equipment is required.

3.1.5 Test Procedure

1. Using the Telescope application, home the telescope axes.
2. Command an azimuth angle of – 270°.
3. Record the reported position and verify compliance.
4. Command an azimuth angle of + 270°.
5. Record the reported position and verify compliance.
6. Move the telescope to its zenith position (90°).
7. Record the reported position and verify compliance.
8. Move the telescope to its horizon position (0°).
9. Record the reported position and verify compliance.
10. Command the telescope to hold position (closed loop).
11. Manually trigger each Elevation and Azimuth inner limit and failsafe limit to verify functionality.
12. Review the results and assign pass/fail status.

3.1.6 Test Results

Item #	Description	Reference	Contract Requirement	Test Results	Pass/ Fail
1	Azimuth Rotation	2	± 270 ° from center reference (± 240 ° limited by enclosure AZ wrap)	-167° to +326°	P
2	Elevation Rotation	2	0 ° to 90 ° from zenith, both directions (continuous 180° from horizon to horizon) (0 ° to 90° hard limits installed to protect enclosure)	0° to 90°	P

	Name	Signature
Test Conducted By:	D. Shelby Stubbe	
Test Accepted By:	Matthew Radovan	
	Test Date	3-2-09

All Az and El inner and failsafe limits tested Functional

3.2 TELESCOPE AXIS CONTROL: SLEW RATES AND ACCELERATIONS

3.2.1 Test Objective and Scope

The objective of this test is to verify that the slew rates and accelerations of the telescope system meet the stated requirements.

3.2.2 Reference Documents

- 2.4 Meter Alt-Azimuth Telescope Contract Number CTR-4875-1

3.2.3 Safety Requirements

- Remain a safe distance from the telescope as it rotates.

3.2.4 Test Equipment

- Stopwatch

3.2.5 Test Procedure

1. Using the Telescope application, home the telescope axes.
2. Command the telescope to perform an azimuth slew of 16° from its current position.
3. Using the stopwatch, measure the time to complete the slew.
4. Command the telescope to perform an azimuth slew of 56° from its current position.
5. Using the stopwatch, measure the time to complete the slew.
6. Command the telescope to perform an azimuth slew of 196° from its current position.
7. Using the stopwatch, measure the time to complete the slew.
8. Command the telescope to perform an elevation slew of 4° from its current position.
9. Using the stopwatch, measure the time to complete the slew.
10. Command the telescope to perform an elevation slew of 24° from its current position.
11. Using the stopwatch, measure the time to complete the slew.
12. Command the telescope to perform an elevation slew of 84° from its current position.
13. Using the stopwatch, measure the time to complete the slew.
14. Verify that all measured times are within ±1 second of the calculated ideal times and determine pass/fail status.

15. Command the Tertiary rotator to move to the Left Nasmyth Port.
16. Command the Tertiary rotator to move to the Right Nasmyth Port.
17. Measure and record the time required to complete the move.
18. Command the Tertiary rotator to move to the Left Nasmyth Port.
19. Measure and record the time required to complete the move.

Axis	Distance (degrees)	Minimum Acceleration (deg/s^2)	Minimum Slew Rate (deg/s)	Calculated Time (s)	Measured Time (s)
Azimuth	16	1	4	8	8.8
Azimuth	56	1	4	18	18.6
Azimuth	196	1	4	53	53.7
Elevation	4	1	2	4	7.3
Elevation	24	1	2	14	17.8
Elevation	84	1	2	44	47.2

3.2.6 Test Results

Item #	Description	Reference	Contract Requirement	Test Results	Pass/ Fail
1	Slew Rates	2	> 4 °/s (azimuth) > 2 °/s (elevation)	4°/s AZ 2°/s EL	P
2	Slew Accelerations	2	>1 °/s^2 (azimuth) >1 °/s^2 (elevation)	1°/s^2 AZ 0.4°/s^2 EL	P/F
3	Tertiary Rotator	7.4	Rotates the tertiary mirror about the primary optical axis to direct the telescope beam to one of two Nasmyth Ports. Time to beam switch is < 1 min, remotely actuated	47.1 sec, 47.3 sec	P

	Name	Signature
Test Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Test Accepted By:	Matthew Radovan	Matthew Radovan
	Test Date	3-2-09

Elevation axis is set to accelerate at 0.4 °/s² :

Distance	calculated time	measured time
10°	10 sec	10.44 sec
30°	20 sec	20.7 sec
90°	50 sec	50.4 sec

3.3 TELESCOPE AXIS CONTROL: POINTING ACCURACY

3.3.1 Test Objective and Scope

The objective of this test is to verify that the pointing accuracy of the telescope system is better than 3 arcsec Root Mean Square (RMS) over the useable elevation range in the factory.

