Grinding Process and Measurement for Optical elements

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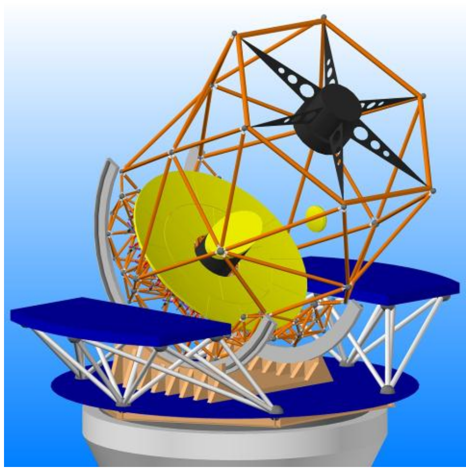
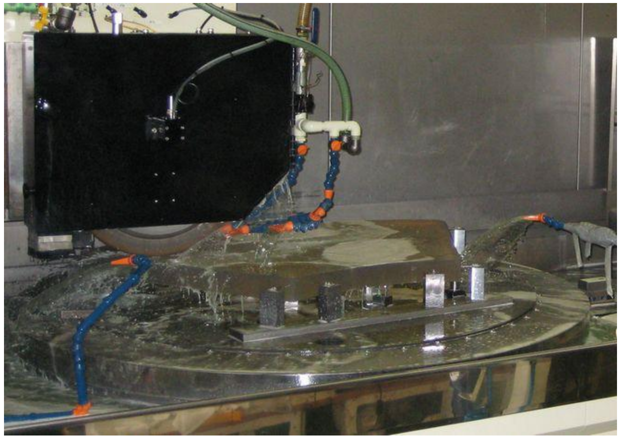
Background



- 3.8m Telescope Project
  - The project started in 2008 to study the segmented mirror techniques and to fulfill the scientific potential in domestic site, Okayama.
  - Developing high precision grinding process is one of the main technical targets for 18 segments and large convex secondary mirror.

Grinding Process

Grinding Machine

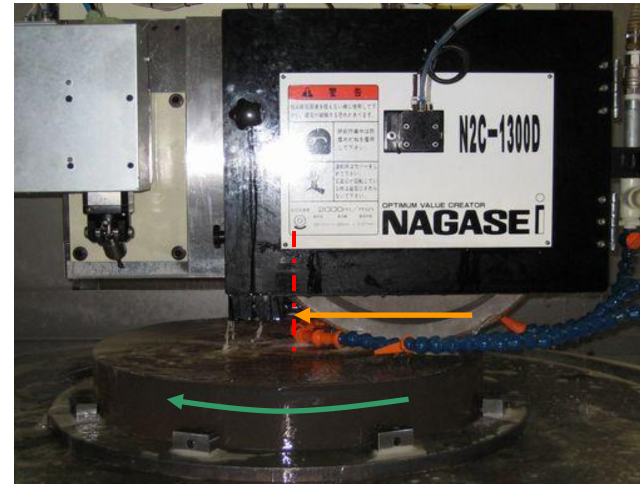


Facility
（Nano Optonics Energy）

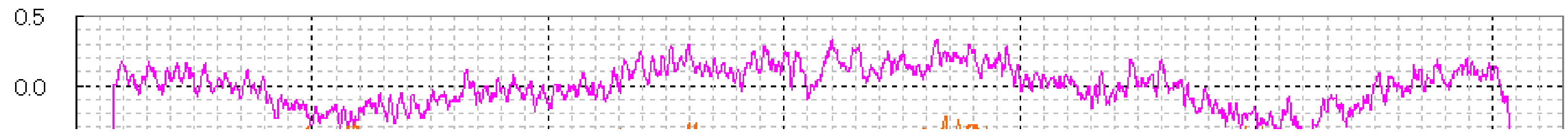
Grinding Machine
（N2C-1300D）

Grinding of Large Optics

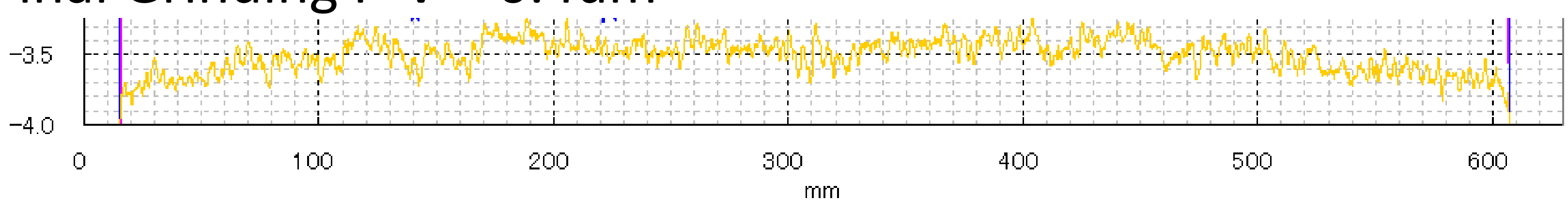
- Size: Φ610
- From: Flat
- Material: Clearseram
- Processing time: several hours



First Grinding P-V=0.7 um



Final Grinding P-V = 0.4um



Grinding Large Optics
Segmented Mirror

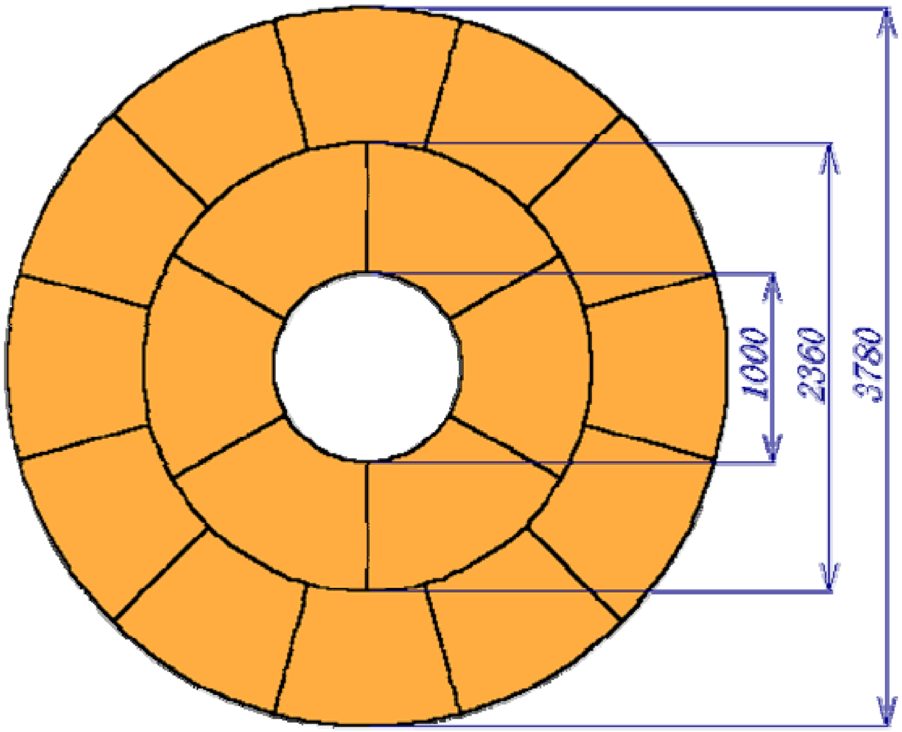
R: 10,000

K: -1.035

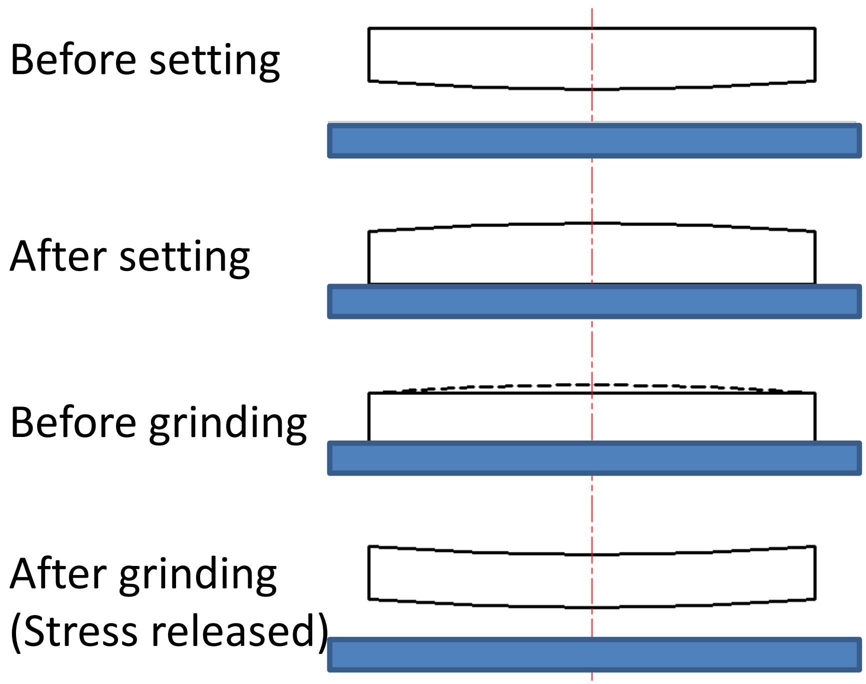
D: ～1000

t : 40-60 (flat backside)

Material: Clearseram-z



Problem of Direct Support



- The error induced by a direct support is several microns in case of large but thin optics.

