Overview of Data for the SLR2000 Tracking Gimbal

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Abstract

This paper addresses performance specifications provided to the gimbal manufacturer and final test data sets obtained before acceptance of the gimbal. Outlined as well are the major dynamic tracking errors identified during the development and testing of the gimbal and the steps taken by the manufacturer and the customer to correct these problems in order to meet stringent pointing and tracking specifications. The paper concludes with a comparison of test data sets taken at the factory and similar test sets taken after field installation of the gimbal.

Introduction

During the spring of 1999 a Request For Proposals (RFP) was issued for the NASA SLR2000 Gimbal and Controller to various manufacturers. The basic requirement within the RFP was for a contractor to design, fabricate, assemble, test, and deliver a gimbal structure to the minimal acceptable specifications given below in Table 1. Responses to the RFP were evaluated, and based on costs and technical content Xybion Corporation located in Clearwater, Florida was chosen as the contractor to deliver the gimbal. Honeywell Technology Solutions Inc. was administrator of the contract with Xybion.

Table 1 Gimbal and Optical Specifications

Gimbal Configuration	EL over Az
Payload	~245 pounds
Travel in Azimuth	Continuos
Travel in Elevation	-5 degrees to 185 degrees
Angle Resolution	0.0000215 degrees (24 bits/0.77 arc seconds)
Azimuth Slew Speed	≥30 degrees/second
Elevation Slew Speed	≥20 degrees/second
Azimuth Acceleration	≥5 degrees/second^2
Elevation Acceleration	≥5 degrees/second^2
Tracking Rates	From Sidereal to ≥5 degrees/second (Both Axes)
Dynamic Tracking Error	1 arc second RMS (Both Axes)
Axis Wobble	3 arc seconds maximum repeatable error
Axis Orthogonality	5 arc seconds maximum repeatable error
Coude Path	Sealed volume 3-inch aperture
Total Beam Deviation	+/- 6 arcseconds under dynamic tracking

Design-Fabrication Summary

In order to maintain a competitive price, Xybion chose to modify an existing gimbal design to meet the SLR2000 Gimbal specifications. A new yoke design would meet the coude path requirements and the higher positioning accuracies would rely on the use of an inductosyn type encoder combined with a software error correction program. The Final Critical Design Review was held December 1999.

By the summer of 2000 fabrication of the gimbal had proceeded far enough to allow testing of the NASA host computer and the servo controller serial and parallel interfaces. Successful integration of the high speed parallel interface (2KHz read update) and the host computer provided a means of recording gimbal angle position and assessing gimbal tracking performance under simulated satellite tracks. At this point the slow process began of identifying tracking errors and their source and possible means to reduce these errors, either through hardware (different type motors, servo-amplifiers, cabling techniques) or software changes. Data collected during this time showed the largest sources of error were due to motor commutation and cogging torque effects. These and other deterministic (repeatable) errors (encoder error, bearing wobble) were corrected with software compensation routines.

The gimbal construction and test phases were complete by November 2001 and preparations were made for the Final Factory Acceptance Testing (FAT). During the FAT tests were run to demonstrate that all gimbal operations fell within the original performance specifications. The most comprehensive test was simulated satellite tracks where the dynamic tracking error could be measured by computing the difference between position commands and the actual gimbal position at a 2000 data points per second rate.

After a successful FAT the gimbal was shipped to NASA Goddard Space Flight Center, Greenbelt, MD. By January 2002 the gimbal had been installed in the SLR2000 facilities and preparations begun for the Field Acceptance Testing. During the next two months the same tracking simulations conducted during the FAT were repeated using the mass simulator and the actual operational telescope.

The completed gimbal is shown in Figure 1 in a test set-up on the factory floor. The mass simulator that duplicates the size, weight, and inertia of the operational telescope is in place. Note that the upper and lower coude path mirrors are visible as the coude cover has been removed. Figure 2 shows the overall gimbal dimensions.

