Laser Tracker Systems for Optical Alignment and Metrology

Tom Zobrist

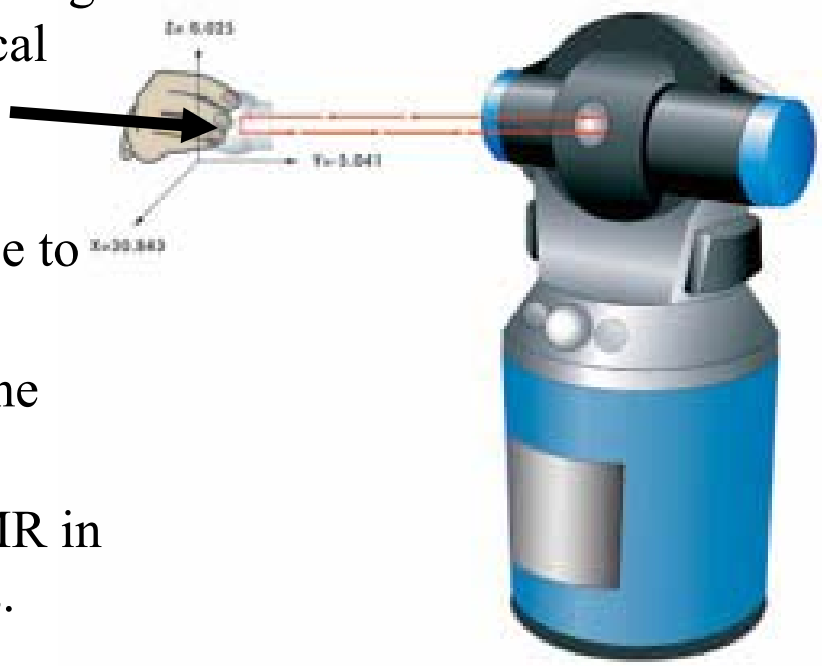
Practical Optics

December 8, 2006

Laser Tracker:

portable coordinate measuring machine

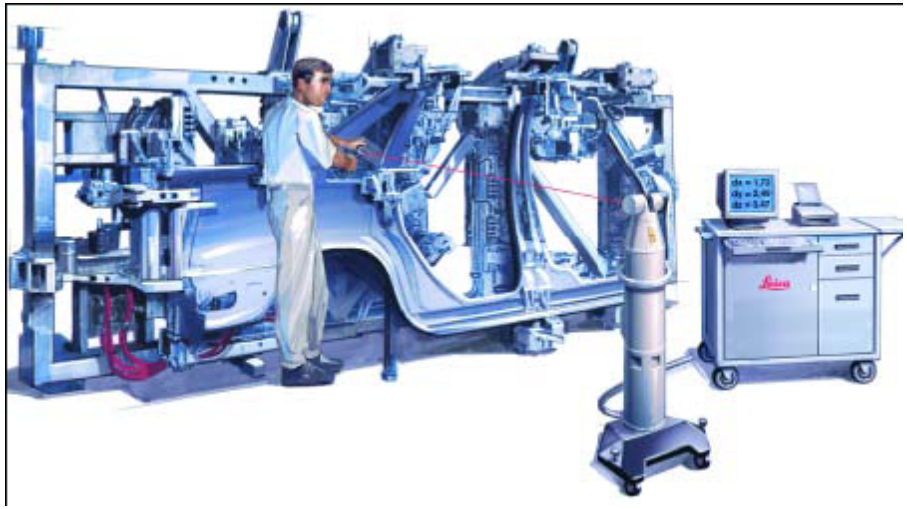
- Uses laser feed-back and motorized steering mirrors to track the location of a spherical mounted retroreflector (SMR).
- Uses a Heterodyne distance measuring interferometer to measure radial distance to SMR.
- Encoders on steering mirrors measure the azimuth and elevation angles.
- Software can record 3-D location of SMR in a variety of coordinate system and units.



What are Laser Tracker used for?

Laser Tracker Applications

Laser trackers are typically used in the automotive and aerospace industries for measuring and alignment of mechanical parts and assemblies.



Who manufactures Laser Tracker?

Three manufacturers of Laser Trackers

- Leica Geosystems (Switzerland)
- FARO (USA)
- API (USA)

Laser Tracker Accuracy and Performance

	API Tracker 3	Leica LTD 640	Faro Tracker Xi
3D Accuracy			
Accuracy of a Coordinate	± 5 µm/m	± 10 µm/m	SQRT[(18µm+3µm/m)^2 +(2µm+3µm/m)^2]
Static (2 sigma)	± 25 µm at 5m	± 50µm at 5m	± 33.2 µm at 5m
Static (2 sigma)	± 0.0010" at 16 feet	± 0.002" at 16 feet	± 0.0013" at 16 feet
	± 50 µm at 10m	± 100µm at 10m	± 48 µm at 10m
	± 0.0020" at 32.4 feet	± 0.0040" at 32.4 feet	± 0.0019" at 32.4 feet
IFM (Interferometer) Performance			
Accuracy of IFM	1 µm/m	± 10µm ± 0.5µm/m	2µm + 0.4µm/m
Range of IFM	0 - 60+ m	0-40 m	0-35m
ADM Performance			
Accuracy	±15µm or 1.5µm/m, (whichever is greater)	± 25 µm (± 0.1mm @45° elevation)	± 10µm + 0.4µm/m
Static (2 sigma)	± 15µm at 10m	± 25µm at 10m	± 14µm at 10m
	± 30 µm at 20m	± 25µm at 20m	± 18µm at 20m
Range (ADM)	0 - 60+ m	1.5-40m	0-35m

How can Laser Trackers be used in Optical Testing?

