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If you can't measure it, you can’t make it: the importance of metrology in optics fabrication Optimax’s 30 year history

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"If you can't measure it, you can't make it"
The importance of metrology for optics fabrication in Optimax's 30 year history
(Presentation given as part of the James Wyant Tribute)

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ABSTRACT

This paper briefly tells the story of the importance of metrology in optics fabrication at Optimax, and highlights Wyko and Jim Wyant's contribution to early Optimax success.

Keywords: Metrology, interferometer, asphere, freeform

1. EARLY OPTIMAX

Optimax[1] was founded in 1991 on the premise of utilizing Computer-Numerically-Controlled (CNC) machining for precision optics. This innovation enabled delivery times for custom optical components to be reduced from 16 weeks to 1 week. Founded with the commitment to use advanced manufacturing technology, the third OptiCam[2] machine OptiPro Systems[3] (CNC Systems in 1991) was installed at Optimax. At the time, Optimax relied on test plates for power and surface figure testing. This lack of metrology regularly limited what was required for verification in those early days.

Wyko let Optimax borrorw their 6" interferometer – a memory from Mike Mandina

> *"Not only did I like it, but I found having that instrument was necessary in order to secure orders. Interferometry became indispensable for Optimax. Within a short period, I ordered a new 6000 interferometer. However, as Wyko was engaged in its own growth, they had a long lead time. They could have left me hanging by taking back the trial unit and making my wait for my order, essentially leave me hanging…. This would have gravely impacted Optimax's ability to ship and book new orders.*
>
> *Wyko made a decision that I have not forgotten and will never forget, they allowed me to keep their interferometer at no charge for over 6 months while mine was being built. This free access to this capability during a critical time in the history of Optimax was truly a godsend. I did not need to layout the cash and I was able to build the business into a stronger financial position to better absorb the cost. I did not have a plan B, and Wyko came through for me.*
>
> *I don't know if Jim Wyant was directly responsible for the decisions that allowed Optimax to use their instrument, but if nothing else, it demonstrates the humanity of the culture that existed at Wyko, which in no small way was a reflection of Jim himself." - MPM*

2. LEAN MANUFACTURING

In 1994 Optimax began to market "Prototype Optics in One Week". A combination of manufacturing and testing capabilities created opportunities for Optimax to support prominent customers, such as the lithography market, NASA, the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL). As Optimax continued to grow, they transitioned to lean manufacturing[4] which required everyone to learn to manufacture and test their own surfaces. Instead of "throwing the optic over the wall" to the next department (ex. grinding to polishing), each optician learned one-piece-flow and was able to take the raw material all the way through the process to the finished product. This process is illustrated in Figure 1.

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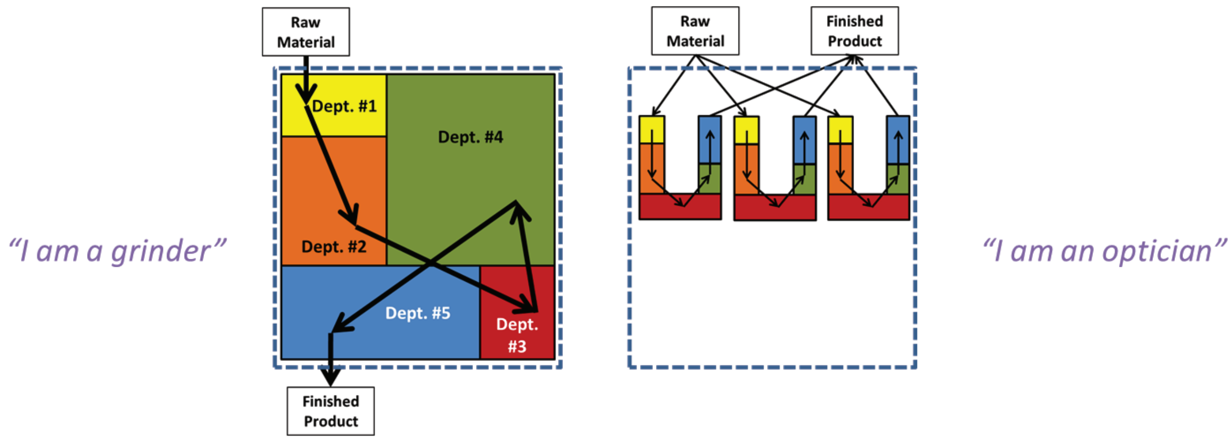

Figure 1: Diagrams illustrating the difference between traditional manufacturing (left) and lean manufacturing (right).