Design-Fabrication Summary (Continued)

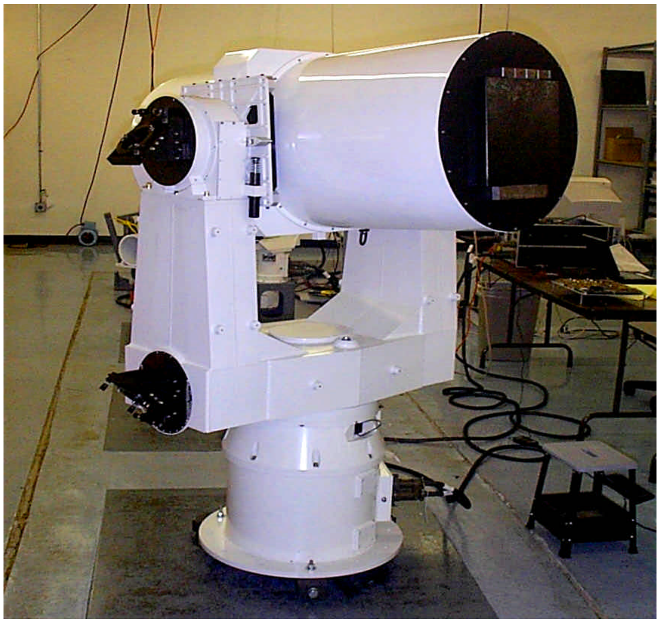


Figure 1 Gimbal with Mass Simulator

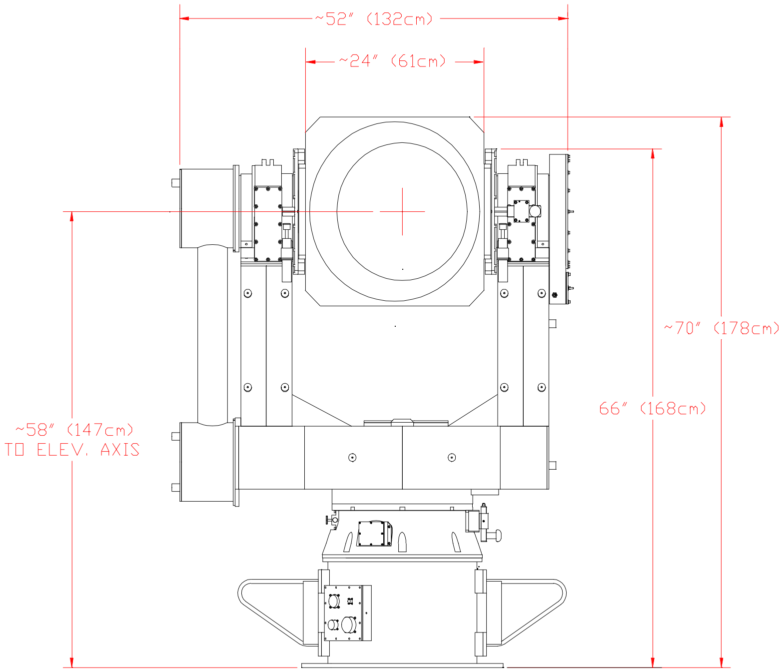


Figure 2 Overall Gimbal Dimensions

Test Results

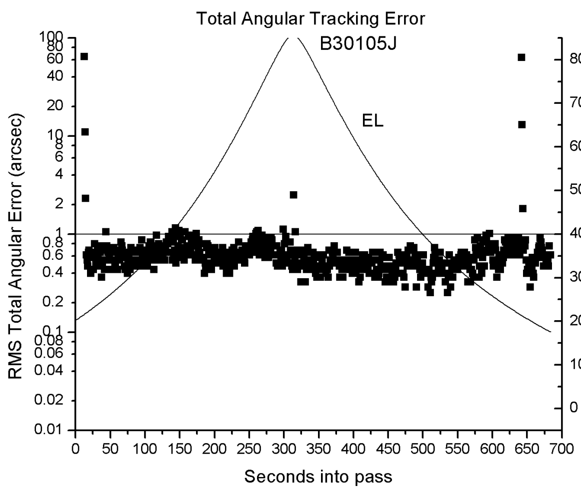
This section shows tracking error plots that were generated during the factory and field acceptance tests for the gimbal. The plots are grouped by satellite track so that any differences between factory testing in November and field testing in January and February can be seen. The plots show the total angular tracking error as a combination of the azimuth and elevation RMS error values. The RMS value for each axis was computed as the difference between the actual gimbal position and the command angle with a correction to the azimuth error as a function of the cosine of the elevation angle. The points plotted are grouped in one-second bins, which equates to 2000 angular differences to equal one RMS point. Each plot shows the gimbal elevation angle as the track progresses with the maximum elevation angle occurring near the center of the plot. A straight line has been drawn across the plot at the 1 arcsecond RMS level (the specification requirement for dynamic tracking performance). In total there were five different satellite tracks with different orbits, velocities, and accelerations chosen to validate the gimbal tracking performance level. Satellite track profiles are shown in Table 2.