3.3.2 Reference Documents

- 2.4 Meter Alt-Azimuth Telescope Contract Number CTR-4875-1

3.3.3 Safety Requirements

Remain a safe distance from the telescope as it rotates.

3.3.4 Test Equipment

- StarCal software
- Camera at non-drive side Nasmyth port

3.3.5 Test Procedure

1. Set a camera at the non-drive side Nasmyth port.
2. Verify that the location of the Shack-Hartmann reference LED is marked on the video monitor.
3. View the currently installed mount model and record the post-fit RMS pointing error.
4. Power down the telescope controls system.
5. Start up the telescope control system and start the telescope server on the TCC.
6. Using Starcal, start a new set of observations and record the positions of ~25 stars distributed throughout the sky.
7. Using these observations, compute the pre-fit RMS error and verify that it is on the order of 3 arcseconds.
8. Review the results and assign pass/fail status.

3.3.6 Note

Due to the limited sky coverage in the factory, observations can only be made for stars within approximately 20-25 degrees from zenith. The installed mount model and all test observations will be limited to stars in this range.

3.3.7 Test Results

Item #	Description	Reference	Contract Requirement	Test Results	Pass/ Fail
1	Pointing Accuracy	2.1	Better than 3 arcsec RMS to 70 ° zenith angle after mount modeling correction	1.55 arcsec RMS	P

	Name	Signature
Test Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Test Accepted By:	Matthew Radovan	Matthew Radovan (See comments)
	Test Date	3-2-09

Post-fit RMS of installed mount model : 1.55 arcsec (Lick-20090225.tx

Pre-fit RMS of 25 star test model : 1.52 arcsec (Lick-20090225 Pre-Fit.txt)

Comments by M. Radovan -
Only open loop tracking was testel. At time of FAT Guider was not ready for demostration and/or testing