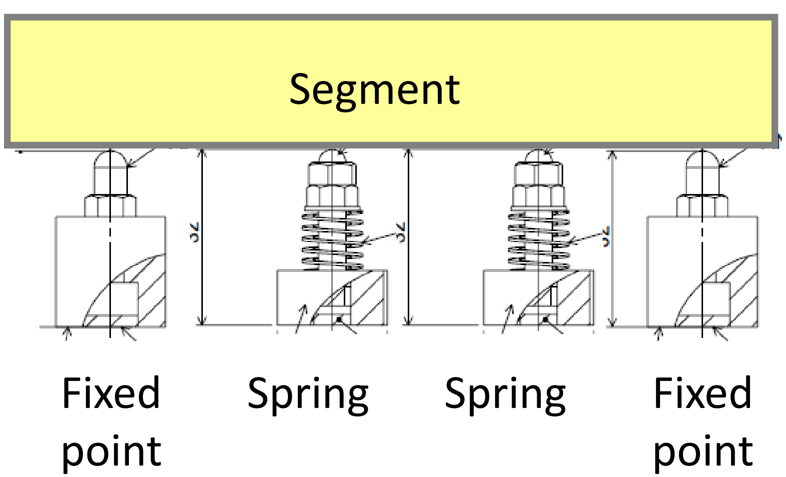
Support System

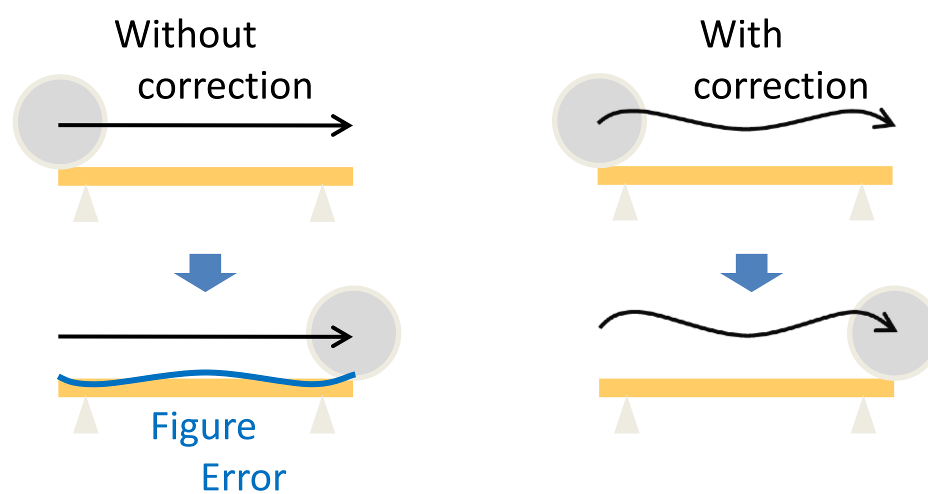
- When the segment sits directly on the table, the segment is deformed by figure errors of the table and back side of the segment, and inconsistency of thermal expansion between the table and segment .
- Ideally the segment is on a kinematic support (whiffletree) under processing, however the whiffletree is not sound against grinding force and is complicated to FEM analysis.

Note: Whiffletree support system works well under the polishing process which controls polishing pressure and time.

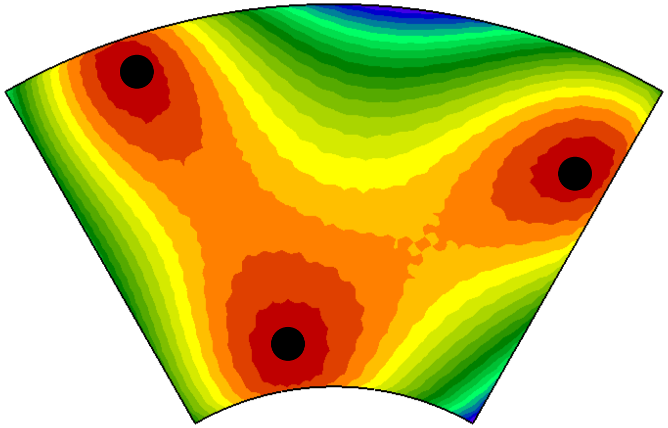
Three Fixed and Spring Support

- Three fixed points are employed for kinematic support.
- 24 springs are for assist of the support and to decrease friction between the segment and fixed points
- The deformation induced by grinding pressure was simulated beforehand, and then a stone is controlled to correct the deformation.





Three Fixed and Spring Support



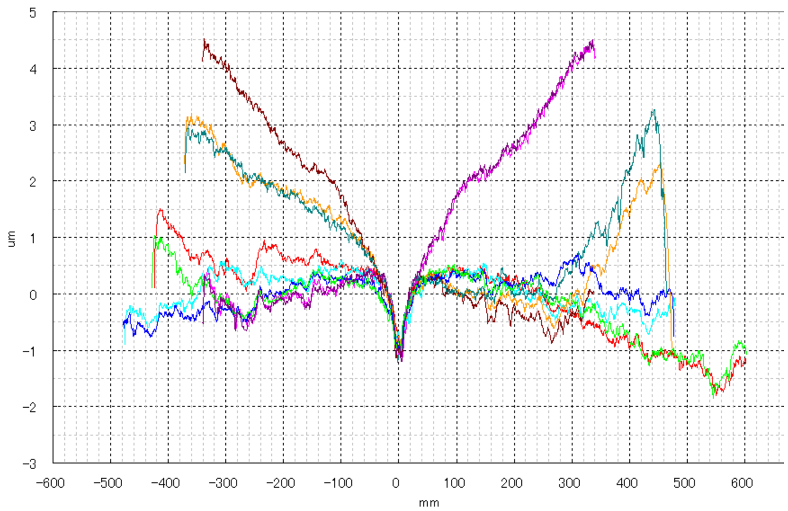
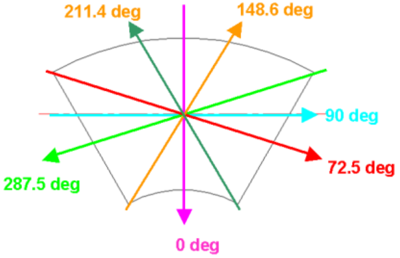
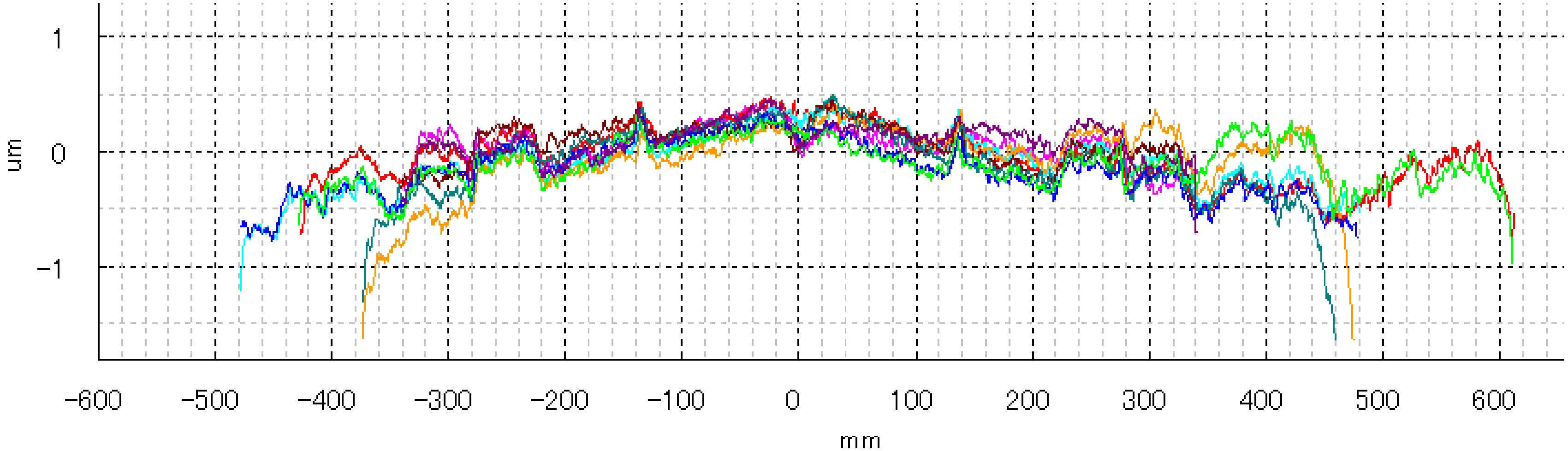