Table 2 – Satellite Track Profiles

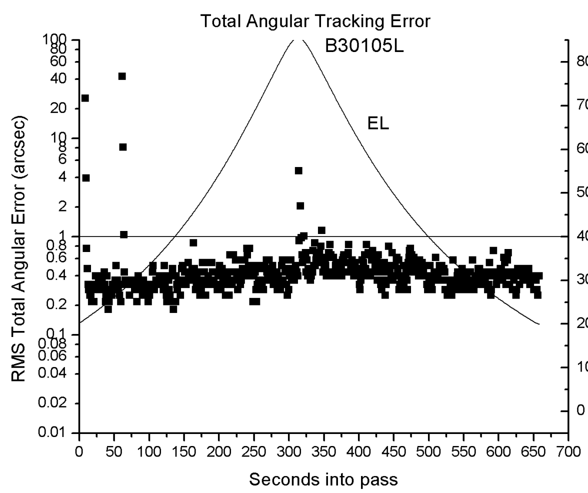
Satellite	Maximum Velocity Degrees/Second	Maximum Acceleration Degrees/Second^2
BEC Designate B30105J 950 Km Altitude Maximum Elevation Angle 85°	Azimuth 4.5 Elevation 0.3	Azimuth 0.2 Elevation 0.03
CHAMP Designate C30001J 470 Km Altitude Maximum Elevation Angle 71°	Azimuth 5.1 Elevation 0.3	Azimuth 0.2 Elevation 0.03
Fizeau Designate F28107J 950 Km Altitude Maximum Elevation Angle 80°	Azimuth 2.7 Elevation 0.3	Azimuth 0.08 Elevation 0.02
GFZ Designate G29112J 320 Km Altitude Maximum Elevation Angle 70°	Azimuth 4.6 Elevation 0.9	Azimuth 0.2 Elevation 0.09
LAGEOS Designate L30515J 6000 Km Altitude Maximum Elevation Angle 85°	Azimuth 0.6 Elevation 0.05	Azimuth 0.005 Elevation 0.001

Test Data Results – Total Tracking Error for Pass 1 (BEC)