Lick-20090225.txt

Star Observations
==========

	Region deg			Star deg		Prefit Residuals arc sec			Postfit Residuals arc sec		
Obs	Azim	Elev	Catalog	Azim	Elev	Azim	Elev	Error	Azim	Elev	Error
1	-39	88	261F	-42.75	87.66	183.32	8.54	183.43	0.99	0.28	1.03
2	-30	82	250F	-30.96	81.54	180.64	10.05	180.89	0.77	-0.41	0.87
3	-39	73	227F	-39.05	72.49	179.71	11.38	180.06	1.46	1.04	1.79
4	-33	67	216F	-33.27	67.43	178.04	12.18	178.44	0.94	0.48	1.06
5	-48	65	193F	-48.23	65.45	177.10	10.47	177.40	0.47	0.34	0.58
6	-33	67	216F	-33.53	67.33	177.70	11.89	178.08	0.62	0.22	0.66
7	-22	65	225F	-22.51	65.22	176.75	12.29	177.17	-0.12	-1.30	1.31
8	-16	68	2484F	-16.54	67.49	176.72	12.77	177.17	-0.45	-1.53	1.60
9	-17	77	2517F	-17.43	77.03	177.70	12.31	178.10	-0.68	-0.76	1.02
10	11	83	274F	9.97	82.83	178.12	15.84	178.76	-0.28	-1.64	1.67
11	23	81	1191F	22.39	80.82	178.56	19.43	179.56	0.43	-0.54	0.69
12	35	84	2568F	34.81	84.45	179.84	20.90	180.96	0.57	-0.96	1.12
13	14	81	276F	14.07	81.08	178.02	18.03	178.88	-0.12	-0.38	0.40
14	6	75	1190F	5.74	74.93	177.06	16.21	177.78	-0.47	-1.26	1.34
15	3	71	2555F	2.75	70.81	176.17	17.19	176.98	-1.05	-0.18	1.07
16	-7	65	2520F	-6.75	64.83	175.14	14.79	175.75	-1.78	-1.55	2.37
17	-13	62	237F	-13.44	62.01	175.31	12.35	175.74	-1.39	-3.17	3.46
18	2	71	2555F	1.67	70.83	176.06	16.34	176.79	-1.19	-0.83	1.45
19	18	81	1191F	17.02	81.16	178.10	18.96	179.05	-0.06	0.01	0.06
20	52	81	1199F	51.83	81.01	179.82	24.20	181.38	0.41	-0.52	0.66
21	25	73	299F	25.17	72.64	177.13	21.45	178.40	0.30	0.14	0.34
22	24	68	307F	24.18	68.16	176.40	23.63	177.95	0.15	1.99	2.00
23	31	64	323F	31.10	64.25	176.11	24.64	177.80	0.73	1.30	1.49
24	44	64	335F	44.08	64.50	174.23	26.02	176.15	-0.49	0.61	0.78
25	45	68	1225F	44.90	68.36	176.09	26.72	178.08	0.52	1.65	1.74
26	46	73	314F	46.32	72.58	177.64	26.15	179.52	1.01	1.36	1.69
27	79	83	296F	78.45	82.93	183.32	28.64	185.44	-0.11	1.41	1.41
28	65	73	320F	64.77	73.07	178.54	28.18	180.71	1.01	1.11	1.50
29	67	67	1237F	66.93	66.59	176.02	29.08	178.38	0.75	1.05	1.29
30	77	64	352F	76.77	63.85	176.01	31.38	178.76	1.11	2.19	2.46
31	89	66	2719F	88.86	65.98	178.53	33.01	181.52	1.25	3.49	3.71
32	94	70	328F	94.42	70.36	181.08	32.40	183.92	0.87	3.27	3.38
33	99	78	2641F	98.69	77.76	184.62	30.49	187.06	0.08	2.16	2.16
34	100	87	286F	100.63	87.56	189.18	29.73	191.18	-1.02	2.17	2.40
35	124	83	295F	124.41	82.81	192.53	28.02	194.46	0.17	1.32	1.33
36	131	75	2630F	131.57	74.77	191.22	28.79	193.33	0.48	1.91	1.97
37	121	66	326F	121.24	66.19	185.27	30.58	187.74	0.53	1.78	1.86
38	147	63	312F	147.37	63.47	191.02	26.06	192.77	0.15	-0.25	0.29
39	151	72	1208F	151.16	71.55	194.07	24.61	195.59	0.02	-0.15	0.15
40	153	80	2595F	153.16	79.74	196.45	22.67	197.70	-0.20	-0.85	0.87
41	167	85	282F	167.64	85.43	199.12	18.85	199.89	-0.65	-1.57	1.69
42	182	80	279F	182.18	79.71	199.89	16.71	200.55	0.71	-1.76	1.90
43	183	74	277F	183.64	74.25	198.51	17.56	199.26	0.42	-1.28	1.35
44	177	66	285F	177.31	66.01	196.11	18.71	196.98	-0.05	-2.30	2.30
45	206	69	256F	206.38	68.77	196.02	14.87	196.57	0.83	-0.43	0.93
46	201	78	269F	201.84	77.51	198.40	14.71	198.91	0.45	-0.36	0.58
47	207	84	2553F	208.25	83.91	198.90	12.19	199.22	-0.04	-0.93	0.93
48	234	79	254F	234.08	78.56	192.82	10.45	193.08	-0.52	0.66	0.84
49	230	73	1173F	229.70	72.59	192.07	11.74	192.41	0.08	0.66	0.66
50	-130	65	232F	-129.31	64.83	189.06	12.04	189.43	0.20	0.13	0.24
51	-108	63	211F	-107.57	63.16	181.67	8.41	181.85	-0.97	-1.30	1.62
52	-111	70	1163F	-110.59	69.42	185.50	8.78	185.70	-0.63	-0.40	0.75
53	-107	80	2518F	-106.38	80.03	188.43	5.70	188.50	-1.61	-1.86	2.46
54	-95	74	1168F	-95.03	73.97	184.04	7.62	184.19	-0.88	0.02	0.88
55	-96	69	1158F	-96.28	68.70	181.96	7.71	182.12	-0.73	-0.57	0.92
56	-90	63	202F	-89.58	63.18	177.94	7.73	178.10	-1.00	-1.01	1.42
57	-78	58	181F	-77.75	57.87	174.40	8.14	174.59	-0.73	-1.27	1.46
58	-77	63	2399F	-77.38	62.60	176.49	8.05	176.66	-0.53	-0.70	0.87
59	-83	73	2470F	-83.13	73.29	181.47	6.48	181.57	-1.02	-0.92	1.38
60	-64	69	221F	-64.20	68.50	178.55	8.62	178.75	0.32	0.16	0.36
61	88	90				<Not Observed>					
62	-118	33				<Not Observed>					

63	-59	33				<Not Observed>						
64	-1	33				<Not Observed>						
65	58	33				<Not Observed>						
66	117	33				<Not Observed>						
67	176	33				<Not Observed>						
68	235	33				<Not Observed>						
69	294	33				<Not Observed>						
70	206	80				<Not Observed>						
71	-30	80				<Not Observed>						
			Min:	-129.31	57.87	174.23	5.70	174.59	-1.78	-3.17	0.06	
			Max:	234.08	87.66	199.89	33.01	200.55	1.46	3.49	3.71	
			P-P:	363.39	29.80	25.66	27.31	25.96	3.24	6.66	3.65	
			Avg:	38.73	72.60	183.11	17.89	184.12	-0.00	0.00	1.34	
					RMS:	183.28	19.59	184.28	0.75	1.36	1.55	

