Join the OptiPro Revolution.

Developments in Non-Contact Metrology and Data Analytics

By: Greg Matthews

Outline

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- Metrology and manufacturing
- UltraSurf platform
- Data analysis software
- Second Star work
- Summary

SBIR Partners

OPTIPRO
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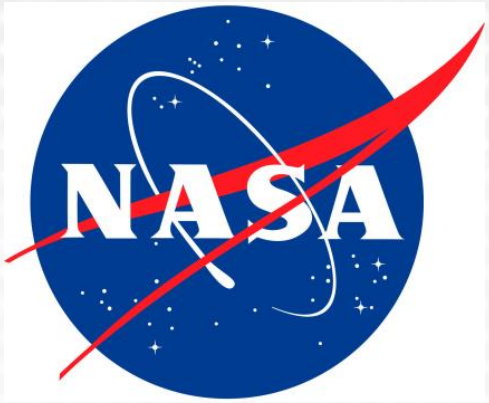

The manufacturing metrology loop

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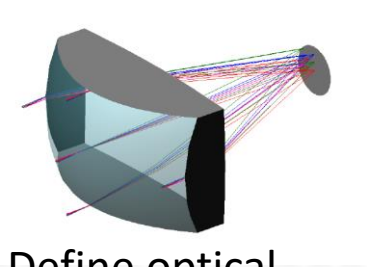
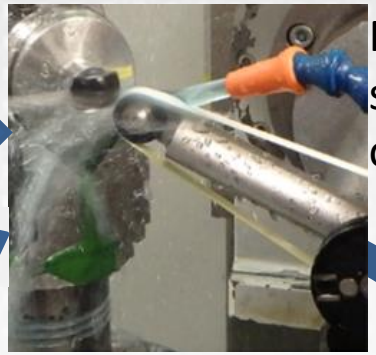
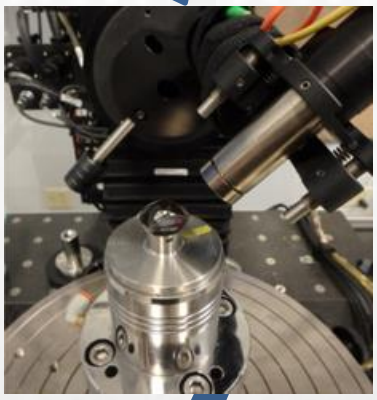


Define optical surface

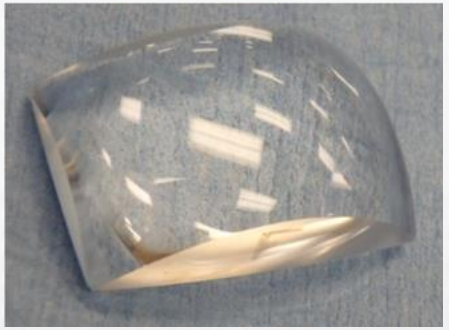


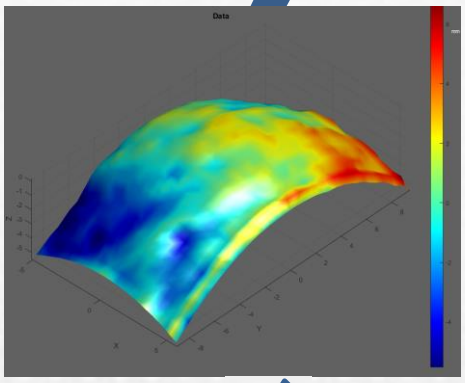
Process the surface in grinder or polisher

Measure the surface



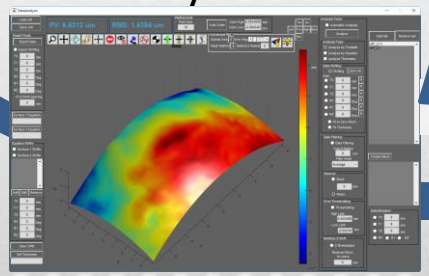
Finished surface





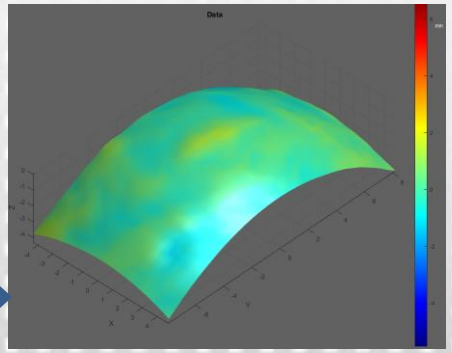
Use Error map to generate a toolpath for deterministic correction

Analyze Data



Surface doesn't meet specification

Surface meets specification



Metrology Options

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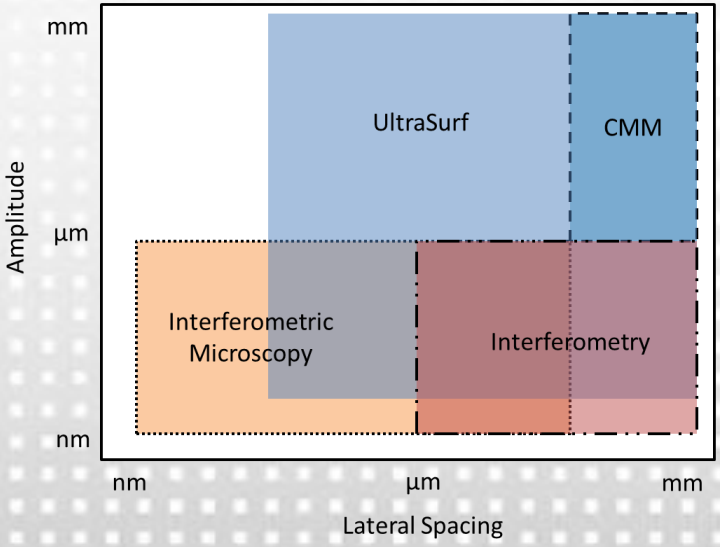
Interferometers and CGHs

UltraSurf

Profilometers

CMM



Interferometric microscope

UltraSurf Background

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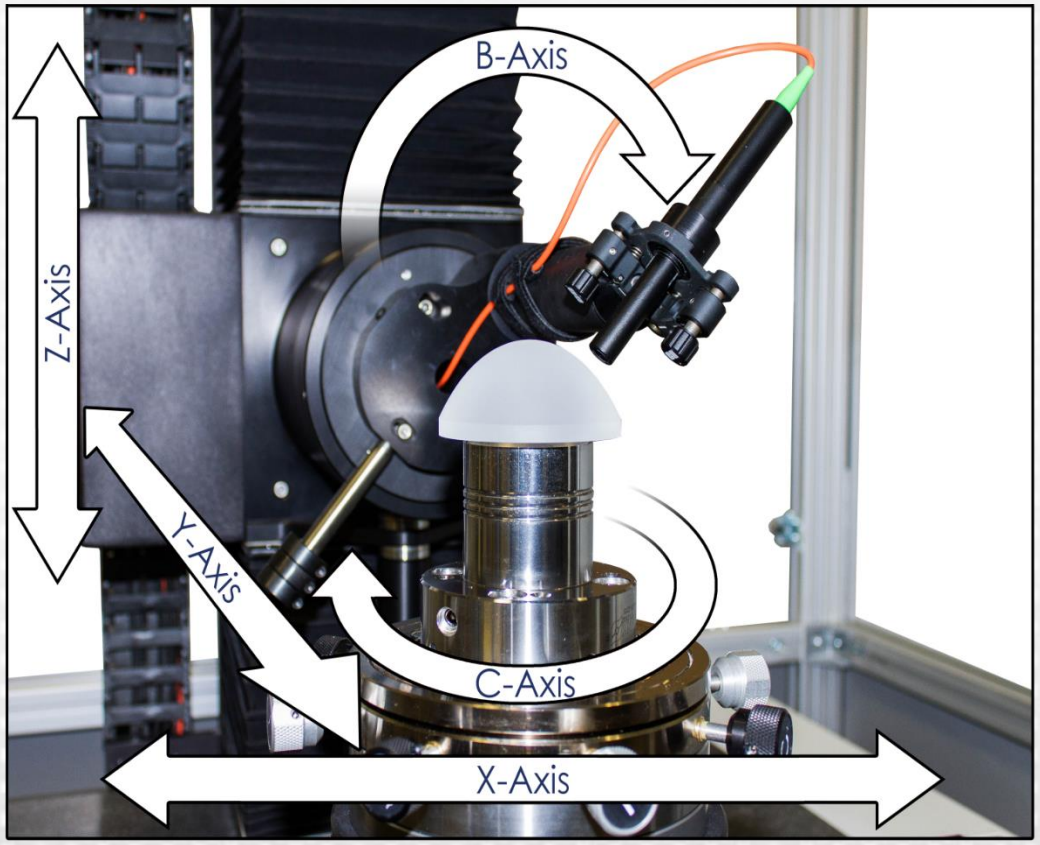