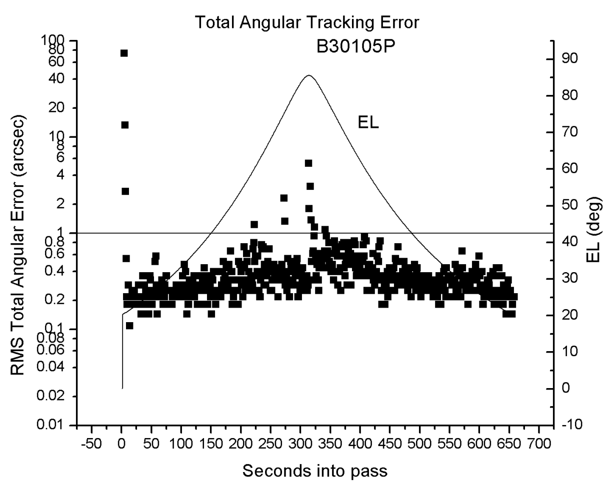
November – Mass Simulator



January – Mass Simulator



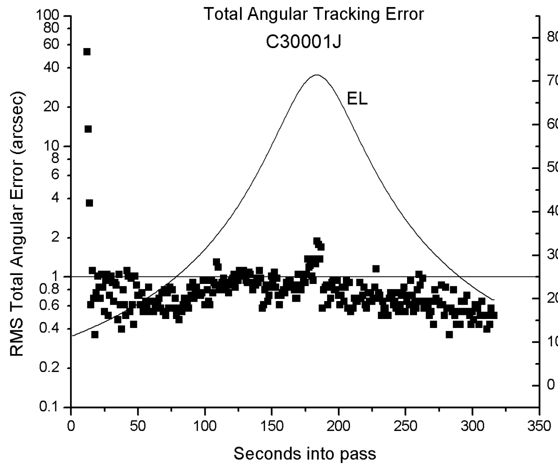
February – Telescope



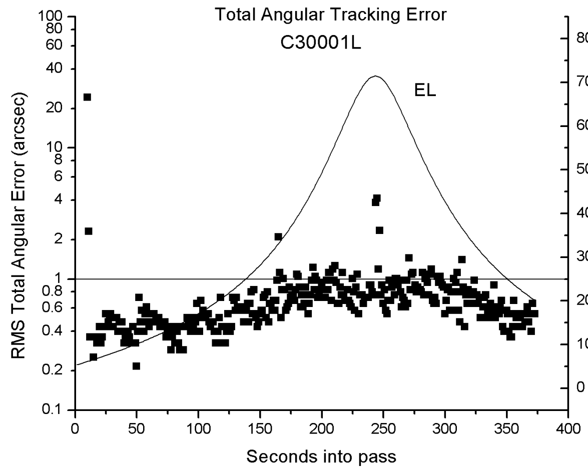
Satellite BEC 950 Km Altitude
Maximum Elevation 85 degrees
Maximum Velocity in Azimuth 4.5 degrees/second
Maximum Velocity in Elevation 0.3 degrees/second
Maximum Acceleration in Azimuth 0.2 degrees/second ^{2}
Maximum Acceleration in Elevation 0.03 degrees/second ^{2}

Test Data Results – Total Tracking Error for Pass 2 (CHAMP)