Using Laser Trackers for Optical Alignment

Three examples:

1. Scanning Offner Relay
2. Bob Parks' example
3. GMT Principal Test

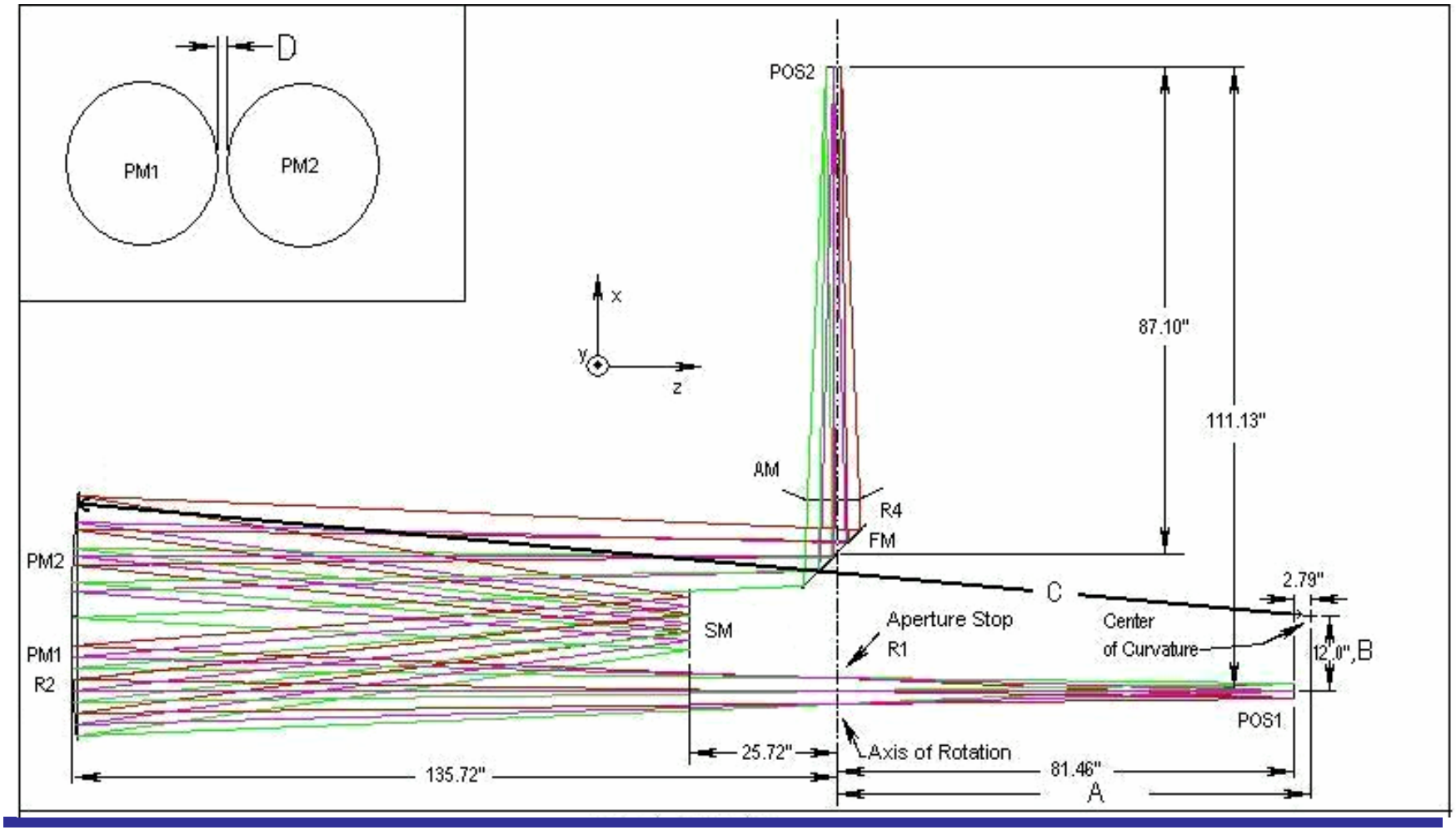
Using Laser Trackers for Optical Metrology

Two examples:

4. NST Primary Mirror
5. GMT Primary Mirror

Example 1: Scanning Offner Relay

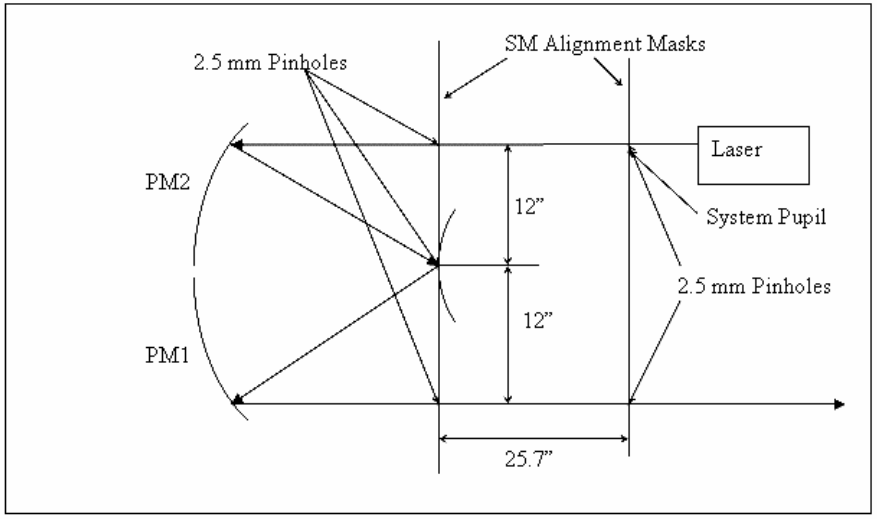
Scanning Offner Relay System Diagram

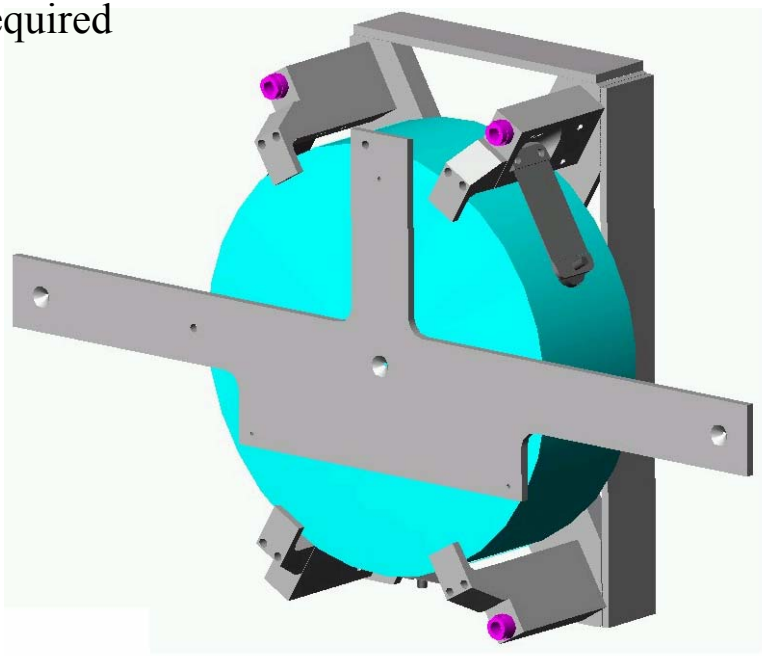


Sheet Metal Mask - OLD

Align Secondary mirror with Alignment Mask and HeNe Laser

- Adjust position of laser until laser is reflected onto vertex of secondary
- Adjust the SM Mirror until laser is reflected through bottom pinhole
- 2.5 mm pinholes give an 8X margin to the required resolution for the SM alignment
- Takes advantage of the Offner symmetry





Example 1: (continued) Scanning Offner Relay

Secondary Mirror Alignment w/Tracker -NEW

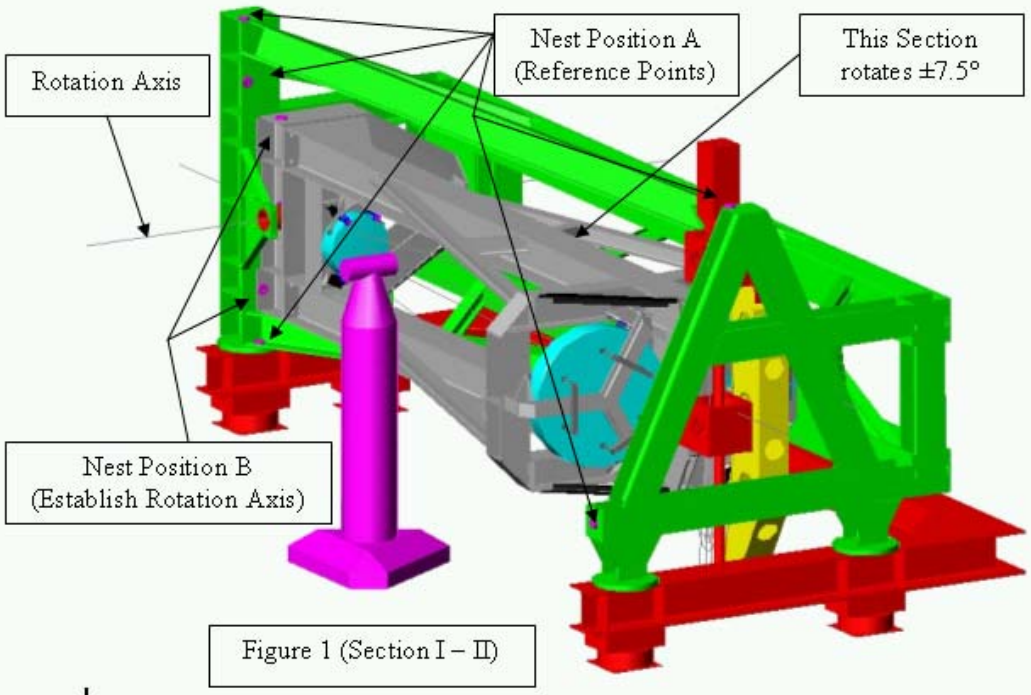


Figure 1 (Section I – II)