- 4 or 5-Axis Non-Contact Measuring System
- Scans With Various Non-Contact Probes
- Precision air bearings
- X,Y,C move the part
- Y is fixed in 4 axis platform
- Z,B move the probe
- C is rotation around Z-axis
- B is rotation around Y-axis

*Typical measurement accuracy is currently +/- 150 nm in the working volume

Measurement Method

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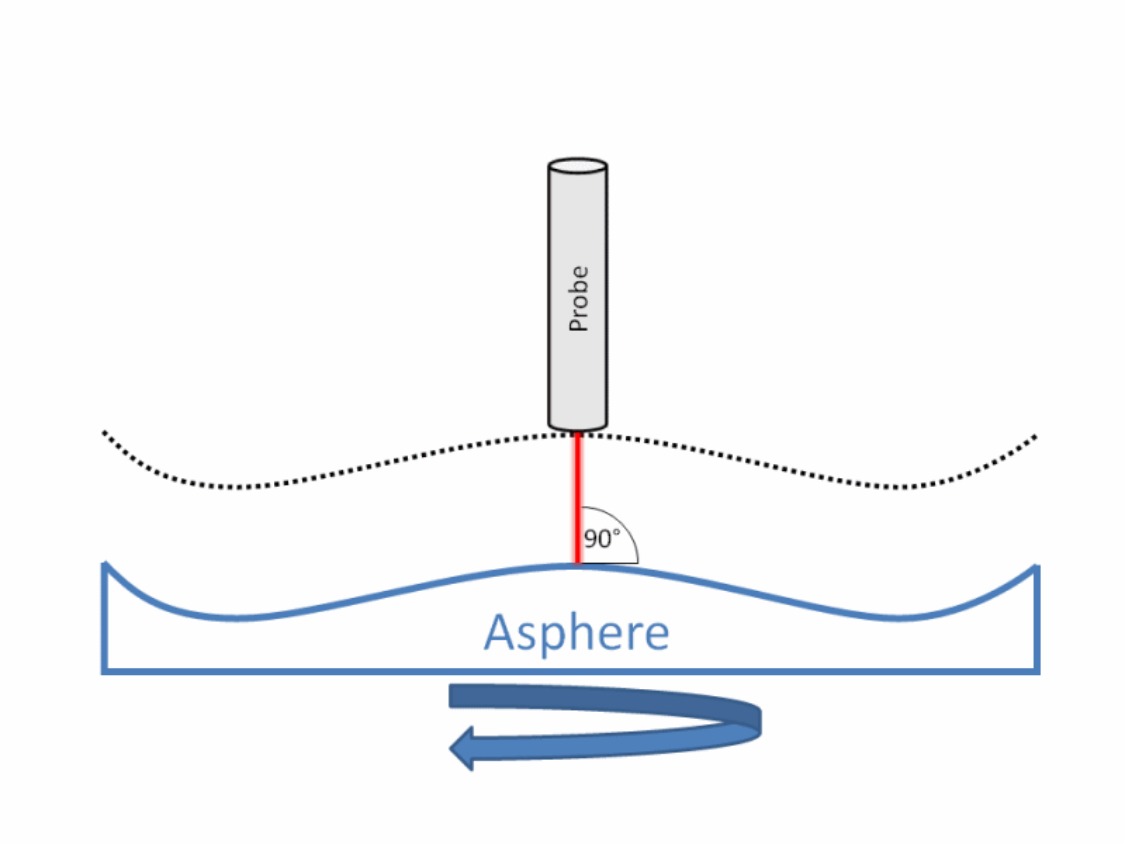
The UltraSurf uses its 5 axis to keep the probe normal to surface as it measures freeforms, acylinders and aspheres.



Multiple Probes for different applications

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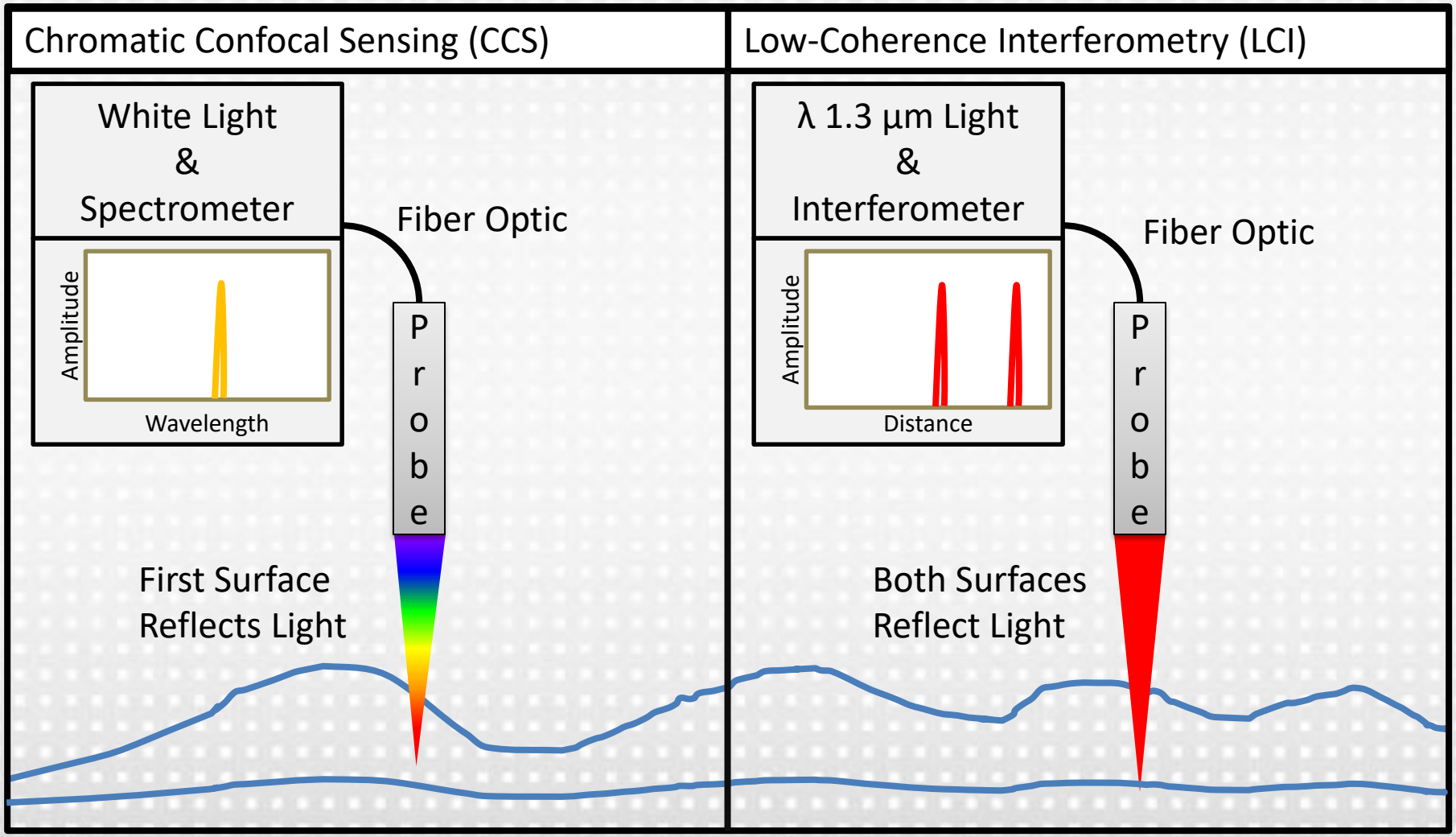
Higher accuracy