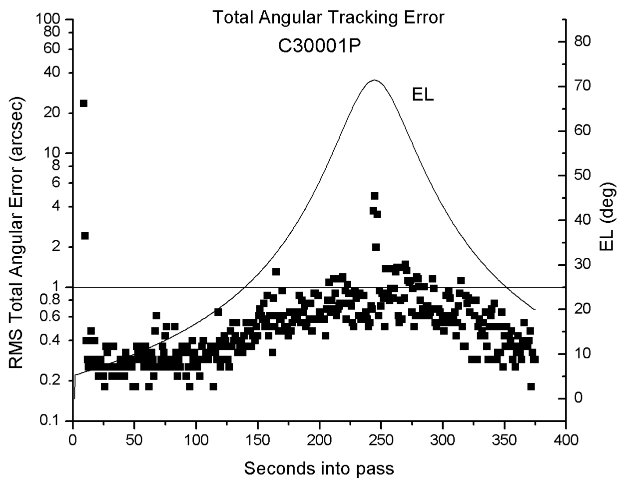
November – Mass Simulator



January – Mass Simulator



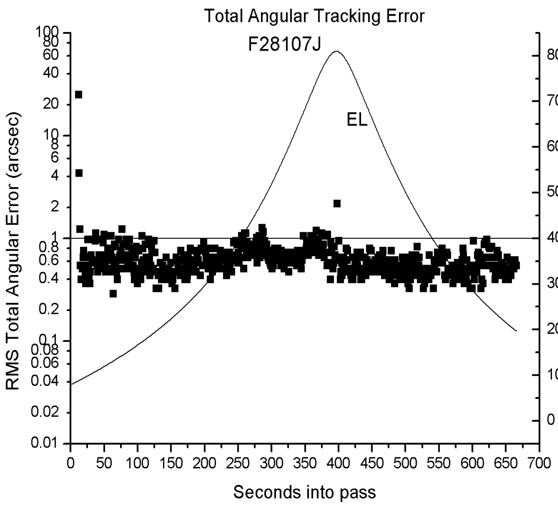
February – Telescope



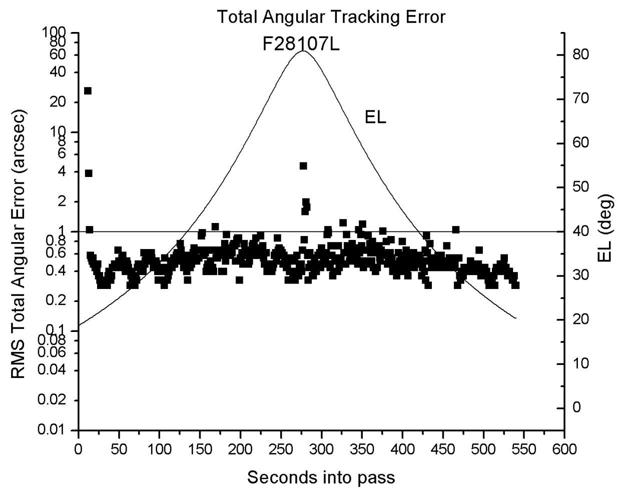
Satellite Champ 470 Km Altitude
Maximum Elevation 71 degrees
Maximum Velocity in Azimuth 5.1 degrees/second
Maximum Velocity in Elevation 0.3 degrees/second
Maximum Acceleration in Azimuth 0.2 degrees/second ^{2}
Maximum Acceleration in Elevation 0.03 degrees/second ^{2}

Test Data Results – Total Tracking Error for Pass 3 (Fizeau)

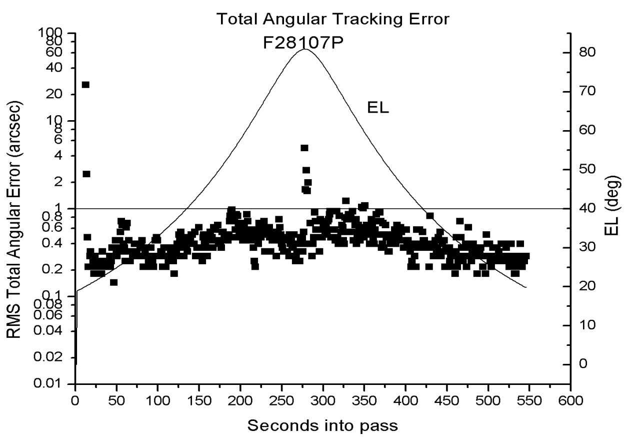
November – Mass Simulator



January – Mass Simulator



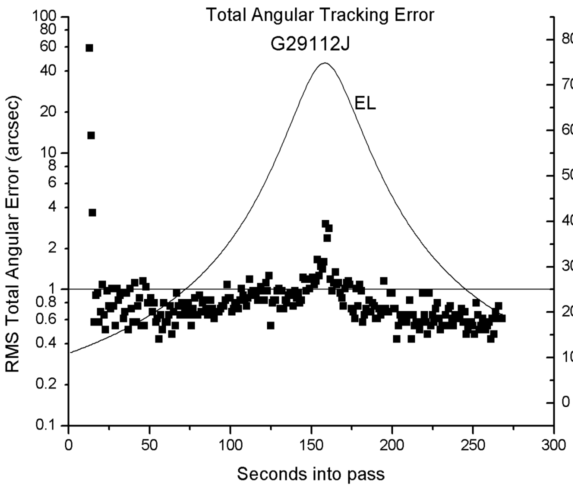
February – Telescope



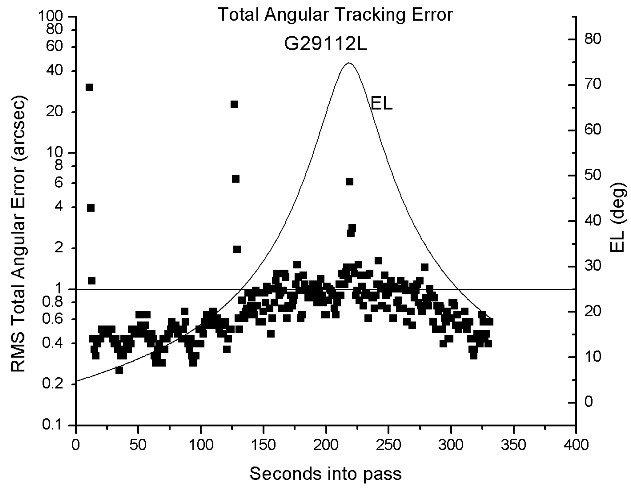
Satellite Fizeau 950 Km Altitude
Maximum Elevation 80 degrees
Maximum Velocity in Azimuth 2.7 degrees/second
Maximum Velocity in Elevation 0.3 degrees/second
Maximum Acceleration in Azimuth 0.08 degrees/second ^{2}
Maximum Acceleration in Elevation 0.02 degrees/second ^{2}