3. ASPHERE METROLOGY

By early 2000 industry demand for aspheres required more metrology options and capabilities.[5-7] In asphere manufacturing, historically the gating item is the metrology, as metrology enables deterministic correction. This yields the adage and the title of this presentation "if you can't measure it, you can't make it". During this time of growth Optimax was quickly growing its metrology capabilities in order to keep up industry demand. With additional capabilities and capacity Optimax developed an asphere decision tree to help promote better communication with customers about asphere metrology. This decision tree is shown as Figure 2.

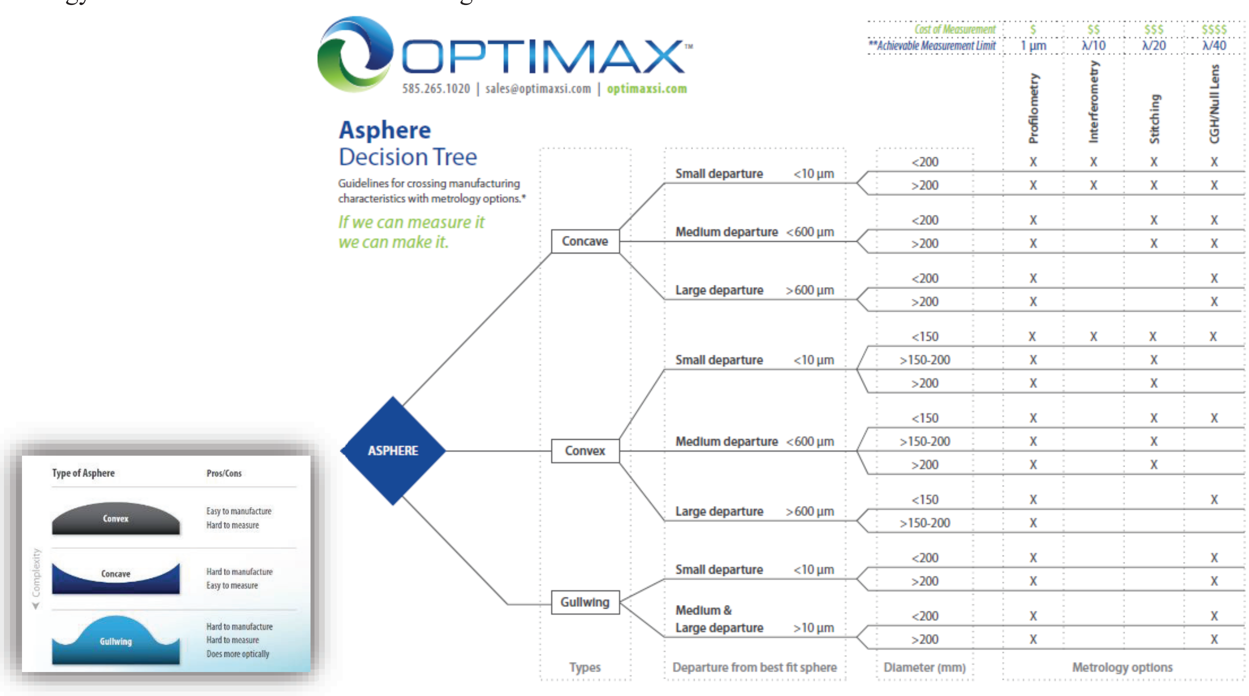

Figure 2: Optimax's Asphere Decision Tree, highlighting the importance of metrology in asphere manufacturing. The inset on the left defines the different asphere shapes.