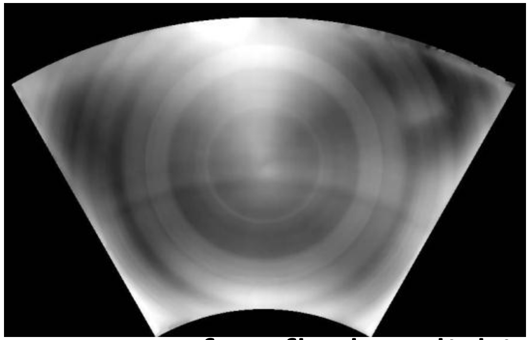
Figure Error
without deformation correction
Each color of the lines corresponds
to that of the right hand figure
(1div = 1 um)



Result



Cross sectional error
Grinding with correction
Each line are described in a same manner of the preceding page
(1div = 1 um)

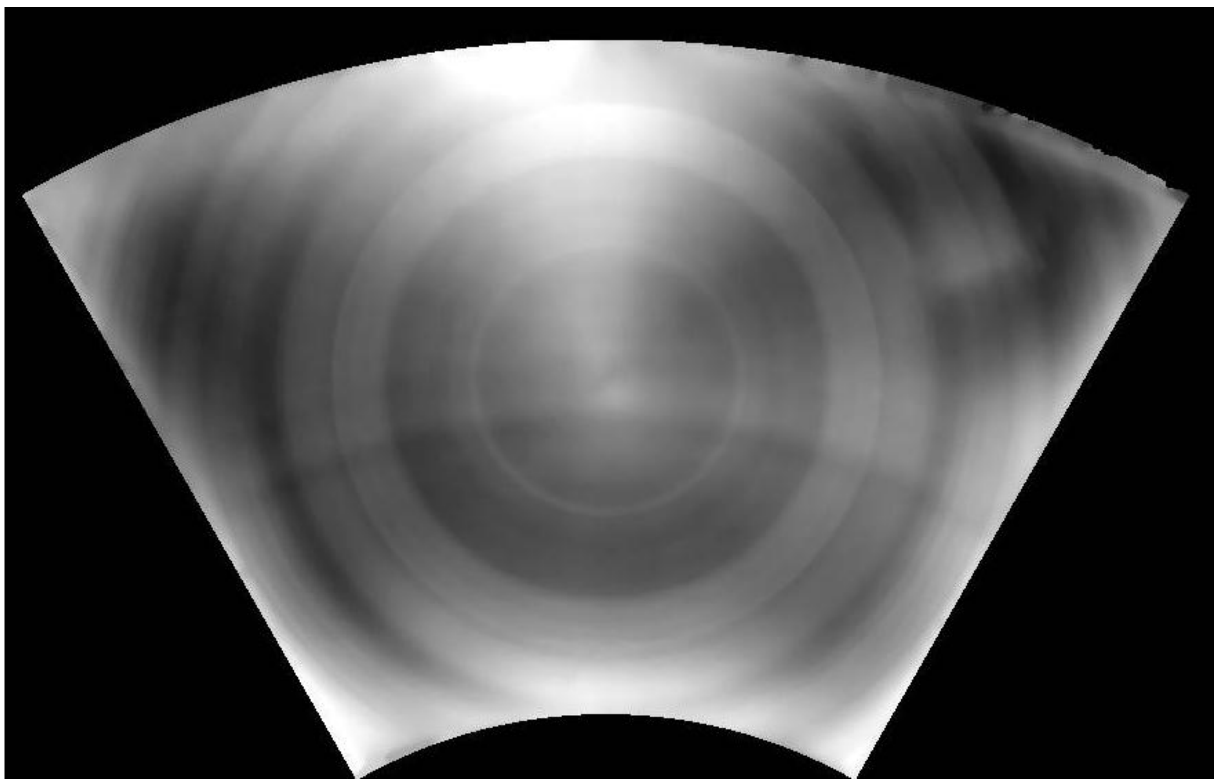


Error map after flash polishing
-1 um to 1 um

Processing time: 10 days
The time will be reduced to several days by optimization of grinding method already developed.