Multiple surfaces



1-10 µm Lateral and 10 nm Vertical resolution

30-200 µm Lateral and 30 nm Vertical resolution

High Speed Data Collection

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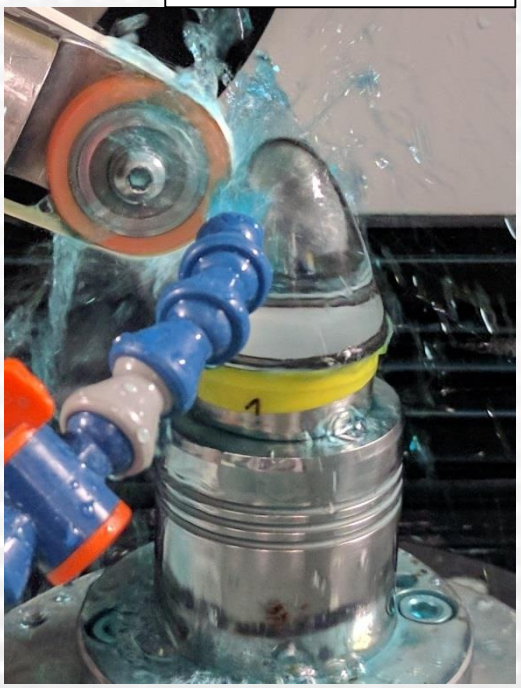
- Developed new data collection code, high speed buffering, multi-axis synchronization and tuning
- Previous measurement rate is 50 Hz (Points Per Second)
- New measurement rate is 1000 Hz (Points Per Second)
- Asphere Example
  - 50 mm Diameter
  - 40 mm sag
  - Full 3D map
  - 200 micron lateral resolution
  - 240,000 data points
- 50 Hz
  - 45 minutes
- 1000 Hz
  - 5 minutes

50 mm Asphere



- <u>The high-speed method enables effective scanning of diffractive optics in 3D</u>

High Speed Data Collection

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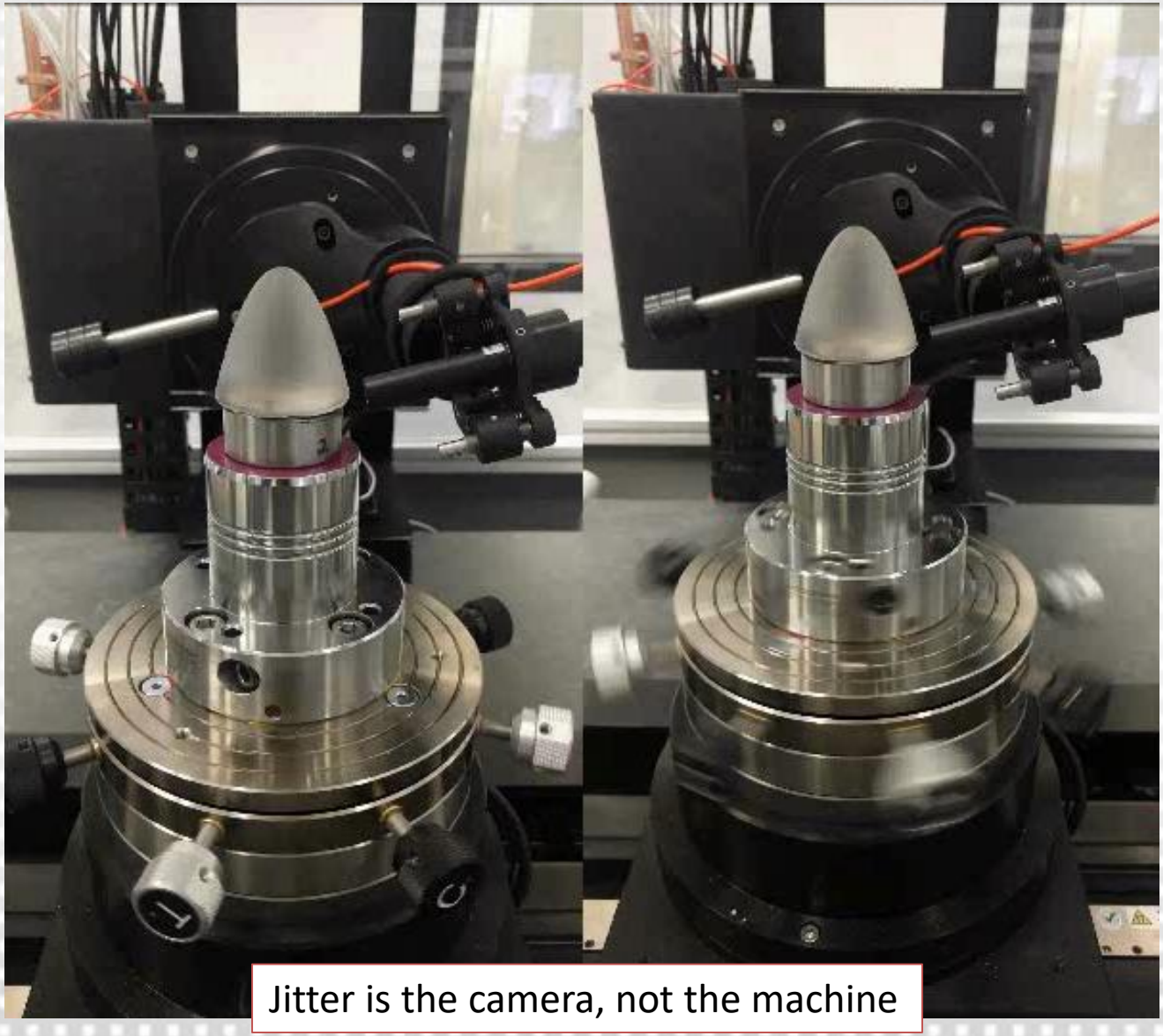

Jitter is the camera, not the machine

Thermal compensation

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- In order to improve accuracy with longer measurement cycles we are adding thermal sensors to UltraSurf platform.
- Actively monitor temperature changes.
- Create dynamic compensation tables to adjust to temperature fluctuations in the environment.
- Ongoing work.

Traditional methods

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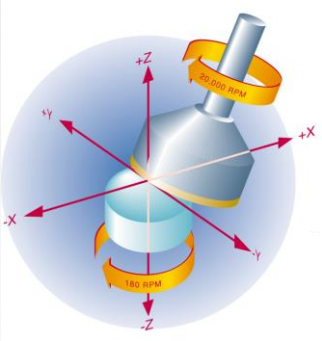

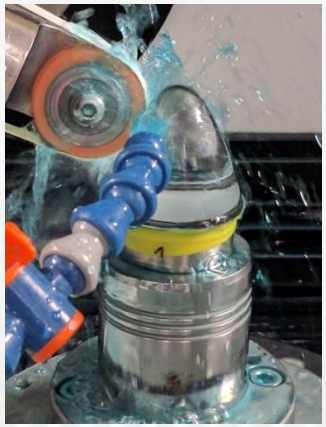

- Rotational symmetric optics are processed on axis
- This allows for the assumption that any measured shifts in X axis, Y axis, or Rotations about X axis, or Y axis are due to measurement setup error.
- This error is normally fit out during the manufacturing process.
- In order to locate the top and bottom optical surfaces to each other a centering step is used.
- Center thickness is the metric that is used to control the thickness of the optic so during processing the center of the surface is used to control the optics location along the Z axis.

Freeform methods

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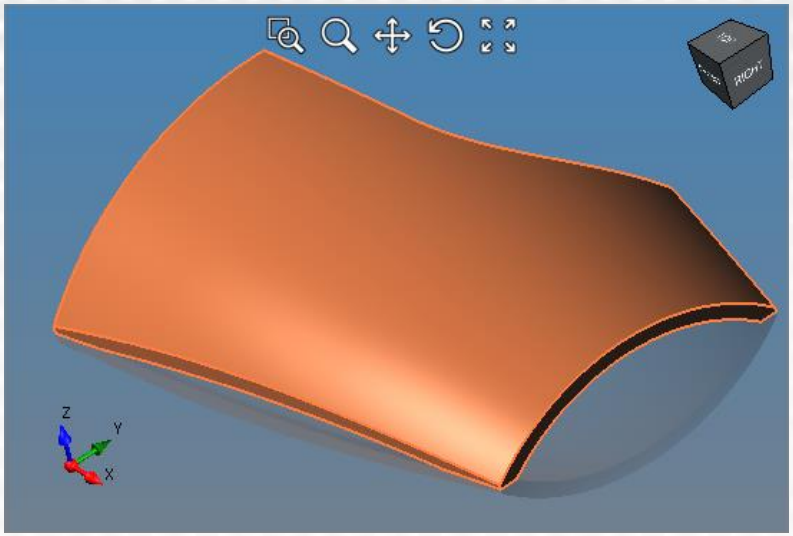
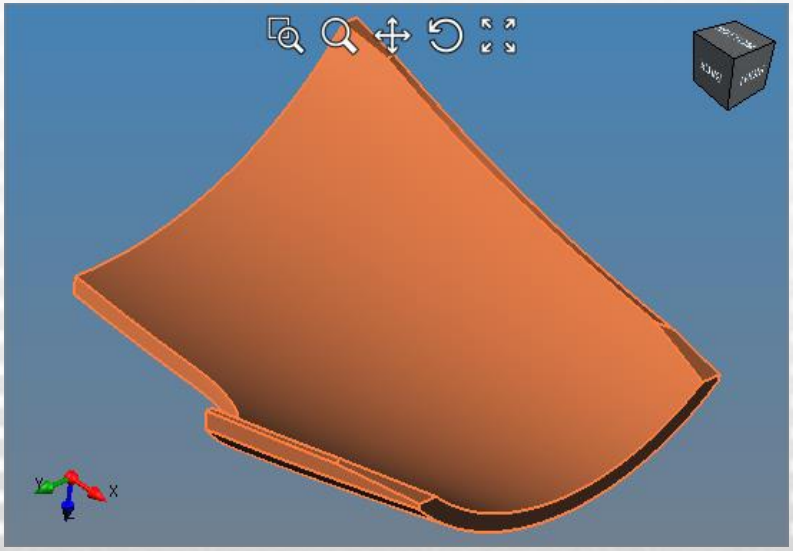
- A Freeform surface may not be generated about a rotational axis.
- It is no longer a good assumption to say that error that is traditionally fit out is only due to measurement setup.
- Unconventional edges can make centering no longer an option.
- Since there is no longer necessarily a “center” tolerancing center thickness is no longer appropriate.
- Surface error may now include wedge, thickness error, positional error.
- Metrology setup up may not be the same as processing setup.