Test Data Results – Total Tracking Error for Pass 4 (GFZ)

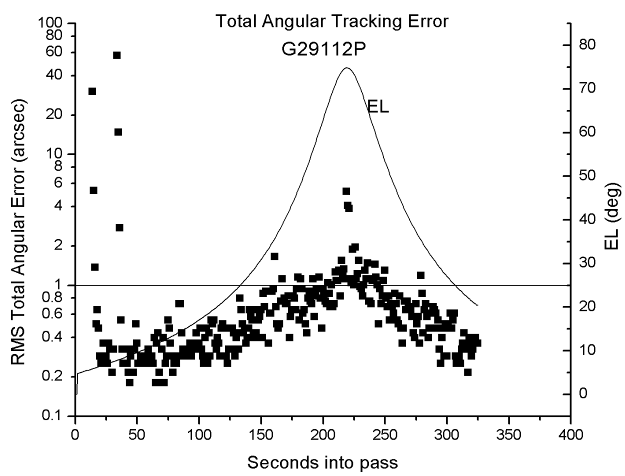
November – Mass Simulator



January – Mass Simulator



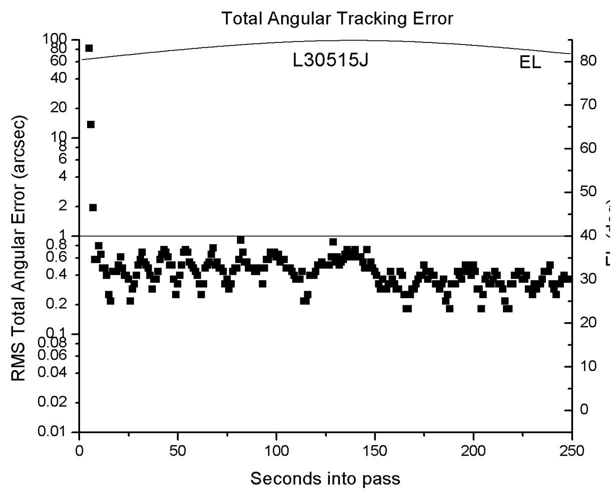
February – Telescope



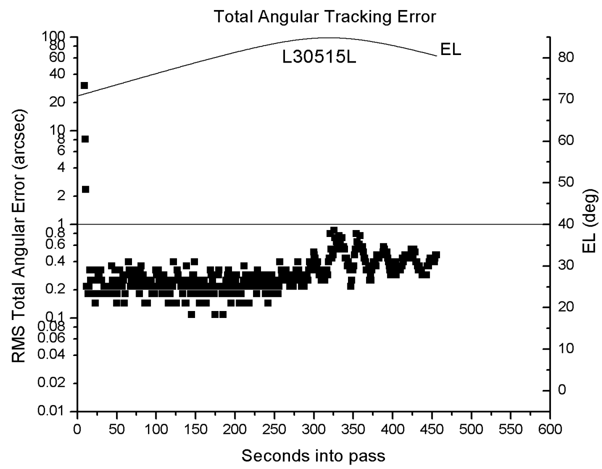
Satellite GFZ 320 Km Altitude
Maximum Elevation 70 degrees
Maximum Velocity in Azimuth 4.6 degrees/second
Maximum Velocity in Elevation 0.9 degrees/second
Maximum Acceleration in Azimuth 0.2 degrees/second ^{2}
Maximum Acceleration in Elevation 0.09 degrees/second ^{2}

Test Data Results – Total Tracking Error for Pass 5 (LAGEOS)