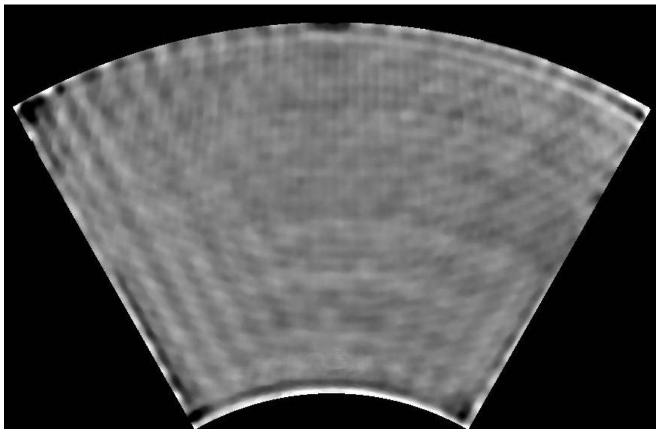
Result

- Smooth and centrosymmetric error.
- Some high frequency error

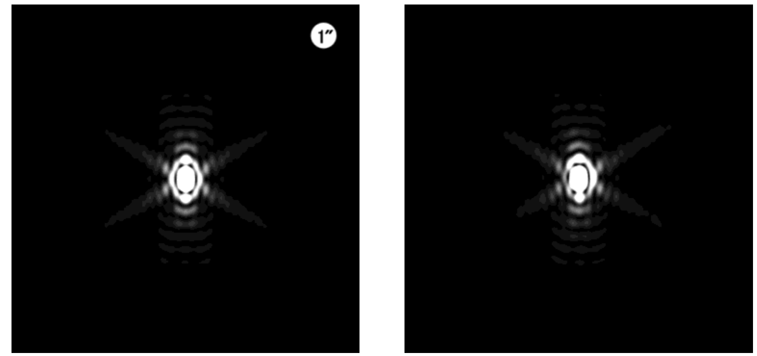


Polishing

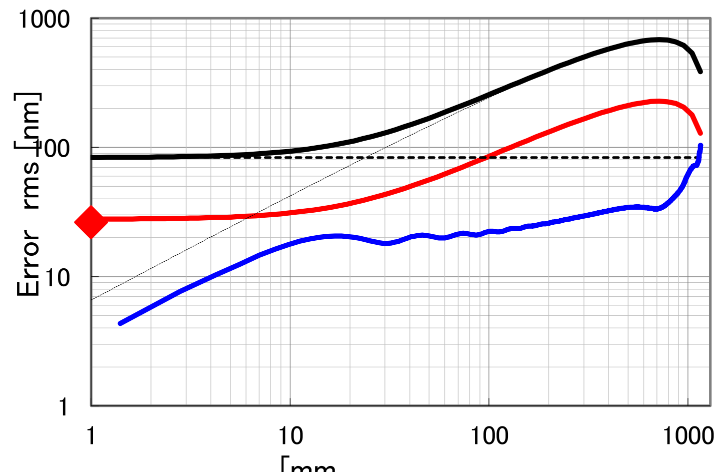
Polishing tools on the grinding machine



Error map after final polishing
-0.1 um to 0.1 um



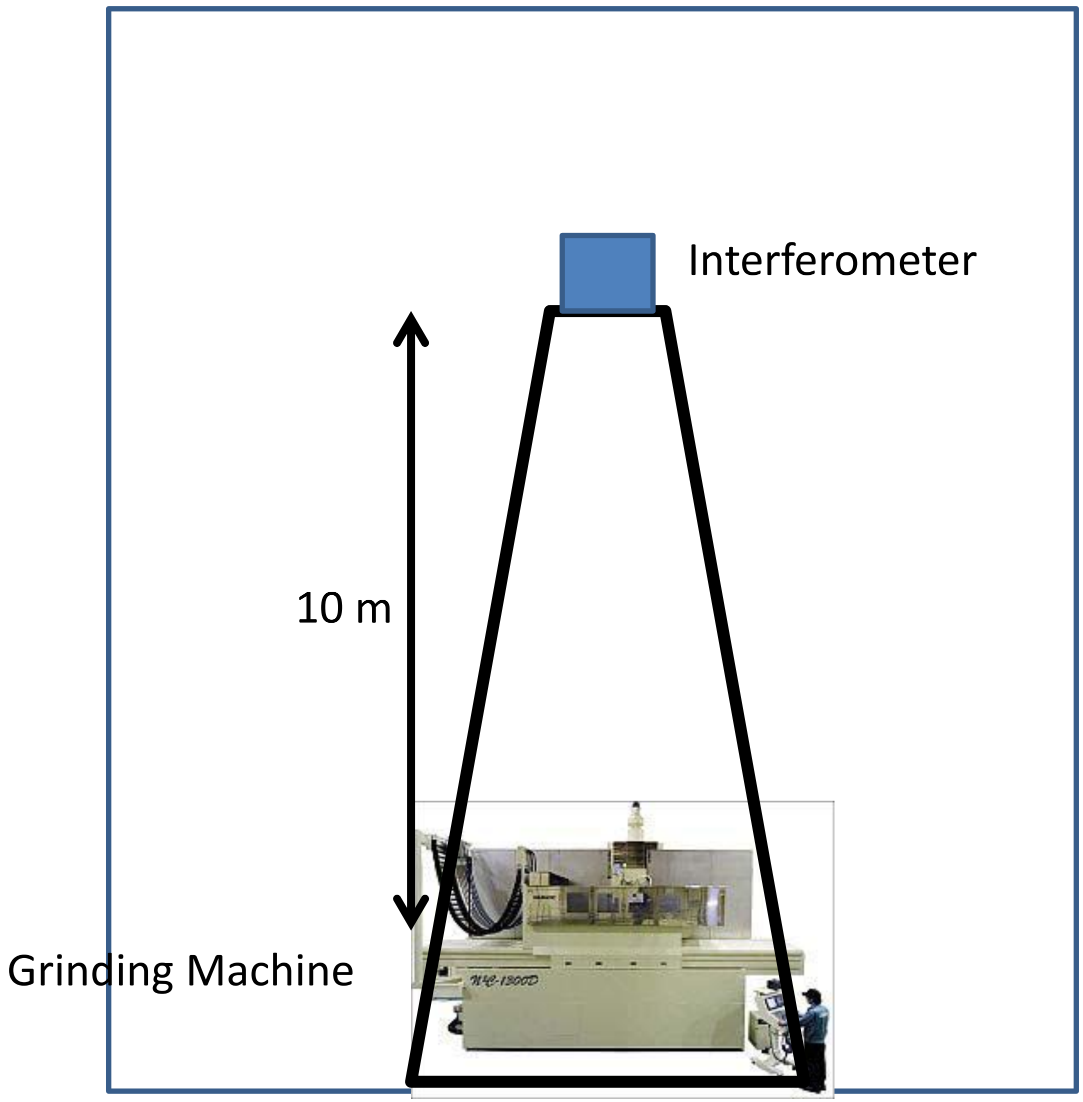
PSF(simulation)
Left: ideal, Right: this work



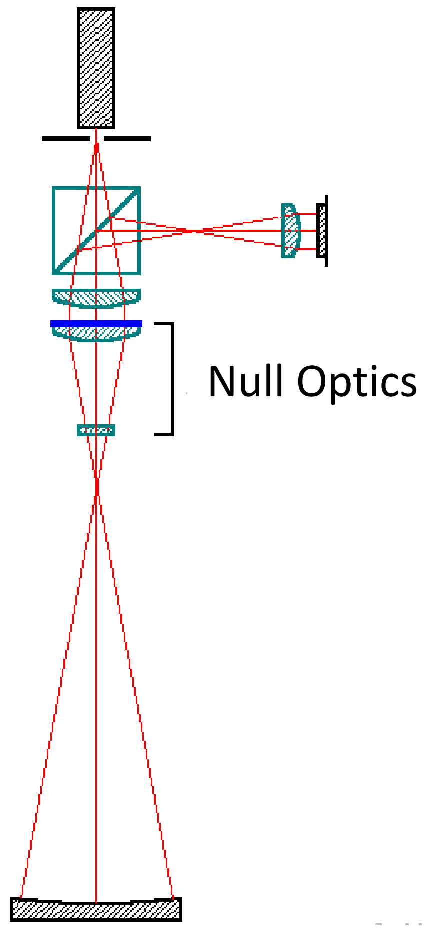
Structure function of the final result.
Red :requirement, Blue: this work