Freeform methods

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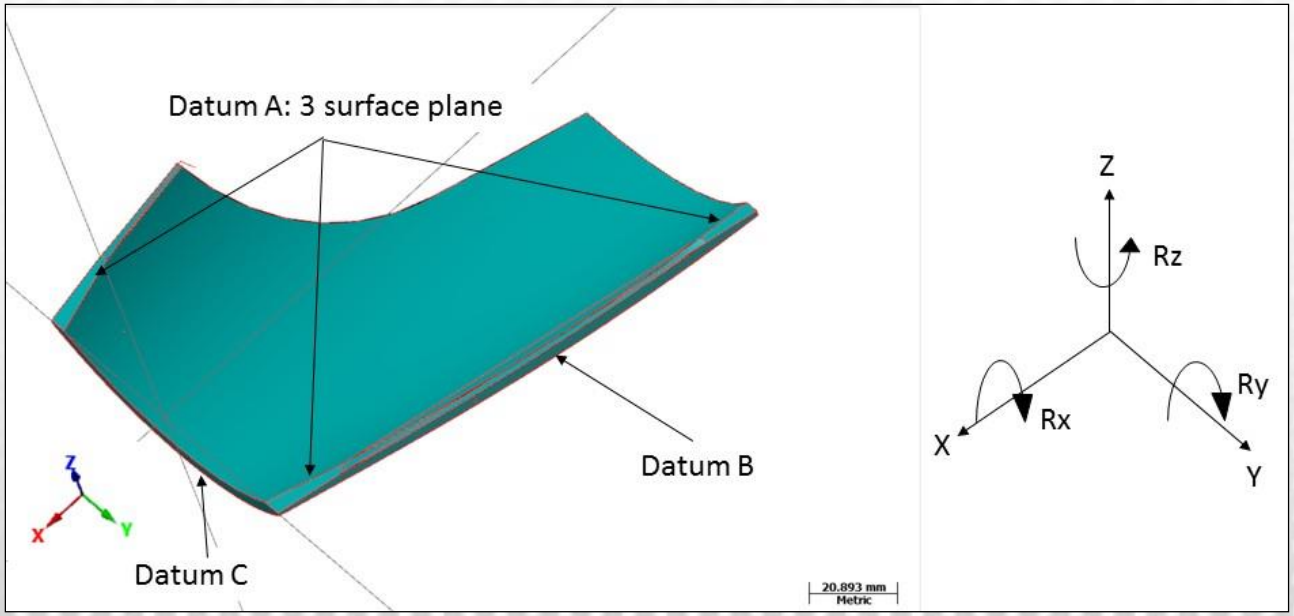
- In order to handle these challenges we need a way to locate the absolute position of these surfaces in space.
- We accomplish this by establishing a reference frame using datums.
- The combination of datums should create an orthogonal coordinate system
- These datums need to be able to be repeatably measured an establish the same reference frame
- This reference frame will be used to locate the surfaces absolutely throughout all stages of processing



Importance of repeatability

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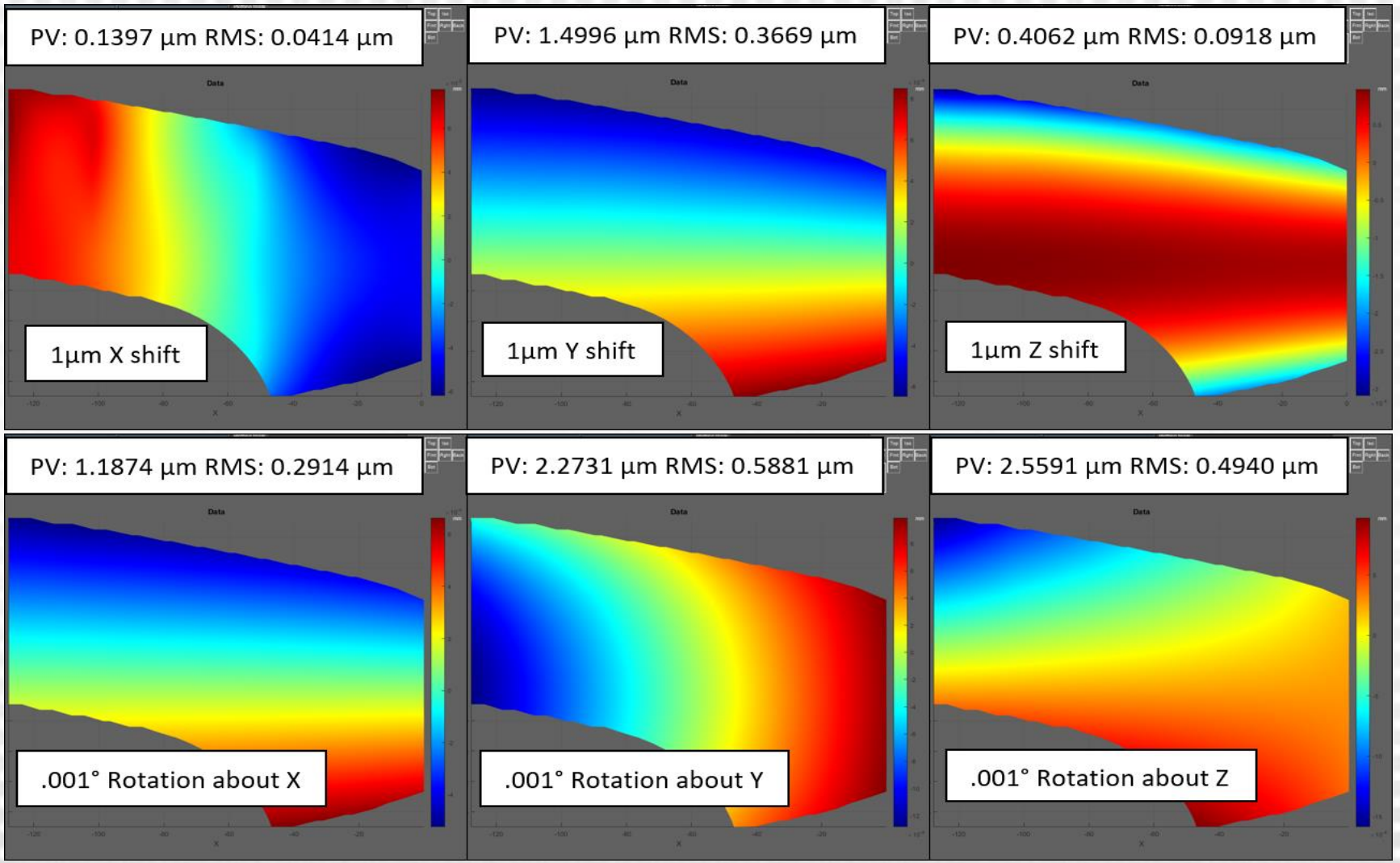

Zeroed data shifted in linear and rotational directions to see the influence on form error