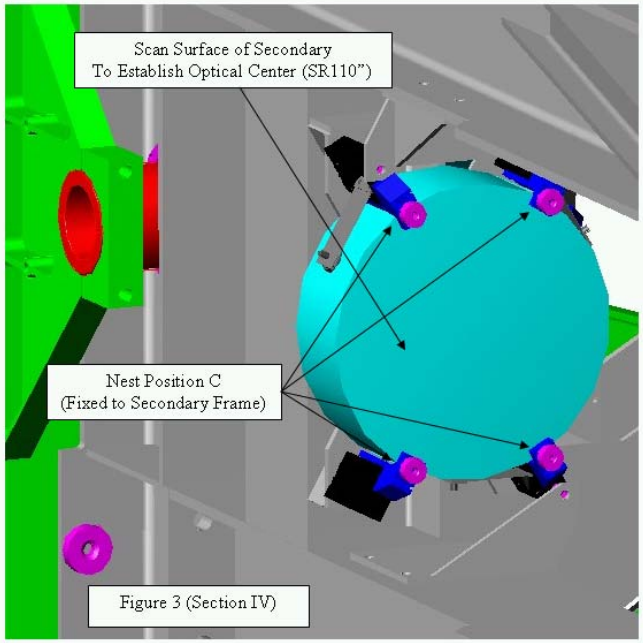
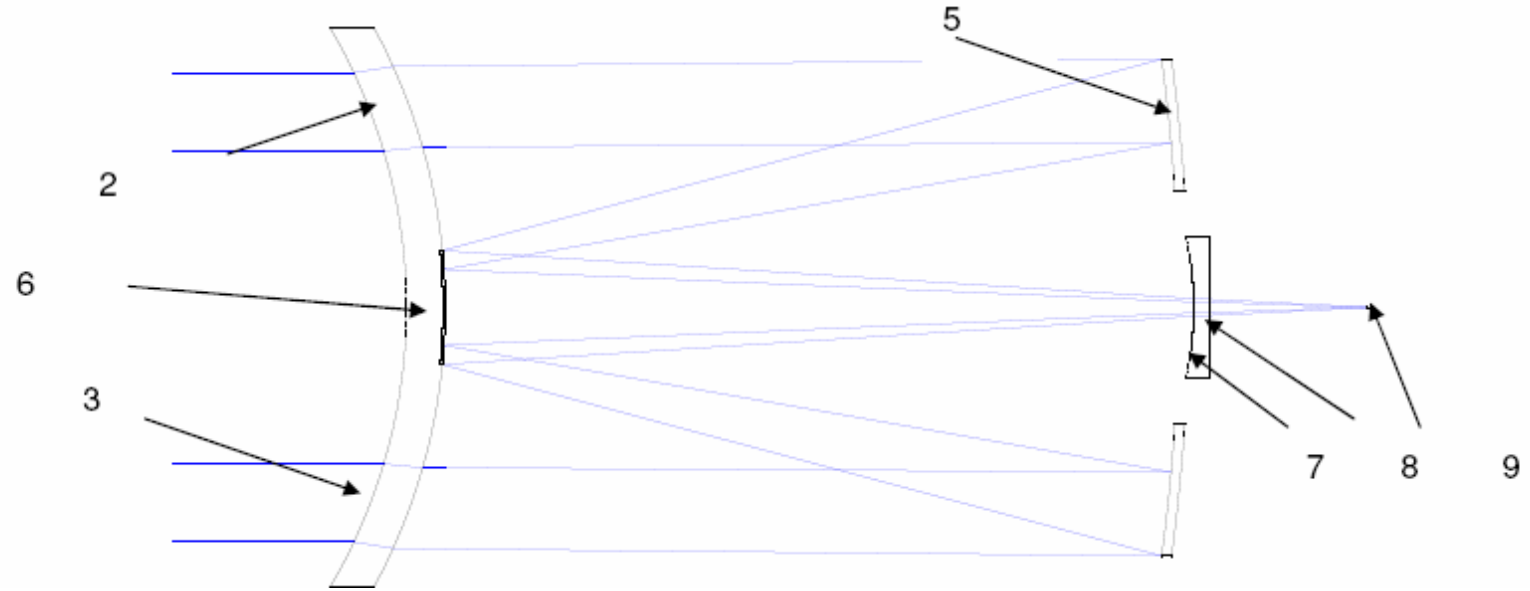


Figure 3 (Section IV)