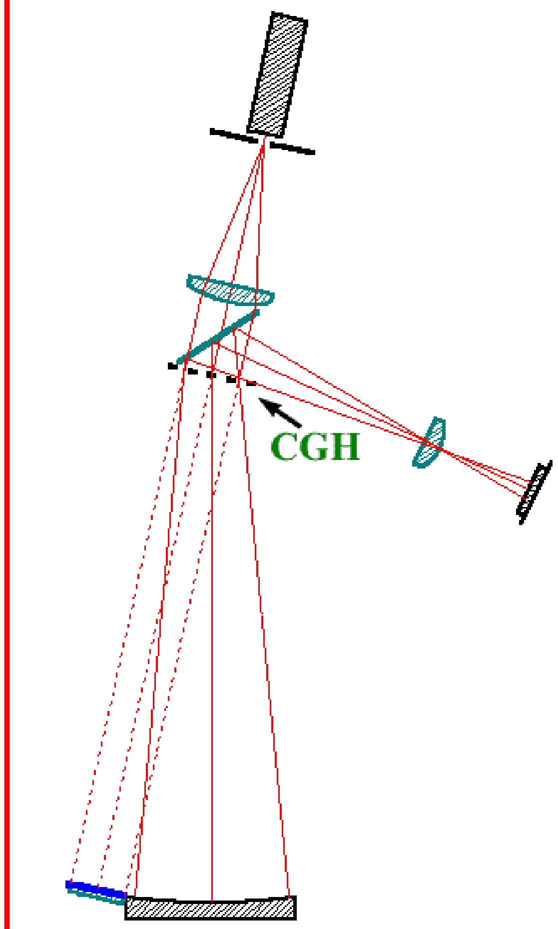
Measuerement

On the Machine Measurement System Interferometer

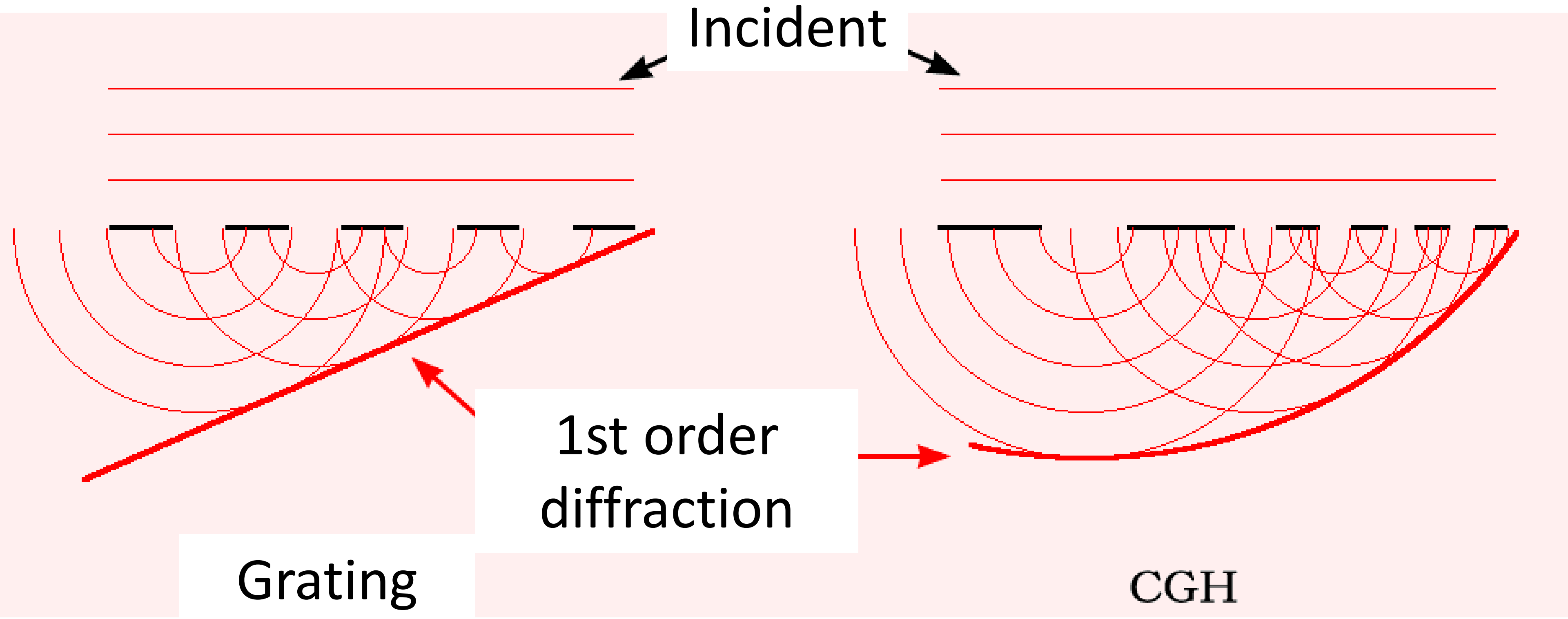


CGH Interferometer



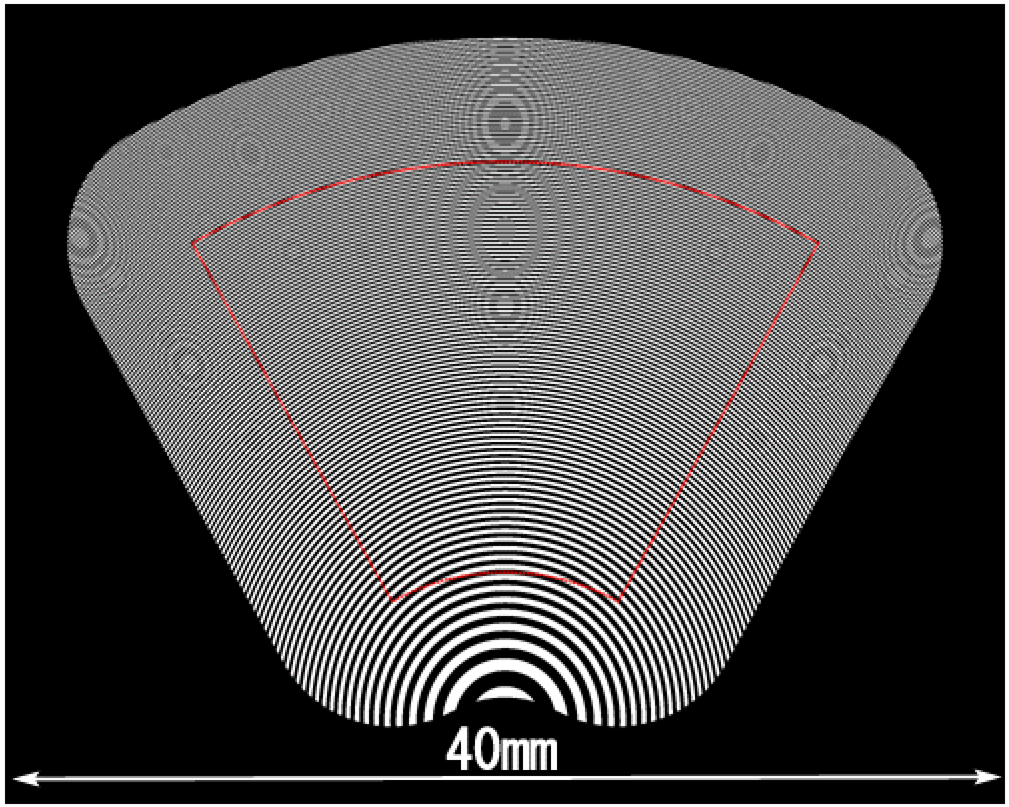


CGH
(Computer Generated Hologram)



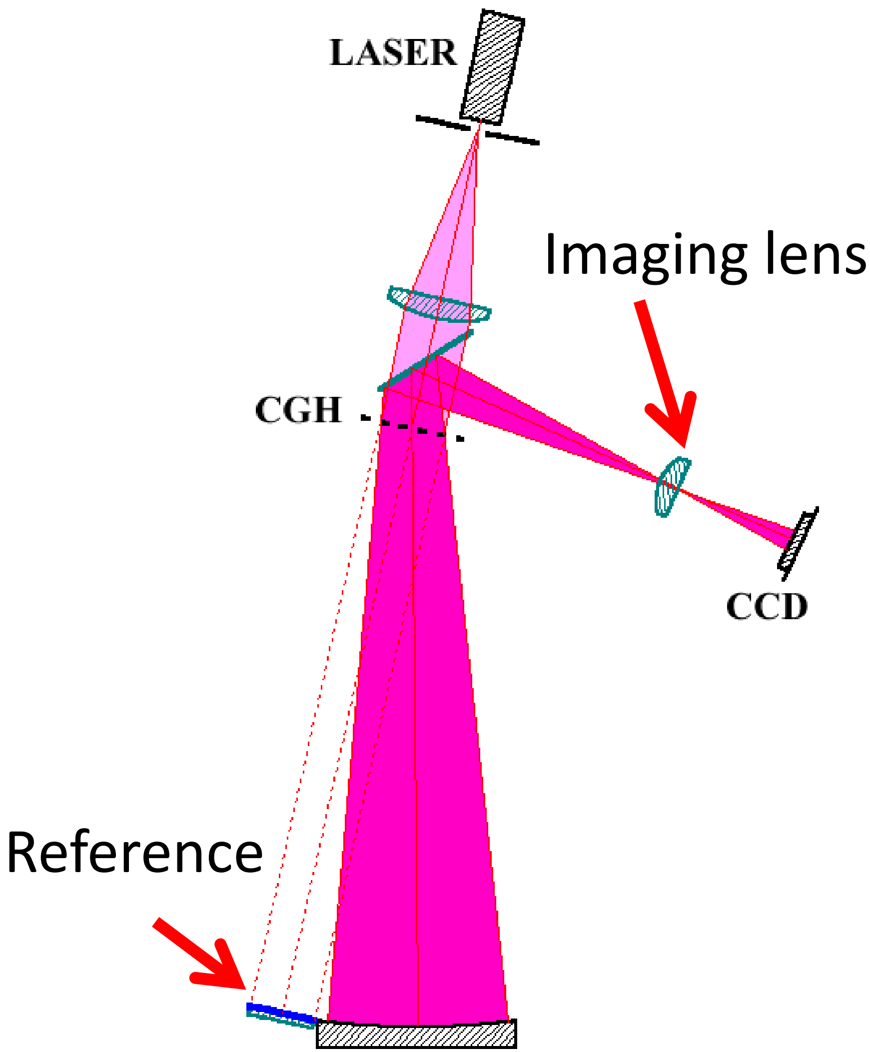
Designed grating pattern produces intentionally distorted wave front

CGH (Computer Generated Hologram)



CGH for the inner segment
Each line represents 30 lines
in the real pattern

CGH Interferometer



Reference beam

Goes through the CGH as 0^{th} order and back through as 1^{st} order

Test beam

Goes through the CGH as 1^{th} order and back through as 0^{st} order

- Semi common pass

→ Robust against turbulence and vibration

- 0^{th} order of reflected test beam

→Easy to design the imaging lens and to obtain high spatial resolution

On the Machine Measurement System
Probe Scan (under development)

Background

- Interferometer is weak in measuring convex surface
  - ex. Secondary mirror of Richey Cretien and some optical elements in instruments
- Grinding machine has very high precision.
  - More precise than any 3-D measurement system
- University of Arizona has developed mechanical profilometer.
- Three orthogonal axes measurement system by using the grinding machine is useful to produce free-form optics (ex. large off axis optics, image slicer, x-ray telescope optics)