UltraSurf capabilities

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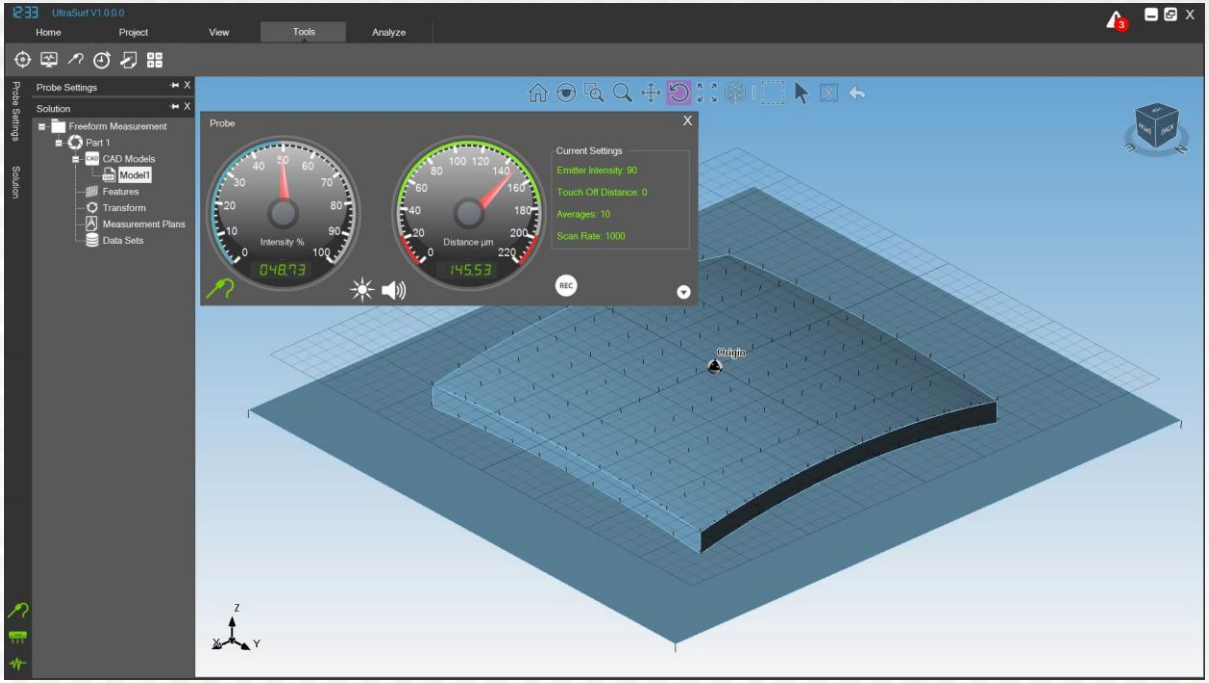
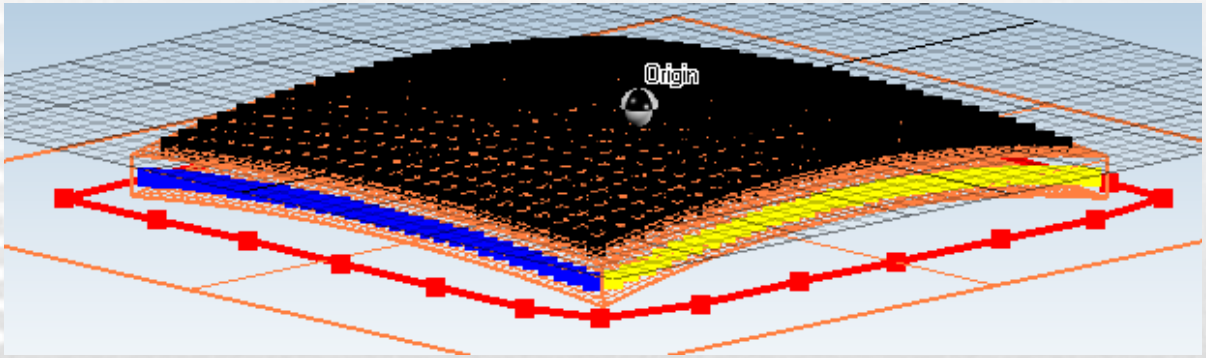
- 5-axis system allows for the simultaneous measurement of datums and the surface
- New software will allow you to build a measurement plan that includes multiple surfaces and datum features.
- This will allow us to separate measurement setup error from surface error that needs to be corrected.
- New software will allow for multiple input formats
- Will run both on machine and offline





Data Analysis Tool

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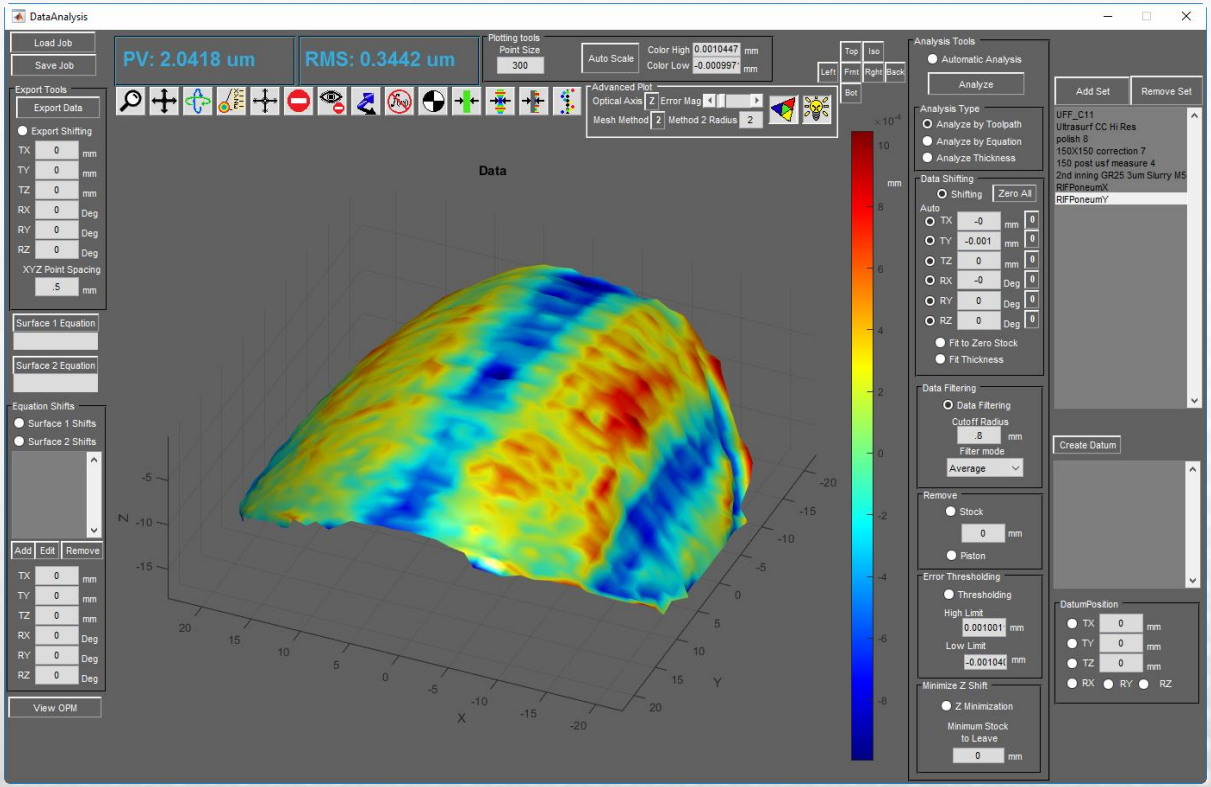
- Collecting the data is only half of the battle
- OptiPro has been developing an Analysis tool to help overcome some of the challenges associated with some of the more extreme optics.
- Graphical user interface
- Can handle multiple inputs from different instruments.
- Offers unique methods for handling 3D data set.