Example 2: Bob Parks' Example

A typical example of an optical system

Surf	Type	Comment	Radius	Thickness	Glass	Diameter
OBJ	STANDARD	Source at ∞	Infinity	Infinity		0
1	STANDARD	Start of rays	Infinity	5		0
2	STANDARD	Front of corr.	-11.78675	0.8307299	K5	12
3	STANDARD	Back of coor.	-12.51825	0		12
4	STANDARD	Dummy surface	Infinity	15.75064		0.002
STO	STANDARD	Primary mirror	-39.67921	-15.75064	MIRROR	10.65653
6	STANDARD	Sec. mirror	-12.51825	16.08293	MIRROR	2.444401
7	STANDARD	Front ff	-6.645839	0.332292	K5	0.3703107
8	STANDARD	Back ff	Infinity	3.398446		0.3485696
IMA	STANDARD	Image plane	Infinity			0.01195214

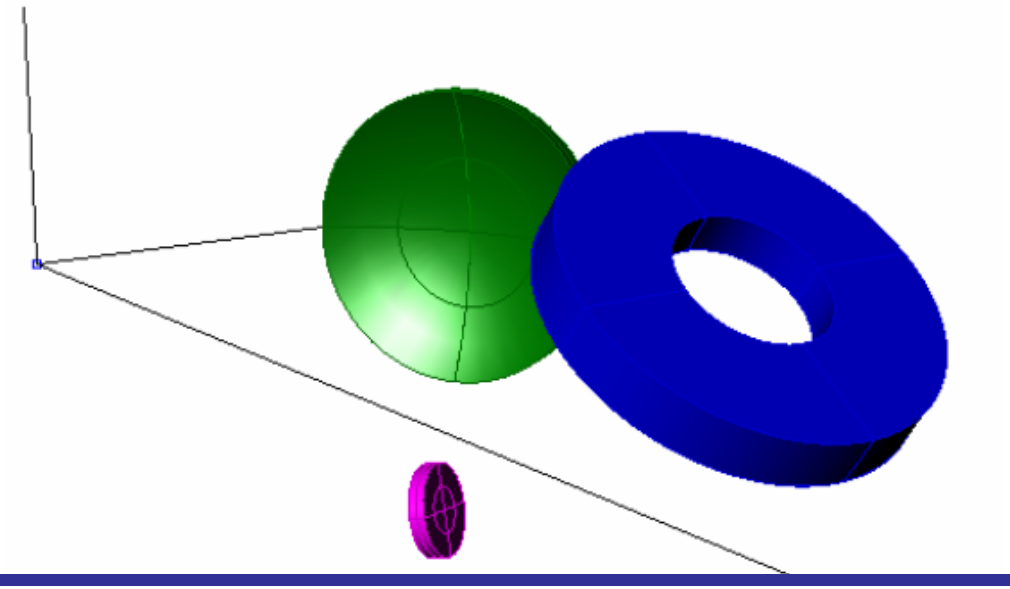


Example 2: (continued) Bob Parks' Example

How best to align the given optics?

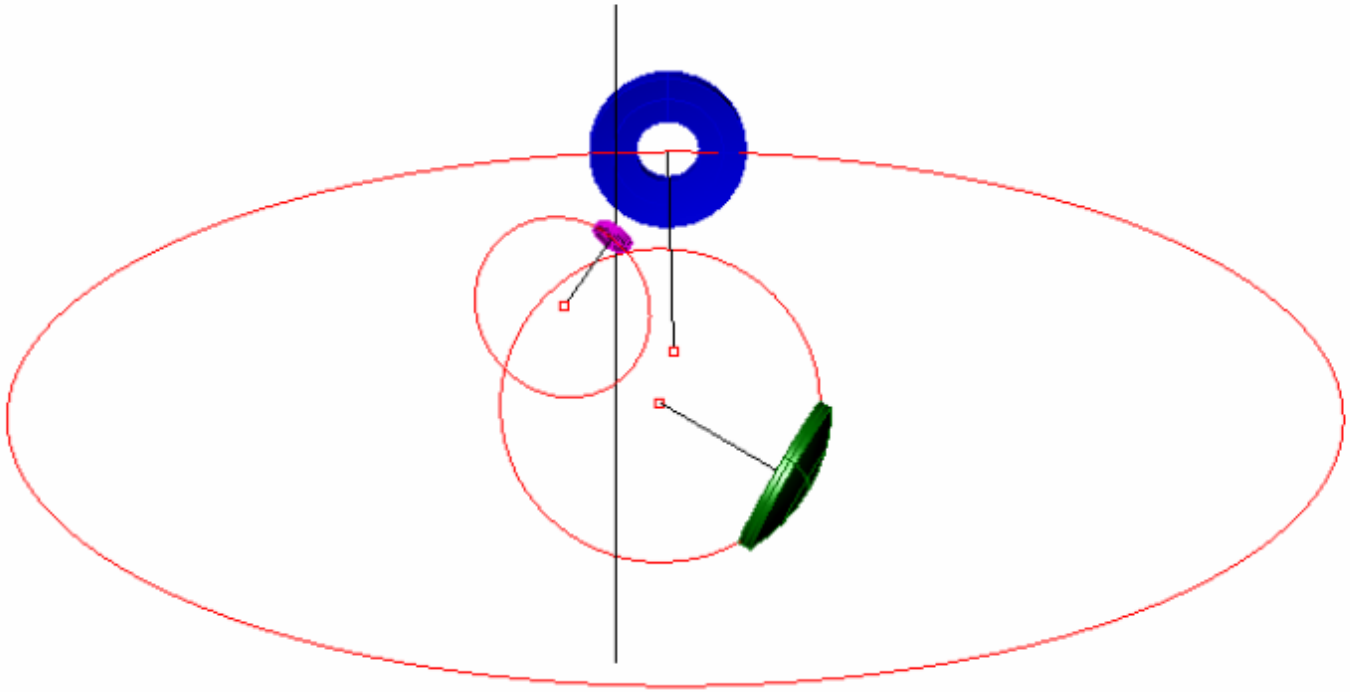
Need for thinking about alignment now obvious