Background
Swing Arm Profilometer

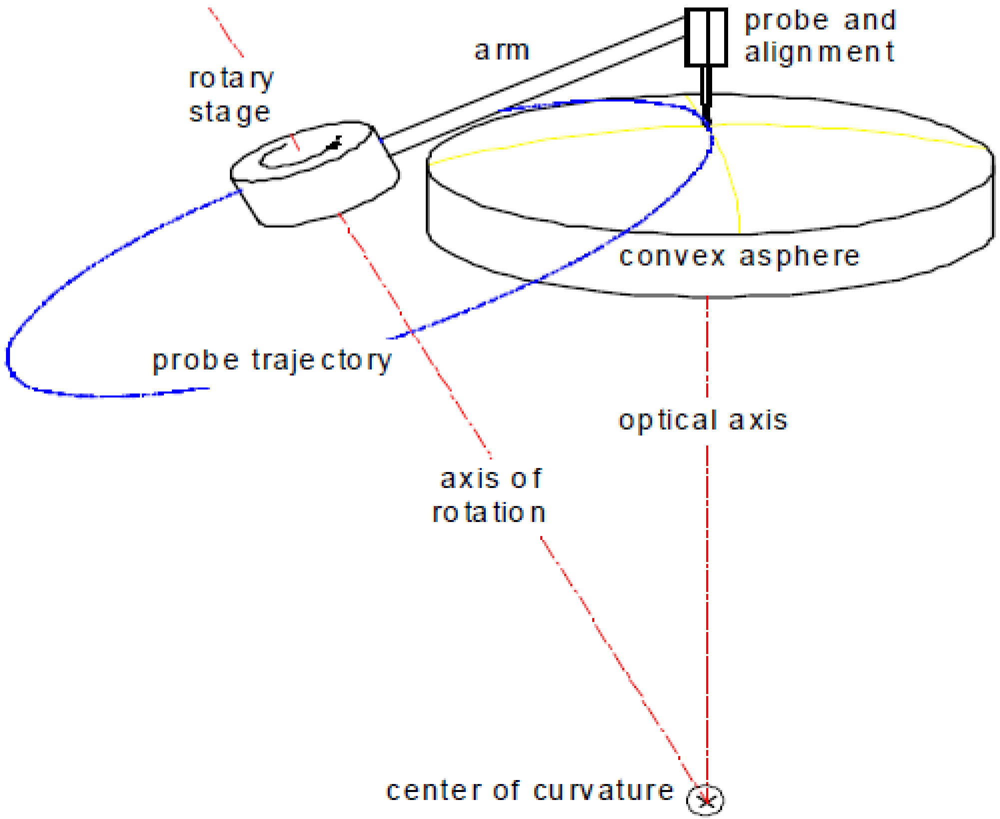


Fig. 1. Geometry of the swing-arm profilometer system

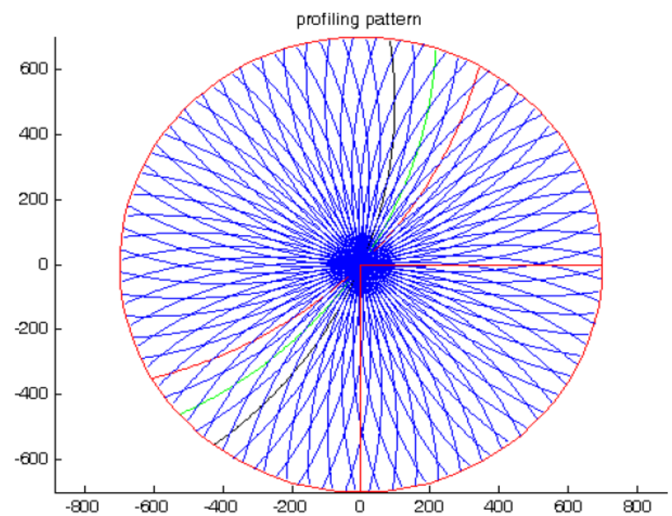


Fig. 3. SOC profiling pattern used for measuring the 1.4m convex asphere, coordinates units are mm

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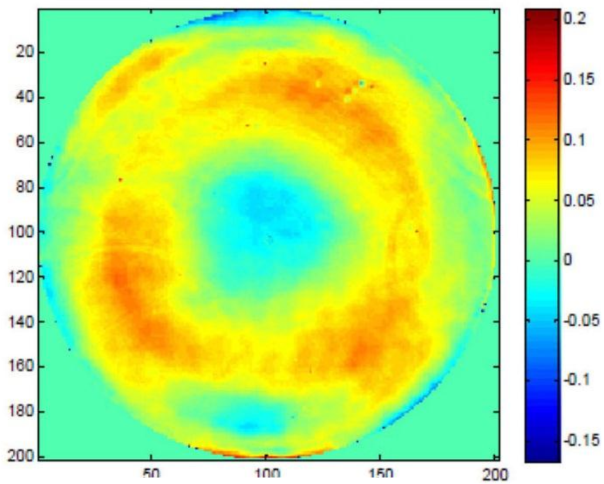
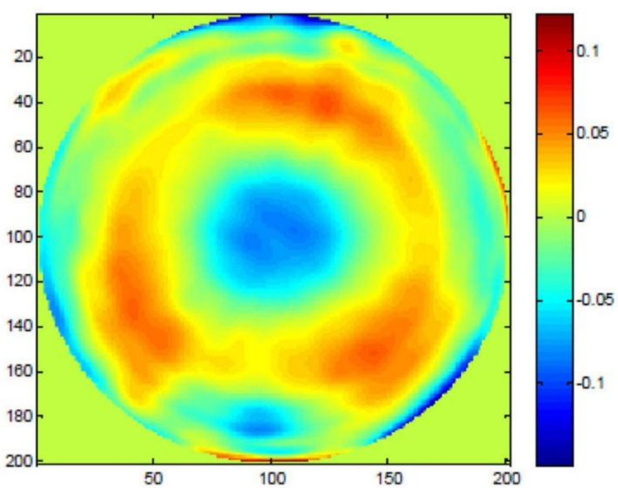
Background
Swing Arm Profilometer

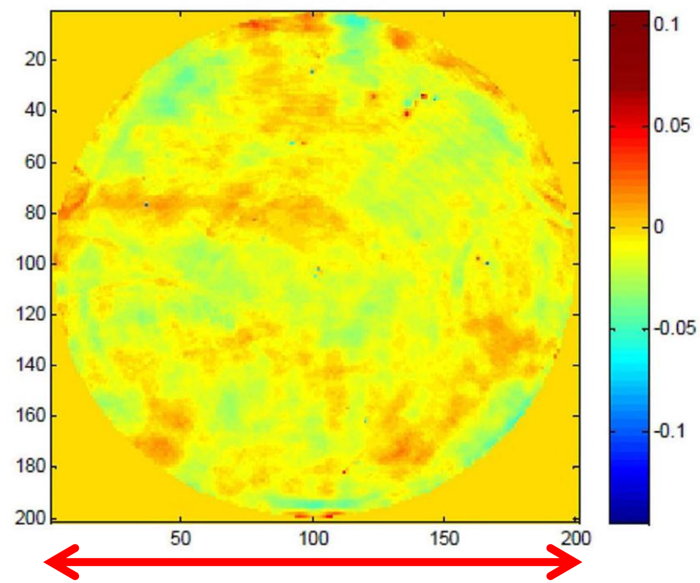
Fizeau RMS=35.7 nm



SOC RMS=35.6 nm



Difference RMS=9.4 nm

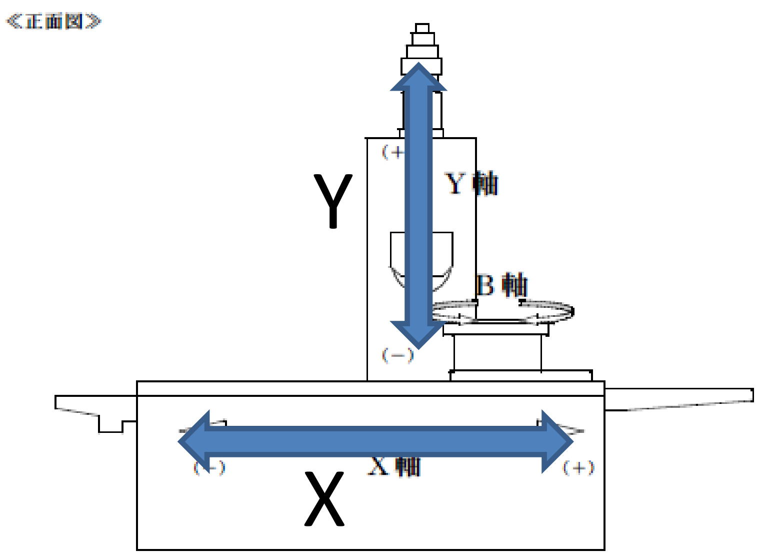


1.4 m

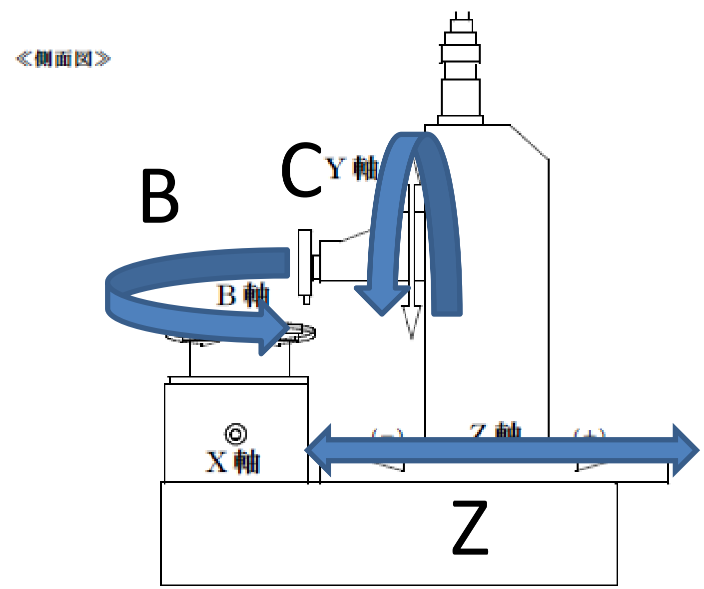
Tilt, Power, Coma, Astigmatism, and Trefoil Removed