Fitting traditional optics

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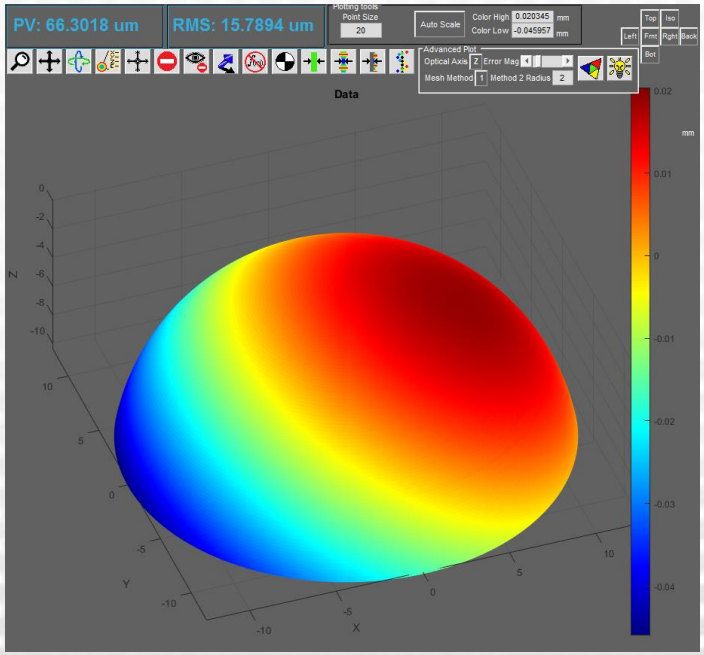
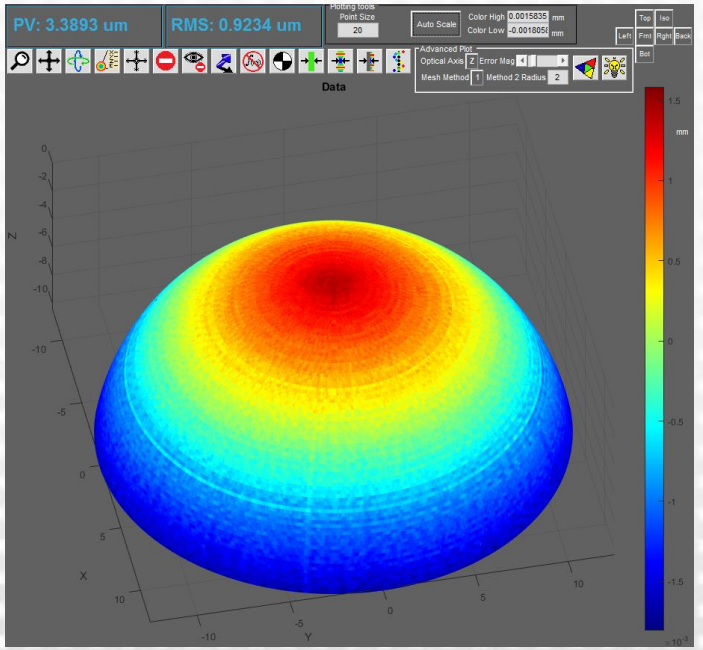
- With the part being processed on center it is safe to assume that decenter and tilt are artifacts of the setup



Measurement setup error removed



Fitting freeforms

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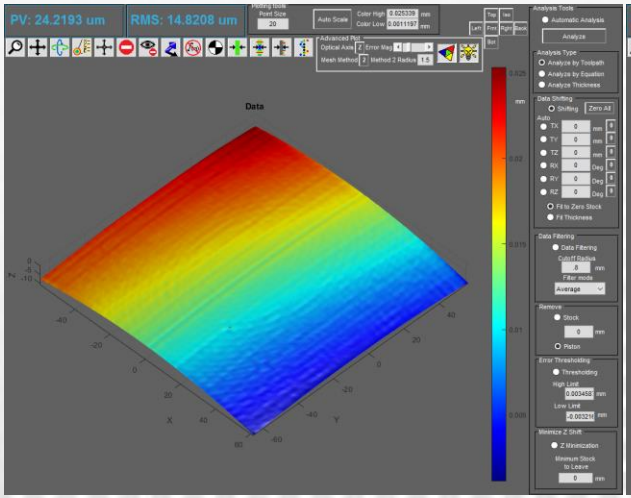
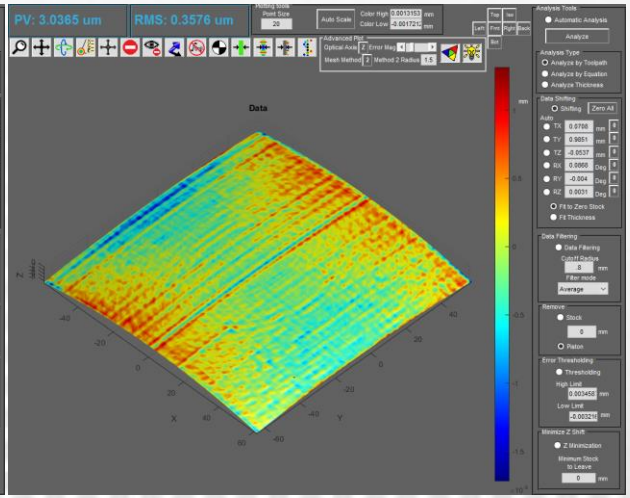
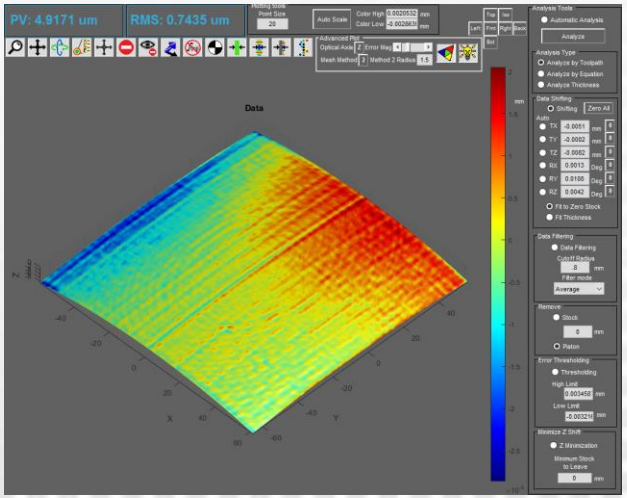
- Since freeform surfaces need absolute positioning the same assumptions can not be made as with rotationally symmetric optics.
- By using the UltraSurf to measure the datums along with the surface and then using our data analysis tool to remove setup error we are able to see the true surface error.
- This is critical to manufacturing because it is an iterative process and the correct error needs to be targeted for the part to converge
- For final metrology fitting all degrees of freedom may be acceptable if the shifts fall within the print tolerances so the tool always displays the data shifts.



Raw measurement with no fitting.



Best fit data assuming all positional error is from setup.



Actual surface form error to the datum reference frame

Data Compression

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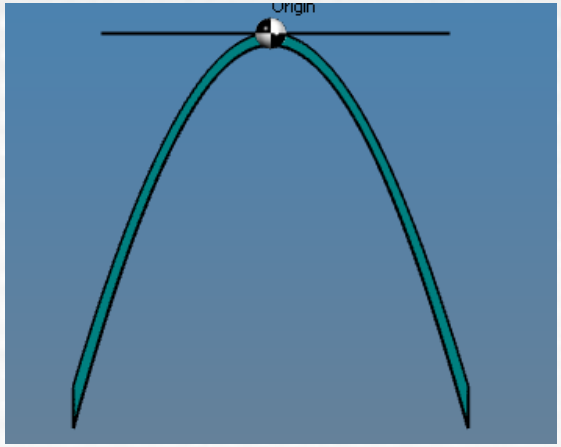
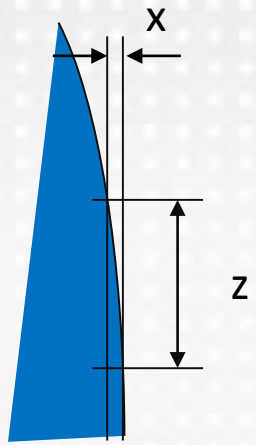
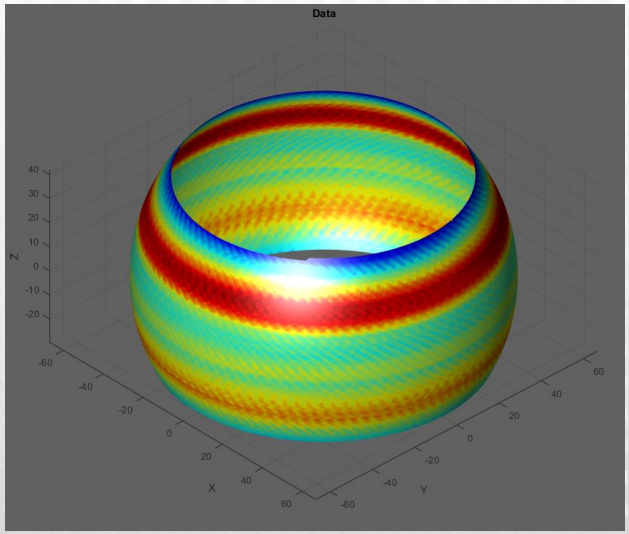
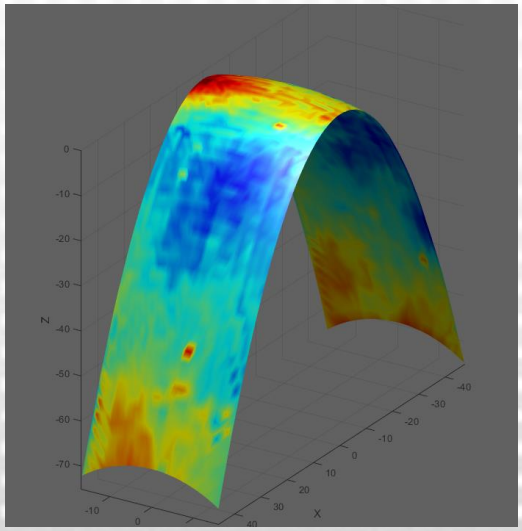
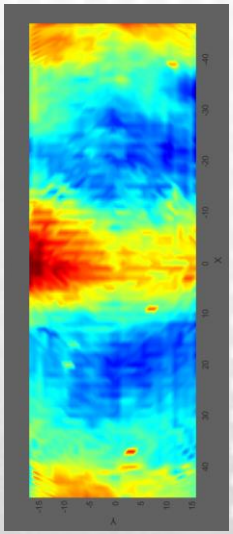
- Traditional data analysis techniques often project the data into a 2 dimensional plane.
- This poses an issue as parts get steeper in the compressed dimension.
- Compression losses can result in an inability to correct higher order error
- Parts like the hyper hemi shown below can't be easily compressed into a plane then mapped back
- Our analysis package aims to handle and export the data without any compression