Mount Model Terms

Term	Std Dev arc sec	Value arc sec	Name	Formula
01	0.70	-233.91	Azimuth Encoder Offset	A=1
02	0.49	979.02	Elevation Encoder Offset	E=1
03	0.12	9.02	X Axis Tilt	A=tEcA;E=-sA
04	0.13	18.21	Y Axis Tilt	A=tEsA;E=cA
05	0.18	99.87	Transverse Misalignment	S=1
06	----	----	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	----	----	Cos(Elevation) in Elevation	E=cE
11	1.40	27.97	Flexure	E=1/tE
12	----	----	Azimuth Encoder Scale	A=A/r360
13	----	----	Elevation Encoder Scale	E=E/r360
14	0.54	-1.12	Sin(2*Azimuth) in Azimuth	A=s(2A)
15	0.51	-4.20	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

Lick-20090225 Pre-Fit.txt

Star Observations
==========

	Region deg			Star deg		Prefit Residuals arc sec			Postfit Residuals arc sec		
Obs	Azim	Elev	Catalog	Azim	Elev	Azim	Elev	Error	Azim	Elev	Error
1	-65	67	221F	-64.78	67.27	0.09	0.35	0.36	0.81	-0.30	0.87
2	-77	80	261F	-76.94	80.11	-0.53	0.22	0.57	0.27	0.04	0.27
3	-37	84	2568F	-38.19	84.18	0.55	0.74	0.92	1.24	0.12	1.25
4	-30	75	2537F	-29.87	74.71	-0.01	1.28	1.28	0.47	0.35	0.59
5	-32	62	225F	-31.70	61.56	-0.43	1.12	1.20	-0.14	-0.13	0.19
6	-16	74	1190F	-16.45	74.23	-1.52	0.42	1.57	-1.18	-0.68	1.36
7	45	88	296F	41.95	88.45	-0.08	0.09	0.12	-0.26	-0.90	0.93
8	33	77	314F	32.73	76.60	0.95	1.79	2.03	0.84	0.53	0.99
9	37	69	335F	36.59	68.79	0.05	1.73	1.73	-0.11	0.28	0.30
10	64	65	2773F	64.14	65.29	1.02	0.95	1.40	0.71	-0.44	0.83
11	101	76	328F	100.99	76.38	1.00	3.31	3.46	0.31	2.61	2.63
12	112	84	2641F	112.63	83.66	1.10	2.15	2.41	0.32	1.76	1.79
13	139	84	305F	139.83	84.23	0.51	-0.25	0.57	-0.28	-0.25	0.37
14	134	71	326F	134.18	70.88	0.48	1.39	1.46	-0.39	1.01	1.08
15	162	66	312F	162.52	65.99	-0.01	-0.94	0.94	-0.85	-1.10	1.39
16	193	66	285F	192.94	65.51	0.63	-1.06	1.23	0.19	-1.02	1.03
17	183	76	1200F	183.12	76.22	0.43	-1.64	1.70	-0.07	-1.39	1.39
18	192	86	295F	193.46	85.64	0.61	-2.33	2.40	0.36	-1.81	1.85
19	224	74	269F	224.38	74.38	-0.08	0.08	0.12	0.14	0.34	0.37
20	230	67	251F	230.67	67.04	-0.40	0.28	0.49	-0.08	0.33	0.34
21	256	65	1163F	256.06	64.65	-1.48	-0.27	1.50	-0.79	-0.50	0.93
22	269	69	1168F	268.87	69.06	-0.98	0.66	1.19	-0.21	0.41	0.46
23	266	85	286F	266.17	84.90	-1.51	-0.30	1.54	-0.79	-0.15	0.80
24	278	69	2470F	278.06	68.65	-0.53	1.03	1.16	0.26	0.65	0.70
25	273	58	202F	273.39	57.98	-1.56	0.86	1.78	-0.80	0.24	0.83
26	88	90				<Not Observed>					
27	-118	33				<Not Observed>					
28	-59	33				<Not Observed>					
29	-1	33				<Not Observed>					
30	58	33				<Not Observed>					
31	117	33				<Not Observed>					
32	176	33				<Not Observed>					
33	235	33				<Not Observed>					
34	294	33				<Not Observed>					
35	206	80				<Not Observed>					
36	-30	80				<Not Observed>					
			Min:	-76.94	57.98	-1.56	-2.33	0.12	-1.18	-1.81	0.19
			Max:	278.06	88.45	1.10	3.31	3.46	1.24	2.61	2.63
			P-P:	355.00	30.47	2.66	5.64	3.35	2.43	4.42	2.44
			Avg:	117.39	73.46	-0.07	0.47	1.33	-0.00	0.00	0.94
					RMS:	0.82	1.28	1.52	0.58	0.93	1.10

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

Term	Std Dev arc sec	Value arc sec	Name	Formula
01	0.81	-233.65	Azimuth Encoder Offset	A=1
02	0.55	979.19	Elevation Encoder Offset	E=1
03	0.14	8.64	X Axis Tilt	A=tEcA;E=-sA
04	0.15	18.92	Y Axis Tilt	A=tEsA;E=cA
05	0.17	99.86	Transverse Misalignment	S=1
06	----	----	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	----	----	Cos(Elevation) in Elevation	E=cE
11	1.61	29.22	Flexure	E=1/tE