Have to establish an axis and C of C for each



Example 2: (continued) Bob Parks' Example

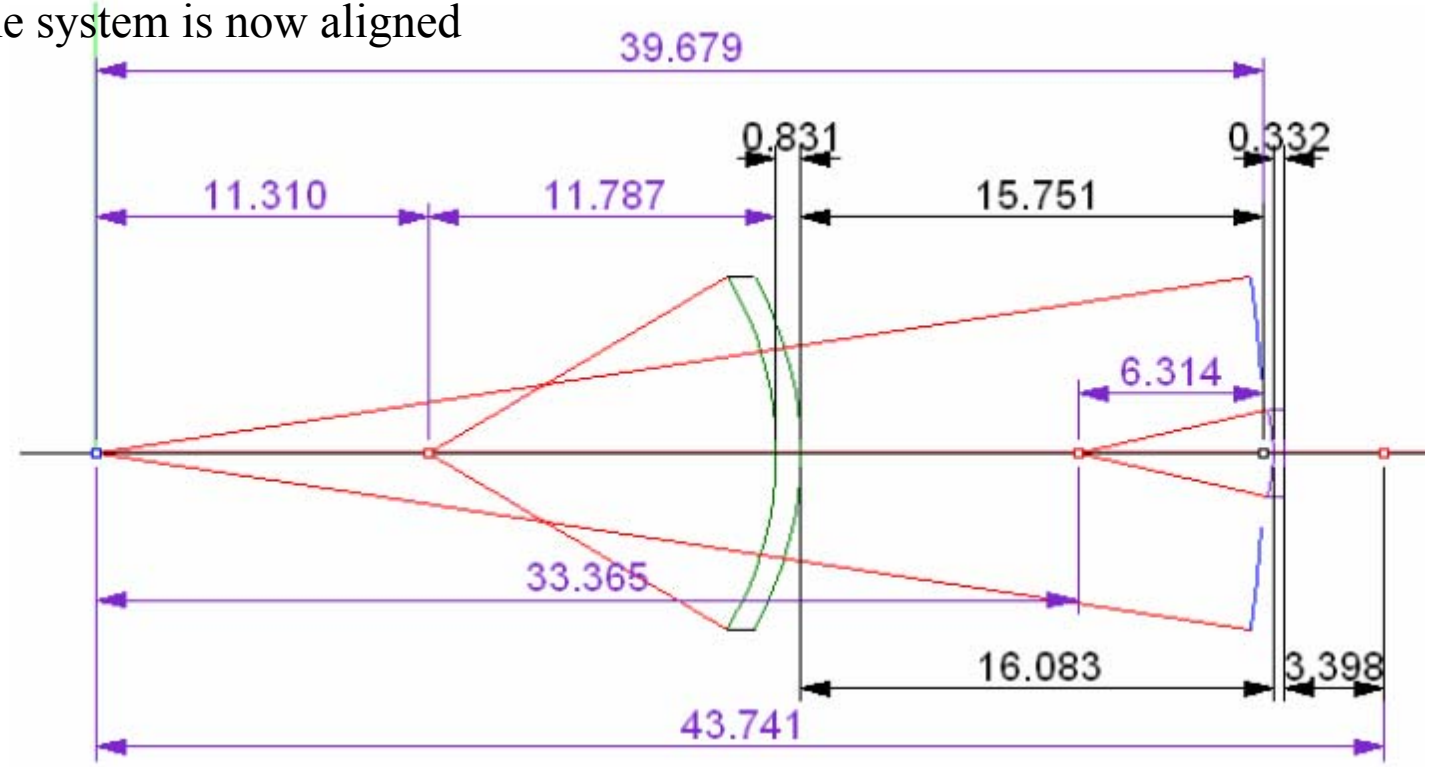
C's of C easy to find optically
Edges define other end of axes