Filtering

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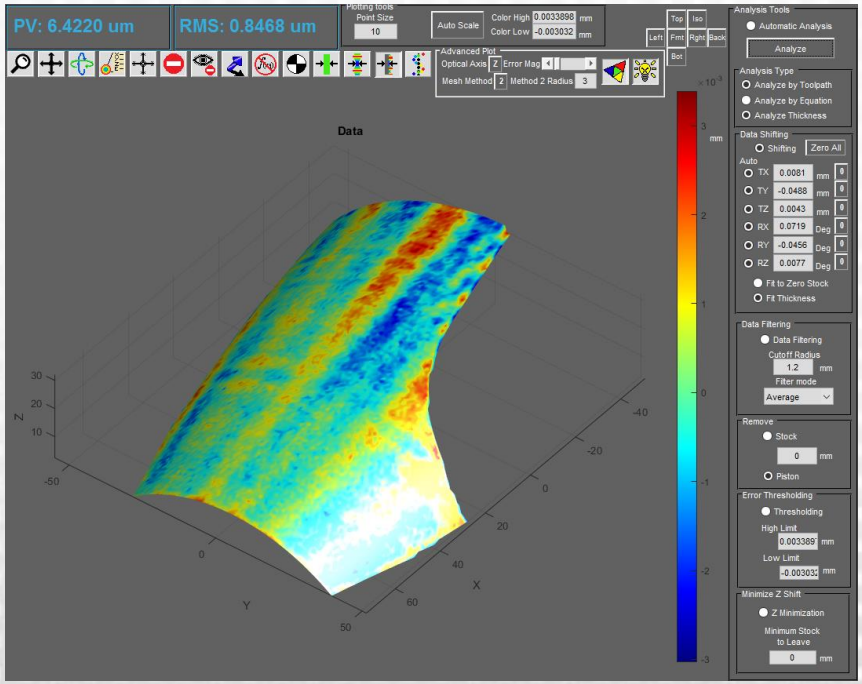
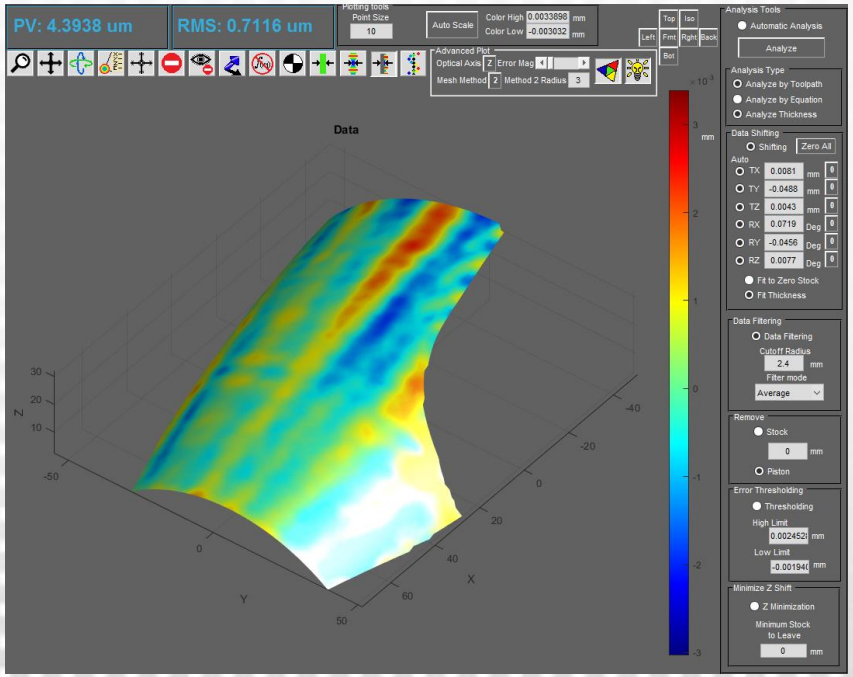
- Filtering can remove high order residual error from the data set.
- Filtering is also necessary to condition the data for manufacturing.
- New filter methods are being written to handle data that hasn't been compressed into a plane.
- Now need to handle X, Y, Z locations and filter error.



Raw data

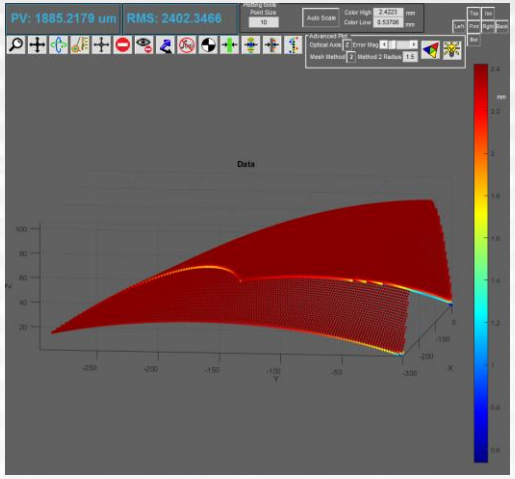


Filtered data

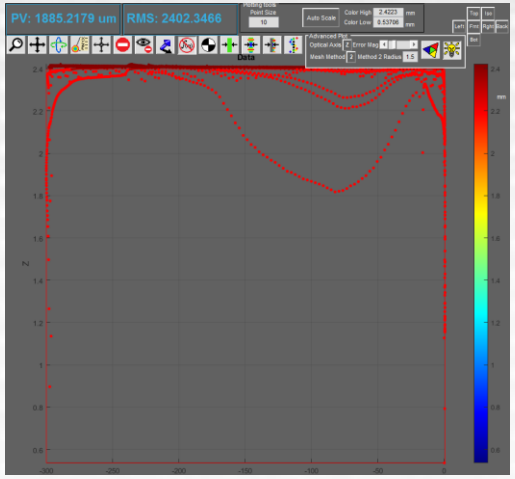
Removing bad data

Join the OptiPro Revolution.

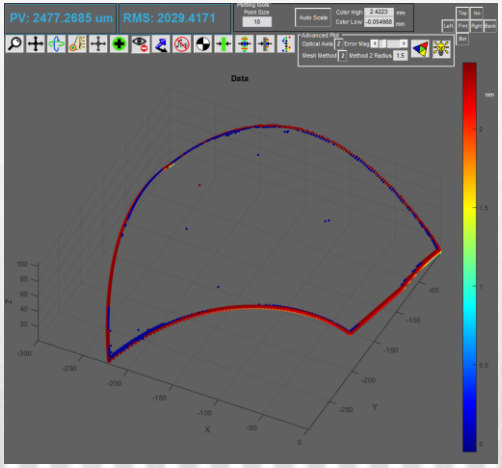
- Erroneous points are always a concern.
- Can be cause by environmental factors, dust, smudges, vibrations.
- Less of a concern in a highly controlled environment but that is it not always practical in a manufacturing setting where it takes multiple iterations to finish a part time is often a factor.
- Bad data can drastically change the result of your measurement
- Our tool gives you the ability to add and remove bad points while staying within a 3D environment