Specification of the Grinding Machine

- 4 axes synchronous control (x, y, z, B- axis)
  - 5 axes in maximum (+ C -axis)



Front View

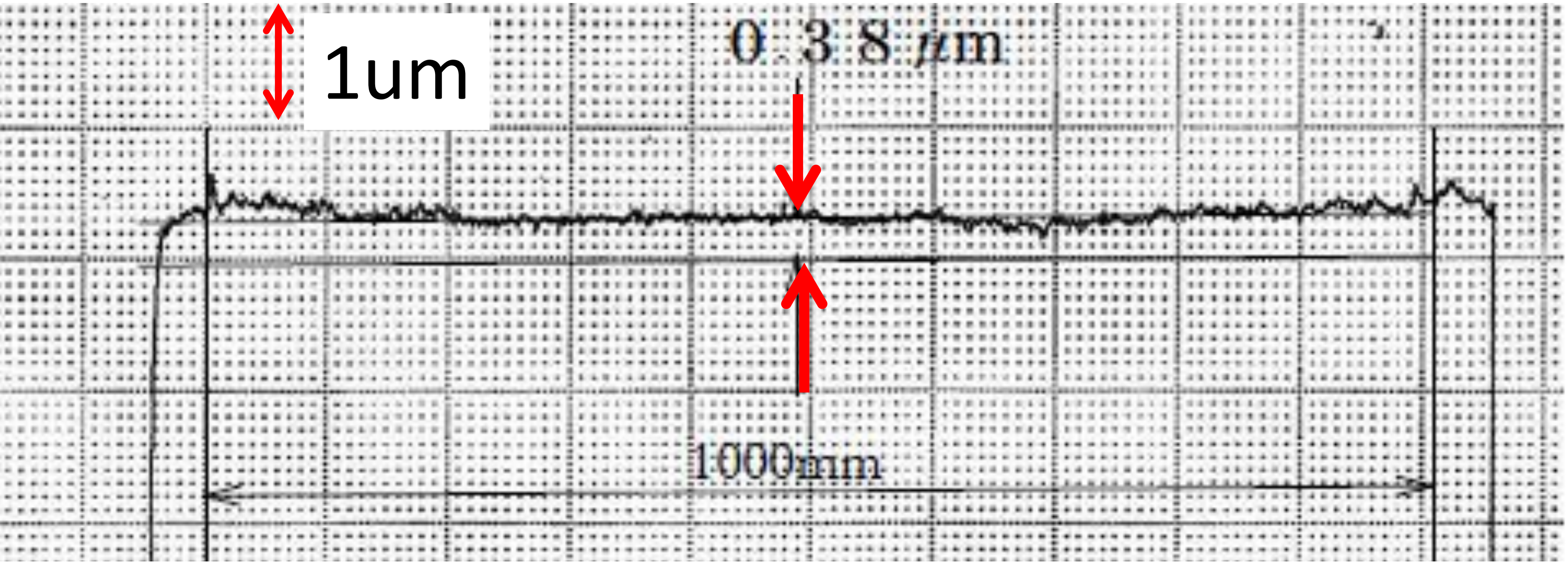


Sidet View

Specification of the Grinding Machine

- Work size ϕ１４OO （TMT segment size）
- Linearity（P-V） 0.38um/1000mm (x)
  0.32um/200mm (y)
  0.35um/1000mm(z)
  0.1um/rotation (B wobble)
- Positional Precision（P-V）
  0.40um/2250mm(x)
  0.17um/280mm(y)
  0.16um/1000mm(z)