Example 2: (continued) Bob Parks' Example

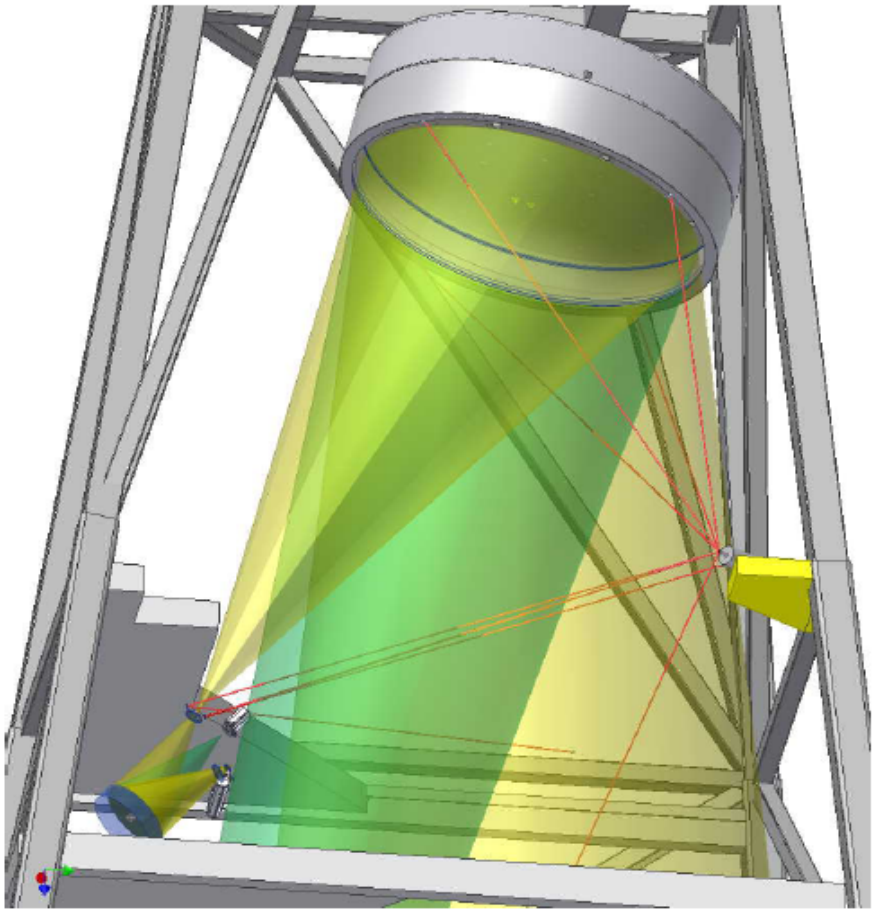
Step to Align System using Laser Tracker and PSM

1. Use laser tracker to position tooling balls at the appropriate locations for the CoCs
2. Align Point Source Microscope (PSM) to tooling balls
3. Align optics to PSM
4. The system is now aligned



Example 3: GMT Principal Test

Alignment of 3.8 m sphere



- Rely on laser tracker in ADM mode (Absolute Distance Measuring)
- Dedicated tracker will be mounted in the tower where it has view of
  - 3.8-m fold sphere
  - intermediate CGH
  - C of C for 3.8-m fold sphere
  - GMT segment
  - 76 cm M2
  - C of C for M2
- Sam will be aligned and fixed in tower
- Fold sphere is moved according to measurements from laser tracker.
- GMT segment is located in test according to tracker measurements.

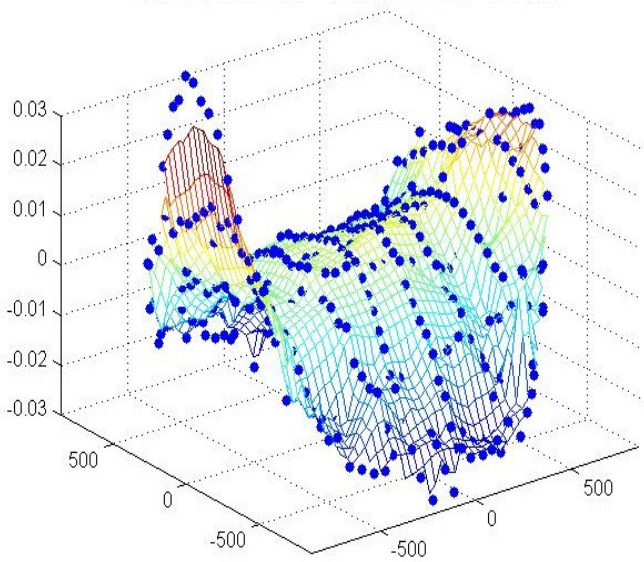
Example 4: NST Primary Mirror

- Laser tracker measurements were used to guide the figuring to an accuracy that would allow optical testing.
- The first optical measurement easily resolved fringes at 633 nm and is in good agreement with the tracker measurement.

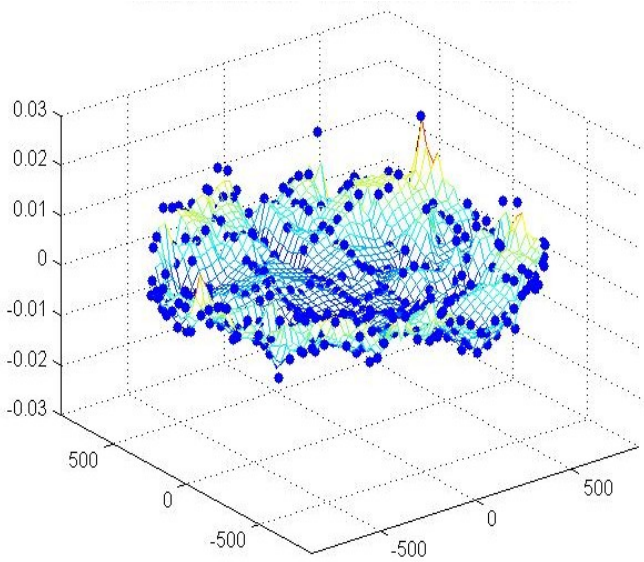
Laser tracker mounted over a 0.95 m mirror. The same arrangement was used for the 1.7 m NST mirror shown to the left.