12	----	----	Azimuth Encoder Scale	A=A/r360
13	----	----	Elevation Encoder Scale	E=E/r360
14	0.70	-1.34	Sin(2*Azimuth) in Azimuth	A=s(2A)
15	0.69	-3.68	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

3.4 TELESCOPE AXIS CONTROL: TRACKING ACCURACY

3.4.1 Test Objective and Scope

The objective of this test is to verify the tracking smoothness over 10 second, 10 minute and 1 hour periods, neglecting seeing effects.

3.4.2 Reference Documents

- 2.4 Meter Alt-Azimuth Telescope Contract Number CTR-4875-1

3.4.3 Safety Requirements

Remain a safe distance from the telescope as it rotates.

3.4.4 Test Equipment

- Camera at the non-drive side Nasmyth port
- Centroid tracking and logging software and computer
- Microsoft Excel software

3.4.5 Test Procedure

1. Power down the telescope controls system.
2. Start up the telescope control system and start the telescope server on the TCC.
3. Acquire and track a suitable star.
4. Start the centroiding software.
5. Center the star image on the video monitor and optimize focus if necessary.
6. Measure and set the pixel scaling factor in the centroiding software by offsetting the telescope by a known amount.
7. Set the centroiding software up to collect data at 10 frames per second and average for 1 second to remove the effects of seeing.
8. Gather star centroiding data for the 10 second, 10 minute and 60 minute periods.
9. Reduce centroiding data to obtain the RMS deviation and record the results.
10. Compare the measured results to the contract requirement and assign pass/fail status.

3.4.6 Test Results

Item #	Description	Reference	Contract Requirement	Test Results	Pass/ Fail
1	Tracking Accuracy	2.1	0.1 arcsec RMS over 10 sec	0.169 arcsec RMS	F
2	Tracking Accuracy	2.1	0.5 arcsec RMS over 10 minutes	0.32 arcsec RMS	P
3	Tracking Accuracy	2.1	2.5 arcsec RMS over 1 hour	1.01 arcsec RMS	P

	Name	Signature
Test Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Test Accepted By:	Matthew Radovan	Matthew Radovan
	Test Date	2-25-09

Tracking data was recorded on a star for just over 60 min. 0.2 sec exposures, running average of 5 centroids was performed to remove the effects of seeing.

The 10 second tracking test is likely seeing limited, even when averaging collected data. Further data will be collected on site to validate this requirement.

See "Lick Tracking Data Analysis (022709).xls"

3.5 OPTICS: WAVEFRONT QUALITY

3.5.1 Test Objective and Scope

The objective of this test is to verify that acceptable wavefront quality has been achieved after optical alignment.

3.5.2 Reference Documents

- 2.4 Meter Alt-Azimuth Telescope Contract Number CTR-4875-1

3.5.3 Safety Requirements

Remain a safe distance from the telescope as it rotates.

3.5.4 Test Equipment

- Shack-Hartmann Wavefront Sensor mounted at the non-drive side Nasmyth port
- PC with CCDSoft and ProSH software installed

3.5.5 Note

Wavefront quality testing is performed at the focal position optimized for the existing optics. The Shack-Hartmann focal plane is mounted at approximately 519 mm from the instrument mounting interface.

3.5.6 Test Procedure

1. Set the Shack-Hartmann WFS onto the non-drive side Nasmyth port and secure.
2. Rotate reference LED into the optical path and power it on.
3. Mark the artificial star position on the video monitor.
4. Setup the CCDSoft and ProSH software to store data in a folder with the date and telescope name in its title. The ProSH software should also be configured to store a zernike data file to the same directory.
5. Using the CCDSoft software, take a reference image.
6. Load the reference image into the ProSH software.
7. Turn off and rotate reference LED out of the optical path.
8. Set the telescope system to image a suitably bright star near zenith and take ~20 images (depending on seeing conditions).
9. Copy the results of the exposures from the Zernike file into the Excel spreadsheet and analyze.
10. Adjust tip/tilt and focus of M2 if necessary.

11. Repeat this procedure until an acceptable wavefront has been obtained.
12. Review the results and assign pass/fail status.