Example
X linearity



Typically P-V = 0.1 um
the value includes the error of the gage

Specification of the Grinding Machine

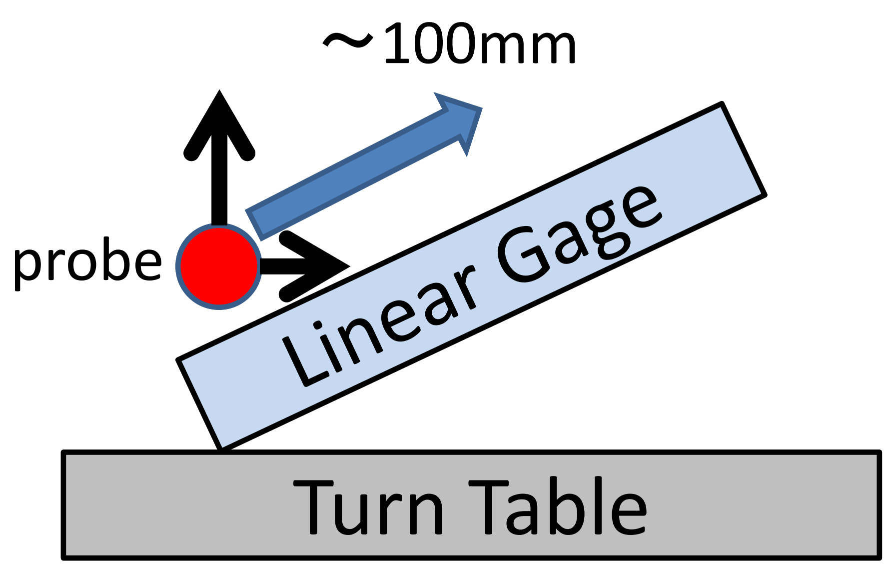
- B-axis

- Synchronous motion precision

X-Y　0.18um

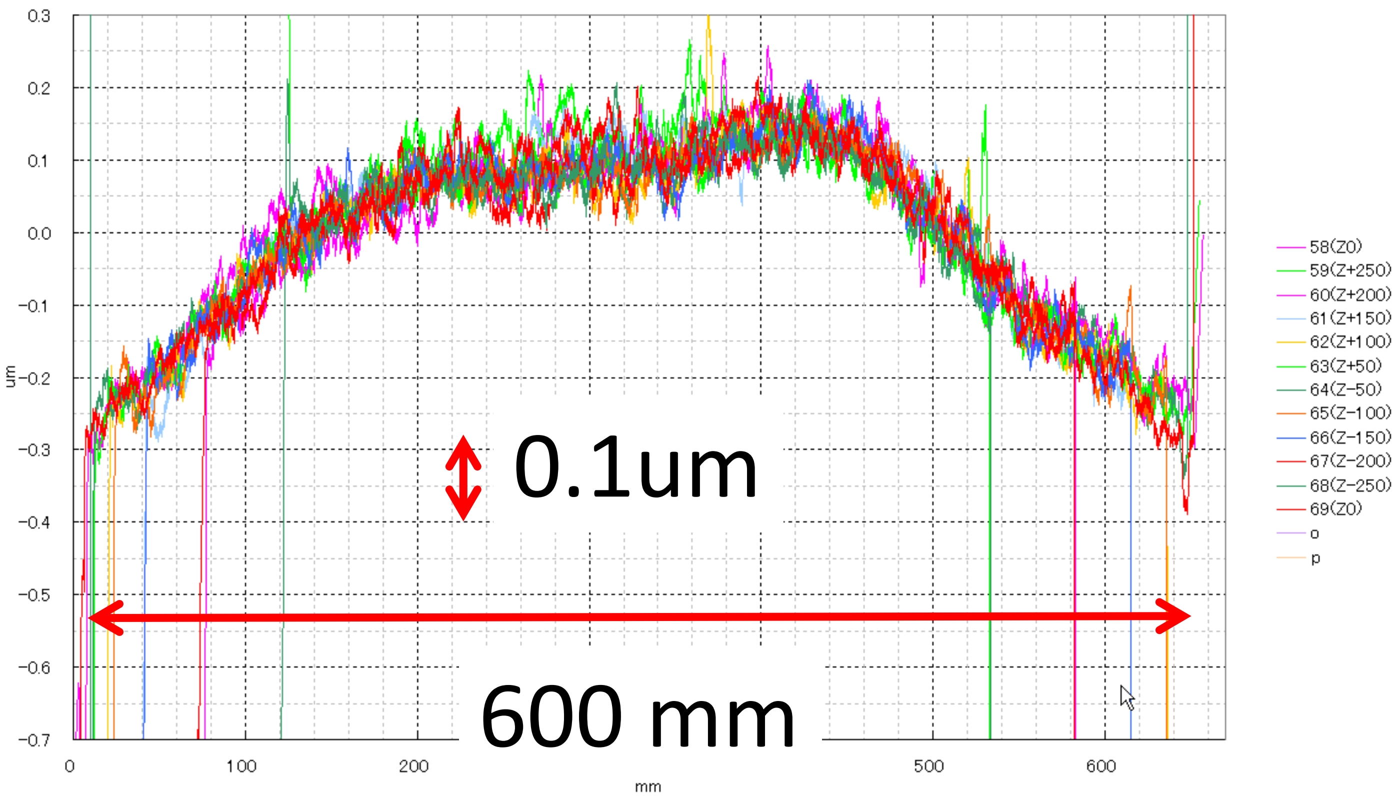
X-Z　0.15um

Y-Z　0.15um

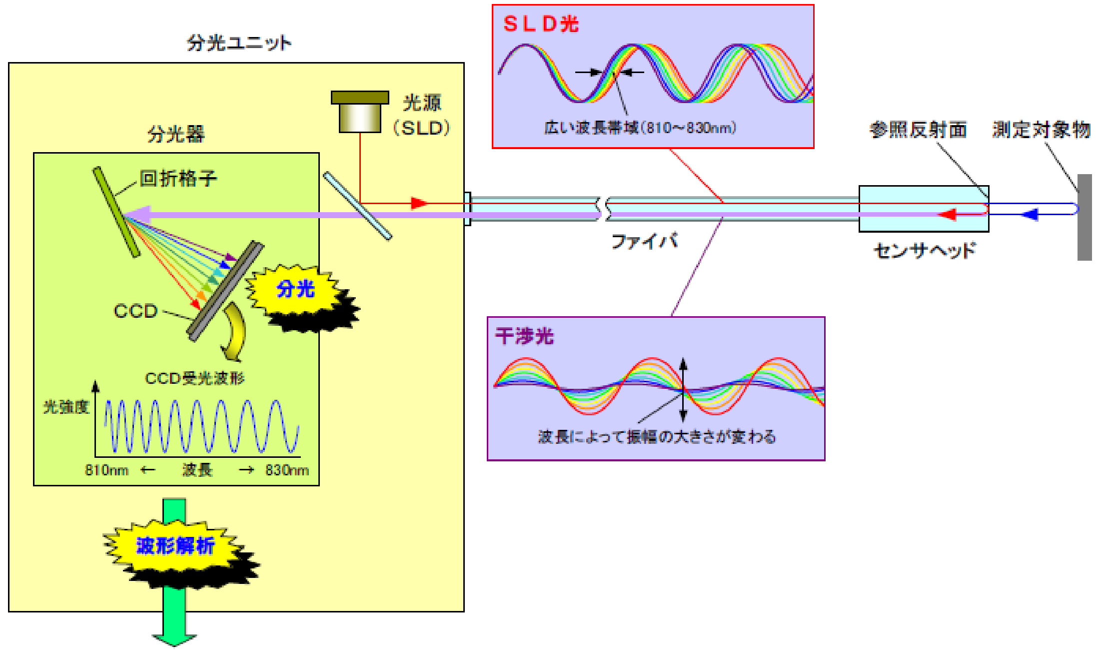


Specification of the Grinding Machine

- Rpeatability: P-V < 0.1 um



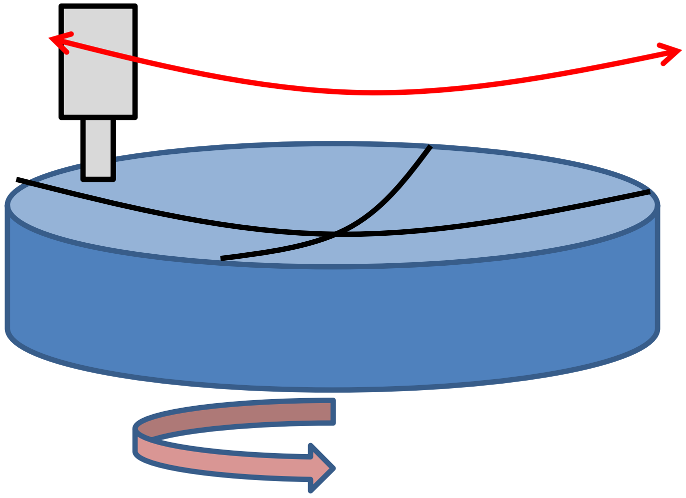
Measurement by the Grinding Machine with a Probe



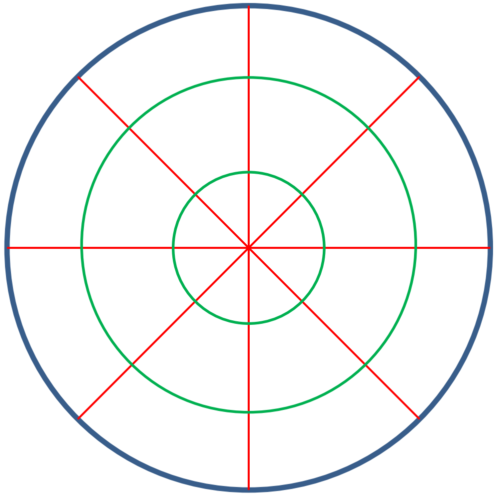
	This work	Arizona
Resolution (nm)	1	< 1
Dynamic Range (mm)	1	6
Angular Dynamic range (degree)	1.5 (7)	5

Preliminary Result

- Single probe
- Two axes synchronous control
- Measuring time : 1 hour



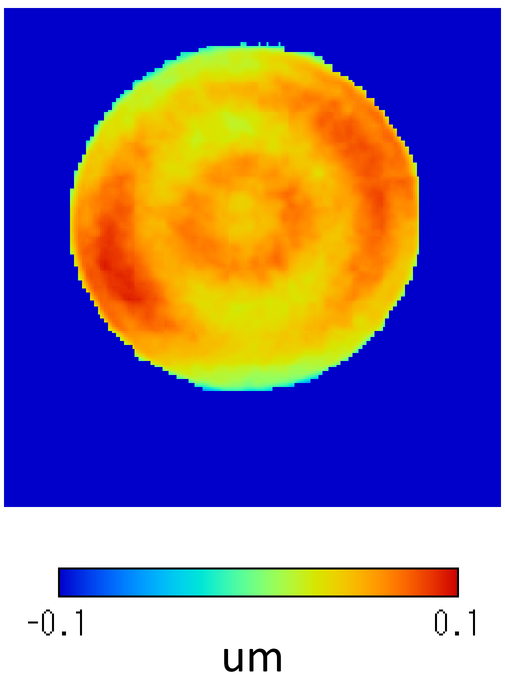
Spherical mirror
Φ150,R1600



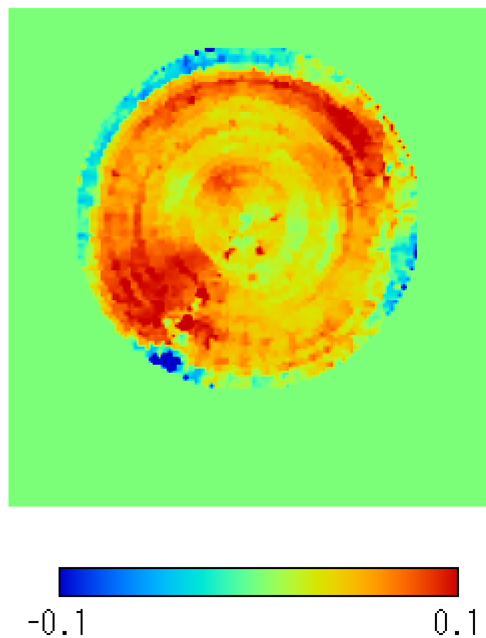
Scanning Path: 4 radial lines and 25 circles

Preliminary Result

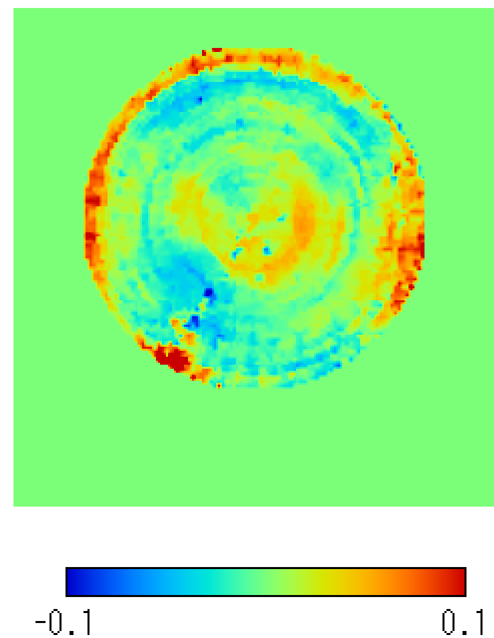
Fizeau
RMS = 15.3 nm



This work
RMS = 27.6 nm



Difference
RMS = 26 nm



With tilt and power removed

Future Work

- Algorithm (maximum likelihood at stitching points, interpolation for producing a continuous surface)
- Scanning path
- Multi probe system (three serial point method)
- Stability of the probes

Summary
Potential of the Facility

- Excellent grinding machine
  - Freeform
  - High precision
  - Large work size

- Measurement system
  - CGH interferometer for off-axis, aspheric, but concave optics
  - Mechanical probe has a potential for freeform optics