Example 4: (continued) NST Primary Mirror

- Laser tracker measurements of the NST mirror surface near the beginning of loose-abrasive grinding and near the end.
- The plots show the departure from the ideal off-axis paraboloid, in mm, with only piston, tip and tilt removed.



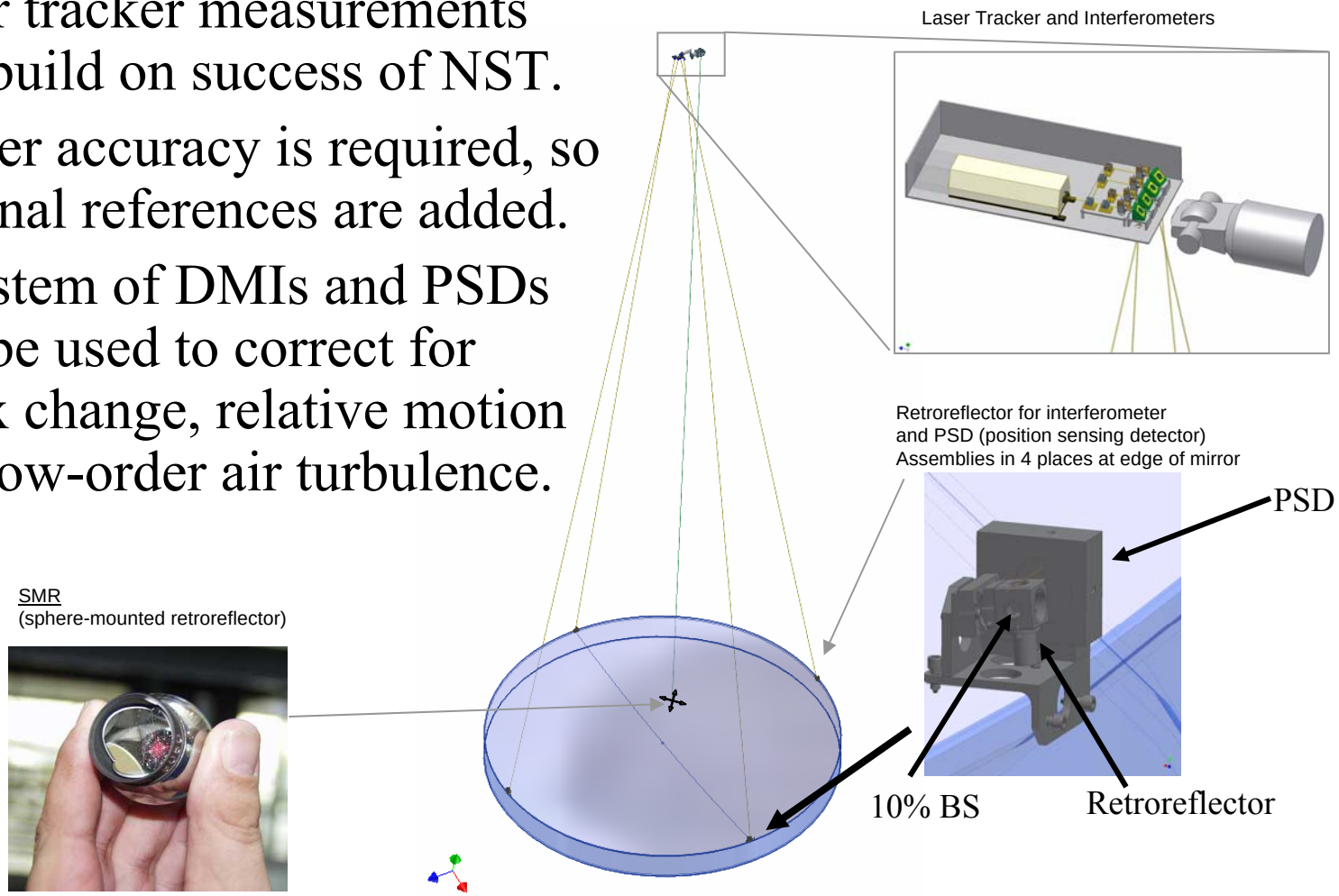
31 March 2005: 14 μm rms



22 April 2005: 4 μm rms

GMT Primary Mirror Metrology

- Laser tracker measurements will build on success of NST.
- Higher accuracy is required, so external references are added.
- A system of DMIs and PSDs will be used to correct for index change, relative motion and low-order air turbulence.



References

- Leica Geosystems (http://www.leica-geosystems.com/)
- API (http://www.apisensor.com/)
- FARO (http://www.faro.com/)
- Alternate surface measurements for GMT primary mirror segments (J. H. Burge, L. B. Kot, H. M. Martin, C. Zhao, and T. Zobrist. Proc. SPIE **6273**, 62732T (2006))
- Manufacture of a 1.7m prototype of the GMT primary mirror segments (H. M. Martin, J. H. Burge, S. M. Miller, B. K. Smith, R. Zehnder, and C. Zhao. Proc. SPIE **6273**, 62730G (2006))