4. FREEFORM METROLOGY AND TOTAL ERROR

Freeform optics manufacturing is similar to manufacturing high departure and complex aspheres.[8-14] The freeform shape is typically initiated in generation and measurement is also a gating item. In addition to surface irregularity form error, **total error** is important for freeforms.[15] As depicted in Figure 3, total error is the combination of surface irregularity, surface texture and positioning errors.

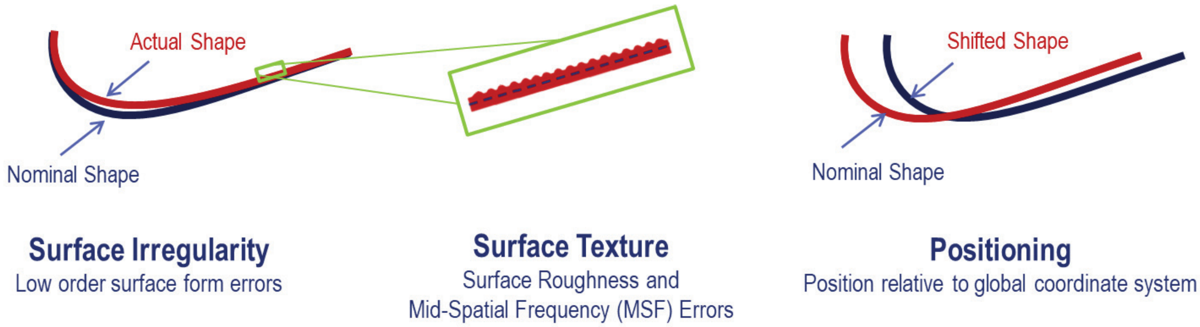

Figure 3: Total Error = (Surface Irregularity + Surface Texture + Positioning) errors

Positioning or errors in locating a freeform in space lead to measurement errors. Alignment errors in measurement can manifest as surface shape errors. For spherical surfaces the alignment error would be tip or tilt, aspheric surfaces the error is coma, but for freeform errors it could be almost anything. The freeform errors depend on the shape of the freeform surface and the type of misalignment. An example of a biconic surface with 0.5^{o} rotational offset is showing in Figure 4 where the rotational alignment error causes astigmatism and higher order terms.

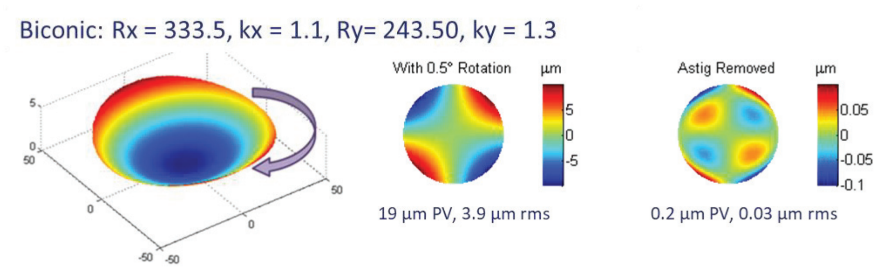

Figure 4: Simulation on a biconic 100 mm circular aperture. A rotational offset of 0.5^{o} causes 19 μm of PV astigmatism.

The best way to control positioning error in freeform measurements is to measure the position relative to fiducials or a global coordinate system.[16] This shows a major advantage of including a coordinate measuring machine (CMM) into the optical manufacturing and testing process for freeforms. Multiple instruments are required for full spatial frequency measurement coverage for freeforms. Optimax is continuously searching for additional metrology tools capable of measuring total error to sub-wave precision on freeforms.

5. CONCLUSION

Measurements are extremely important in the optics manufacturing process. Increasing design complexity demands increasingly better metrology. Thank you to Jim Wyant, and all of the metrology innovators out there.

You can only make an optic as good as you can test it!

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