3.5.7 Test Results

Item #	Description	Reference	Contract Requirement	Test Results	Pass/ Fail
1	Wavefront Quality	4.2	~ 160 nm (80 % ee in 0.5 arcsec to 2 arcmin Field of View (FOV)) Degrades at Kolmogorov power spectrum Applies at 5 m/s wind and 1 deg C temperature gradient	99 nm RMS	P

	Name	Signature
Test Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Test Accepted By:	Matthew Radovan	Matthew Radovan (See Comments Below)
	Test Date	2-25-09

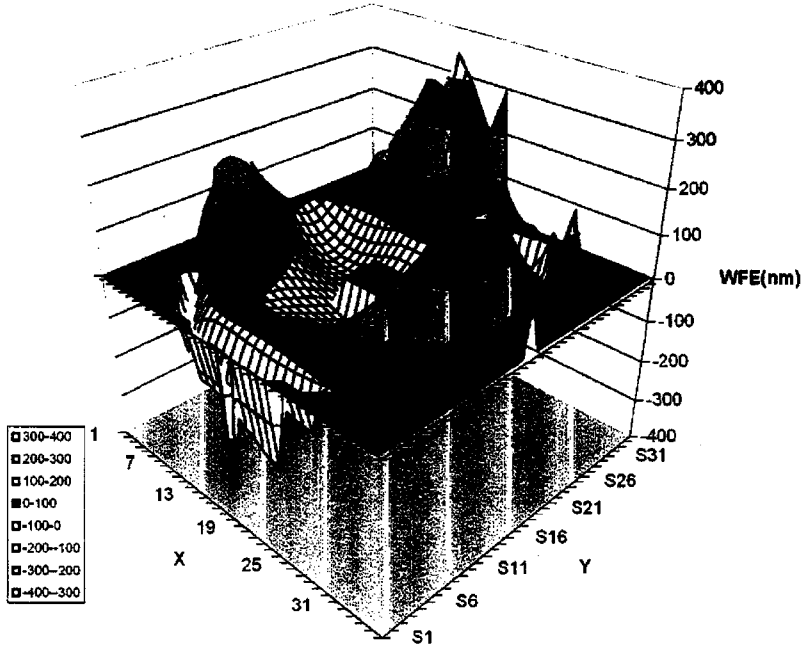
A total of 36 45 second exposures were taken and analyzed to give an RMS wavefront error of 98 nm.

~~All~~ Acceptance test of image quality were done at focus location that is 8" away from the contract specification. Image quality at the prescibed location does not meet the contract specification. This condition will be fixed when the new secondary is installed

MK

Wavefront Calculated from Zernike Coefficients

Use	ZEMAX Std Zernike #	EOST SH Zernike #	FRINGE Zernike #	n	m	Aberation	Mag (nm)	Scale	Contribution
0	1	1	1	0	0	Piston	0.00	1.00	0
0	2	3	2	1	1	TiltX	-332.89	2.00	0
0	3	2	3	1	1	TiltY	-923.24	2.00	0
1	4	5	4	2	0	Focus	94.38	1.73	54.49
1	5	4	6	2	2	Astig 45	75.23	2.45	30.71
1	6	6	5	2	2	Astig 0	45.88	2.45	18.73
1	7	8	8	3	1	Coma Y	-74.95	2.83	-26.5
1	8	9	7	3	1	Coma X	48.69	2.83	17.22
1	9	7	11	3	3	Trefoil	130.05	2.83	45.98
1	10	10	10	3	3	Trefoil 0	56.72	2.83	20.05
1	11	13	9	4	0	Primary Spherical	-14.45	2.24	-6.461
1	12	14	12	4	2	Sec Astig X	63.11	3.16	19.96
1	13	12	13	4	2	Sec Astig Y	-2.39	3.16	-0.755
1	14	15	17	4	4	Tetrafoil X	4.20	3.16	1.328
1	15	11	18	4	4	Tetrafoil Y	-43.14	3.16	-13.64
1	16	19	14	5	1	Sec Coma X	-5.11	3.46	-1.474
1	17	18	15	5	1	Sec Coma Y	-65.33	3.46	-18.86
1	18	20	19	5	3	Sec Trefoil X	-4.16	3.46	-1.2
1	19	17	20	5	3	Sec Trefoil Y	-22.78	3.46	-6.577
1	20	21	26	5	5	Pentafoil X	-77.75	3.46	-22.44
1	21	16	27	5	5	Pentafoil Y	35.15	3.46	10.15
1	22	25	16	6	0	Sec Spherical	-6.67	2.65	-2.521
1	23	24	22	6	2	Tertiary Astig Y	-16.28	3.74	-4.351
1	24	26	21	6	2	Tertiary Astig X	-32.54	3.74	-8.698
1	25	23	29	6	4	Sec Tetrafoil Y	29.09	3.74	7.774
1	26	27	28	6	4	Sec Tetrafoil X	-6.45	3.74	-1.724
1	27	22		6	6	Hexafoil Y	9.90	3.74	2.645
1	28	28		6	6	Hexafoil X	1.04	3.74	0.278
1	29	32	24	7	1	Tertiary Coma Y	-16.01	4.00	-4.002
1	30	33	23	7	1	Tertiary Coma X	0.51	4.00	0.129
1	31	31	31	7	3	Tertiary Trefoil Y	23.38	4.00	5.844
1	32	34	30	7	3	Tertiary Trefoil X	-17.11	4.00	-4.278
1	33	30		7	5	Sec Pentafoil Y	-17.93	4.00	-4.483
1	34	35		7	5	Sec Pentafoil X	-1.71	4.00	-0.427
1	35	29		7	7	Septafoil Y	34.14	4.00	8.536
1	36	36		7	7	Septafoil X	15.41	4.00	3.852
0	37		25	8	0	Tertiary Spherical	100	3.00	0
0	38		32	8	2	Quatenary Astig X	100	4.24	0
0	39		33	8	2	Quatenary Astig Y	100	4.24	0
0	46		34	9	1	Quatenary Coma X	100	4.47	0
0	47		35	9	1	Quatenary Coma Y	100	4.47	0
0	56		36	10	0	Quatenary Spherical	100	3.32	0