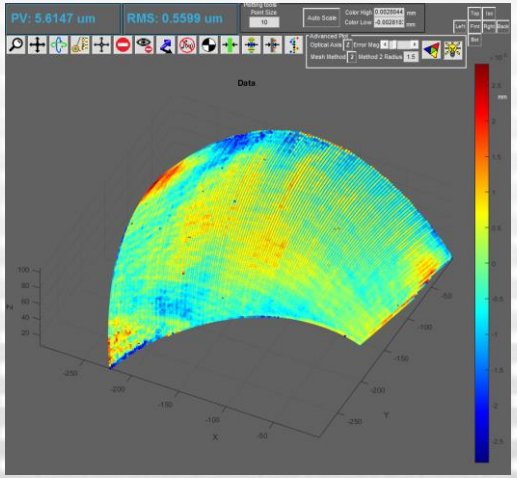
Raw 3D data



Points selected in perspective view



Removed points



Cropped 3D data

Thickness with Ultrasurf

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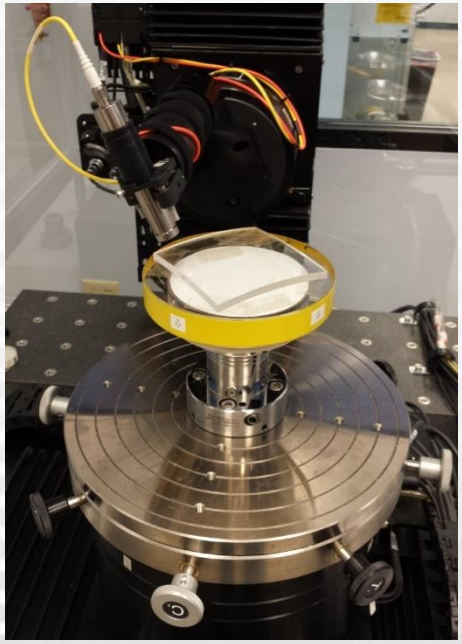
- The low-coherence interferometric probe has the ability to measure two surfaces simultaneously.
- Coupled with the ability to also measure datums this allows you to absolutely characterize a two surface optic in a single setup.
- This decreases both measurement time and error introduced from having to do multiple setups.



Single set up on the UltraSurf

Convex and concave set up on a CMM

Analyzing thickness

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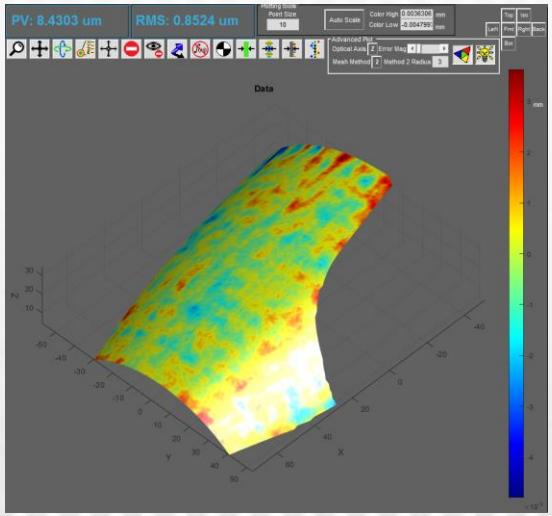
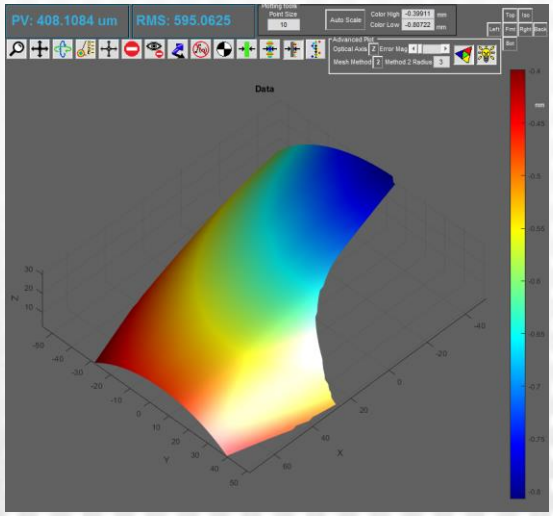
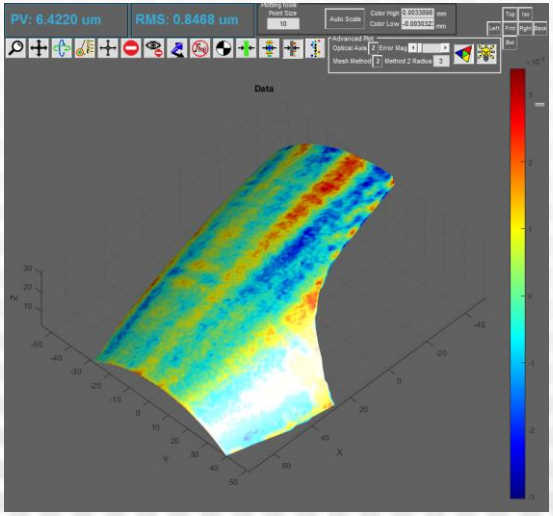
- Once we have thickness data we have several options to view the data
- We have the ability to separate out surface one error, surface two error, and thickness error.
- We can view the second surface error relative the any position the first surface is in or vice versa
- We can also look at what the surfaces look like individually best fit.
- This data can be used to deterministically correct the part and fix “wedge”.



Convex surface to datums



Concave surface relative to convex surface. This shows the “wedge” between the two surfaces.



Concave surface best fit

Additional analysis features

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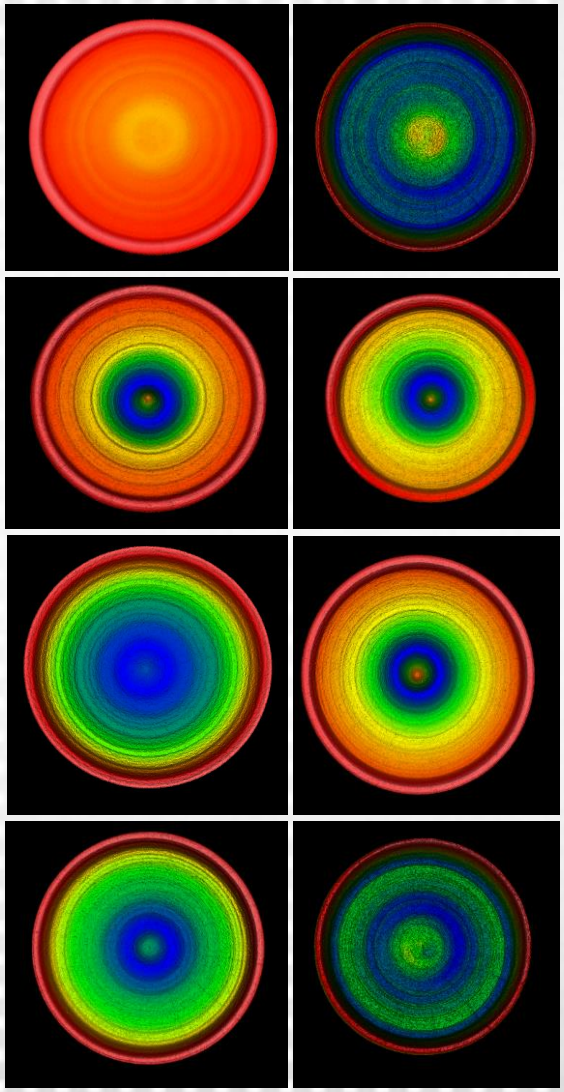
- Stock handles that allow you to process the part by removing material normal to the surface.
- Thresholding which allows you to adjust the extremes of the error for practical manufacturing.
- Fitting that accounts for extra stock and fitting that moves the shape right to nominal.
- Multiple export formats and shifting to move the error map into the proper location
- Equation importing that can handle up to two surfaces relative to each other in space.
- Multiple visulization tools

Second star

- We are currently working with Second Star Algonumerics to supply them with experimental data to aid in the development of their BeatMark Software.
- Ran an experiment where several parts were processed and data was recorded across several different metrology instruments.
- Second star hopes to use this data to develop a tool that will be able to identify what kind of process parameters contribute to specific errors in a part.
- This technology should be effective across multiple platforms and will increase the manufacturability of precision optics which entail multiple process parameters.



Summary

Join the OptiPro Revolution.

- Freeform optics present new challenges to manufacturing and metrology methods.
- The enhancements to the UltraSurf platform will meet the new requirements for complex optics.
- We continue to develop advanced data analysis tools that can be used throughout the manufacturing process and for final metrology.
- We are continuing to work with Second Star in the development of their BeatMark software.

Thank you

Join the OptiPro Revolution.

The technologies we have developed through the SBIR programs have allowed OptiPro to commercialize new manufacturing and metrology products vital to the advancement of the precision optics industry.