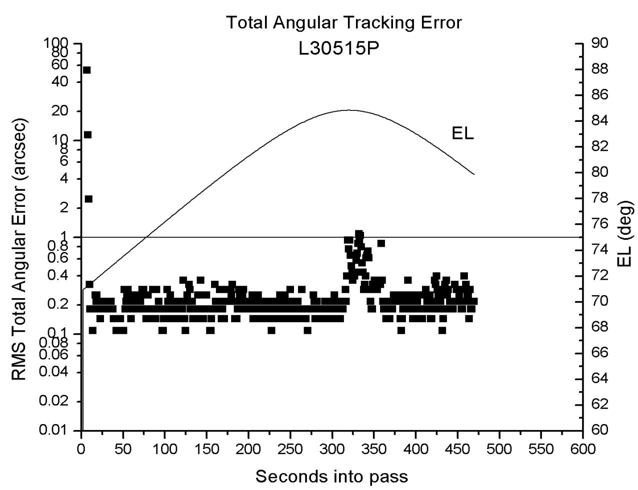
November – Mass Simulator



January – Mass Simulator



February – Telescope



Satellite LAGEOS 6000 Km Altitude
Maximum Elevation 85 degrees
Maximum Velocity in Azimuth 0.6 degrees/second
Maximum Velocity in Elevation 0.05 degrees/second
Maximum Acceleration in Azimuth 0.005 degrees/second ^{2}
Maximum Acceleration in Elevation 0.001 degrees/second ^{2}

Test Summary – Average RMS Error in Arc Seconds

Table 3 contains a summary of the average RMS error in arcseconds for each of the previous satellite tracks for the identified time periods. Also shown in the table are the resultant tracking errors when the gimbal was driven at various constant velocities in each axis. As before, the tracking error is the computed RMS value of the difference between the actual gimbal position and the command angle. Data for the azimuth velocity tests was recorded at 2000 samples per second while the gimbal rotated over 360 degrees and data for the elevation velocity tests was collected from approximately 5 degrees to 175 degrees.

Table 3 Test Summary – Average RMS Error in Arc Seconds

Type Track	November	January	February
Satellite B30105.cof	0.61 AZ/ 0.54 El.	0.57 AZ/ 0.47 El.	**0.50 AZ/ 0.47 El.**
Satellite C30001.cof	0.68 AZ/ 0.65 El.	**0.65 AZ/ 0.65 El.**	0.72 AZ/ 0.72 El.
Satellite F28107.cof	0.54 AZ/ 0.57 El.	0.57 AZ/ 0.54 El.	**0.54 AZ/ 0.50 El.**
Satellite G29112.cof	**0.79 AZ/ 0.75 El.**	0.93 AZ/ 0.90 El.	0.90 AZ/ 0.79 El.
Satellite l30515.cof	0.65 AZ/ 0.47 El.	0.65 AZ/ 0.32 El.	**0.57 AZ/ 0.25 El.**
Star Z0010881	0.53 AZ/ 0.61 El.	0.18 AZ/ 0.25 El.	**0.14 AZ/ 0.18 El**.
Az. Velocity 5°/Sec.	No Data	**1.18**	1.19
Az. Velocity - 5°/Sec.	“	**1.29**	1.29
Az. Velocity 2°/Sec.	“	**0.79**	0.83
Az. Velocity – 2°/Sec.	“	**0.79**	0.90
Az. Velocity 1°/Sec.	“	**0.75**	0.79
Az. Velocity - 1°/Sec.	“	**0.68**	0.68
El. Velocity 5°/Sec.	No Data	**0.89**	0.97
El. Velocity - 5°/Sec.	“	**1.40**	1.80
El. Velocity 2°/Sec.	“	0.97	**0.86**
El. Velocity – 2°/Sec.	“	**1.29**	1.83
El. Velocity 1°/Sec.	“	**0.61**	0.65
El. Velocity - 1°/Sec.	“	**0.75**	1.22

* Bolded entries indicate the minimum value

Summary

In general the gimbal meets or exceeds the specifications listed in the original RFP with occasional glitches, points very close to PCA in low earth orbiting satellite tracks, and dynamic tracking velocities near 5 degrees per second where the tracking error can exceed the 1 arc second RMS requirement. The servo system incorporates software routines to correct tracking errors, so future performance improvements may be possible.

References

1. Technical Proposal No. BP-204, 5 April 1999, Prepared by Xybion Corporation Sensor Positioning Systems, 11528 53rd Street North, Clearwater, Florida 33760-4825

2. Request for Proposal For the NASA SLR2000 Gimbal and Controller, March 10, 1999 AlliedSignal Technical Services Corporation 7515 Mission Drive, Lanham, Maryland, USA 20706-2218