Mask Round:	1	1 or 0	
Mask Outer Radius:	1		
Mask Inner Radius:	0.17	Lick Pupil 0.17 (assuming 400 mm M2 obs)	
RMS WFE, RSS of Contributions	98.81	nm	
RMS WFE pt by pt calculated	97.43	nm	
PV WFE pt by pt	664.01	nm	
Max Term	36		
Remove Focus	N	Remove SA	N
Remove Coma	N	Renove Astig	N

3.6 SECONDARY ACTIVE TIP/TILT FOCUS SYSTEM

3.6.1 Test Objective and Scope

The objective of this test is to verify that the ranges of motion and slew rates of the secondary mirror mount satisfy the stated requirements.

3.6.2 Reference Documents

- 2.4 Meter Alt-Azimuth Telescope Contract Number CTR-4875-1

3.6.3 Safety Requirements

Observe general safety procedure when working on or near the telescope.

3.6.4 Test Equipment

- Stopwatch

3.6.5 Test Procedure

1. Command the secondary tip/tilt axis to move to its center of motion.
2. Command the tip/tilt stage to move to + 18 arcsec from the center of motion.
3. Record the reported position.
4. Command the tip/tilt stage to move to - 18 arcsec from the center of motion.
5. Record the reported position.
6. Using the stopwatch, measure and record the time required for the tip/tilt stage to move through 36 arcsec.
7. Command the secondary focus axis to move to its center of motion.
8. Command the focus axis to move to + 10 mm from the center of motion.
9. Record the reported position.
10. Command the secondary focus axis to move to - 10 mm form the center of motion.
11. Record the reported position.
12. Using the stopwatch, measure and record the time required for the focus stage to move through 20 mm.
13. Compare the results to the contract requirements and assign pass/fail status.

Axis	Commanded Position	Reported Position
Tip/Tilt	-18 arcsec	-18" tip -18" tilt
Tip/Tilt	+18 arcsec	+18" tip +18" tilt
Focus	-10 mm	-1.5 mm
Focus	+10 mm	+8.5 mm

Axis	Distance Moved	Maximum Velocity	Maximum Time (s)	Measured Time (s)
Tip/Tilt	36 arcsec	5 arcsec/s	7.2	4.3
Focus	~~20~~ 5 mm	100 µm/s	50 ~~200~~	41.2

3.6.6 Test Results

Item #	Description	Reference	Contract Requirement	Test Results	Pass/ Fail
1	Range (tip/tilt)	5.1	± 18 arcsec	> ± 18 arcsec	P
2	Slew Rate	5.1	> 5 arcsec/s	~ 8.4 arcsec/s	P
3	Focus Range	5.2	± 10 mm travel of secondary mirror	± 5 mm	F
4	Focus Slew Rate	5.2	> 100 µm/s	~ 121 µm/s	P

	Name	Signature
Test Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Test Accepted By:	Matthew Radovan	Matthew Radovan
	Test Date	3-3-09

Due to a mechanical failure on the quasi static focus mechanism, the focus range is limited to -1.5 mm to + 8.5 mm. The slew speed was tested over a 5 mm range. The mechanical failure will be repaired during disassembly and initial work on site. The range of motion will be demonstrated during subsequent testing on site.

3.7 STRUCTURAL RESONANCE

3.7.1 Test Objective and Scope

The objective of this test is to verify that the telescope has a structural resonance greater than 6Hz.

3.7.2 Reference Documents

- 2.4 Meter Alt-Azimuth Telescope Contract Number CTR-4875-1

3.7.3 Safety Requirements

Observe general safety procedure when working on or near the telescope.

3.7.4 Test Equipment

- Accelerometers
- Data Acquisition System
- MatLab software
- Dead Blow Hammer or Wood Block

3.7.5 Test Procedure

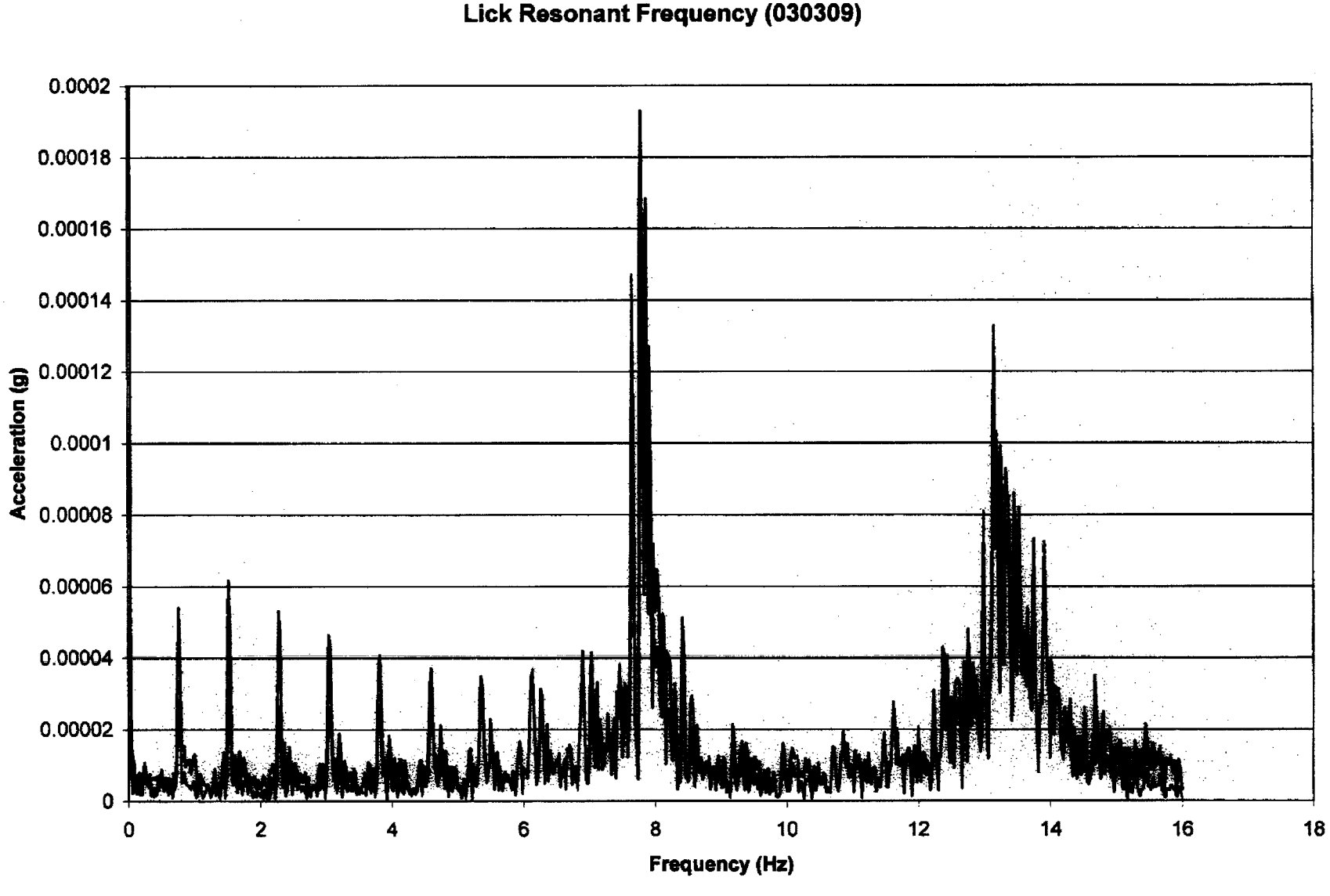
1. Set the telescope to horizon pointing.
2. Mount the accelerometers on the fork tine.
3. Connect the data acquisition system to the accelerometers
4. Start data acquire.
5. Firmly impact the fork tine with the dead blow in the horizontal direction, just above the Nasmyth port.
6. Record and store the data.
7. Analyze the stored data and determine the lowest resonant frequency of the telescope.
8. Review the results and assign pass/fail status.

3.7.6 Test Results

Item #	Description	Reference	Contract Requirement	Test Results	Pass/ Fail
1	Structural Resonance	3	> 6 Hz	~7.8 Hz	P

	Name	Signature
Test Conducted By:	D. Shelby Stubbe	D. Shelby Stubbe
Test Accepted By:	Matthew Radovan	Matthew Radovan
	Test Date	3-3-09

see "Lick Structural Resonance (030309).xls"


Lick Resonant Frequency (030309)
Acceleration (g)
0.0002
0.00018
0.00016
0.00014
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
0
2
4
6
8
10
12
14
16
18
Frequency (Hz)