Optomechanical analysis in the fabrication of conformal and free form optics

Victor Genberg*, Gregory Michels, Gary Bisson
Sigmadyne, 803 West Ave, Rochester, NY 14611

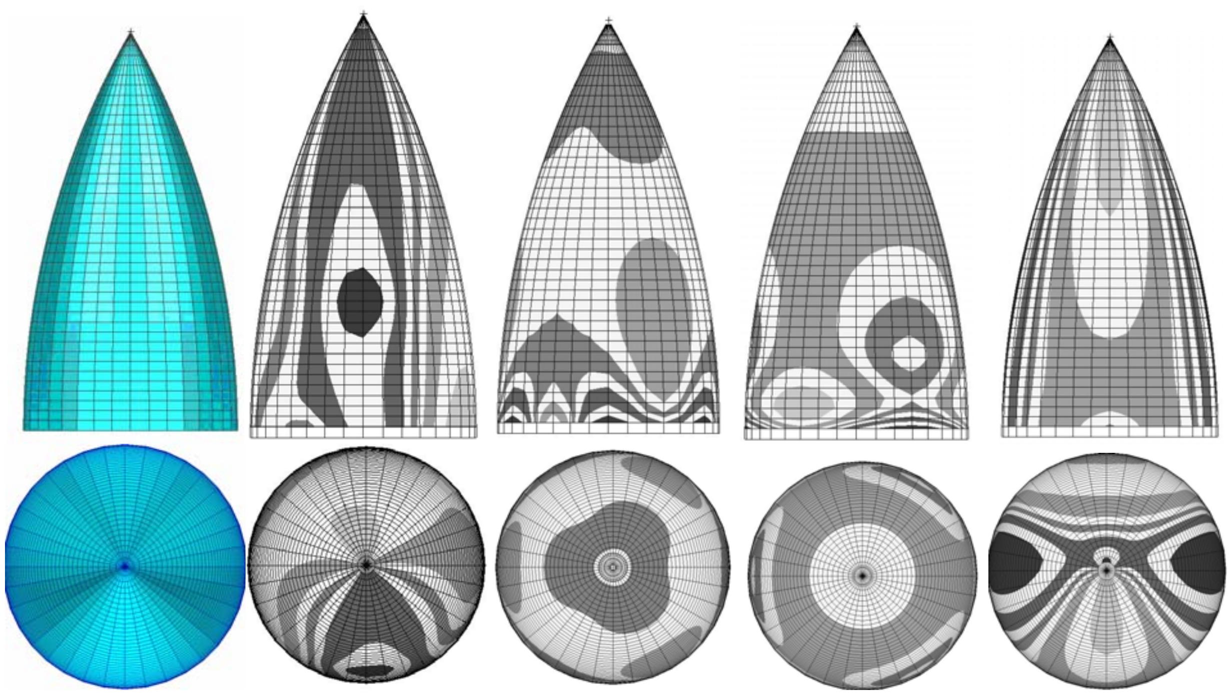
ABSTRACT

Finite element analysis can be used to support the fabrication of conformal and free form optics. This paper describes SigFit, a useful tool in interfacing finite element (FE) analysis with optical design codes and interferometric testing. The tools can be used to optimize the grinding and polishing process, investigate anomalies in test results, and provide 'back-out' arrays to simulate 0g performance.

Keywords: conformal optics, free form optics, stressed-optic polishing, Twyman effect, optomechanical analysis.

1.0 GRINDING OF CONFORMAL OPTICS

Grinding of conformal optics is a difficult task due to part distortion. To improve the grinding process, optomechanical analysis using finite element (FE) tools can provide the local part distortion under grinding loads. In Figure 1a, an ogive blocked at 3 points at the base ring is subjected to unit loads over its surface. The finite element deformation in Figure 1b is of the full surface for a grinding force at one location.



(a) (b) (c) (d) (e)

Figure 1: Ogive surface normal displacements for grinding forces and Twyman stress

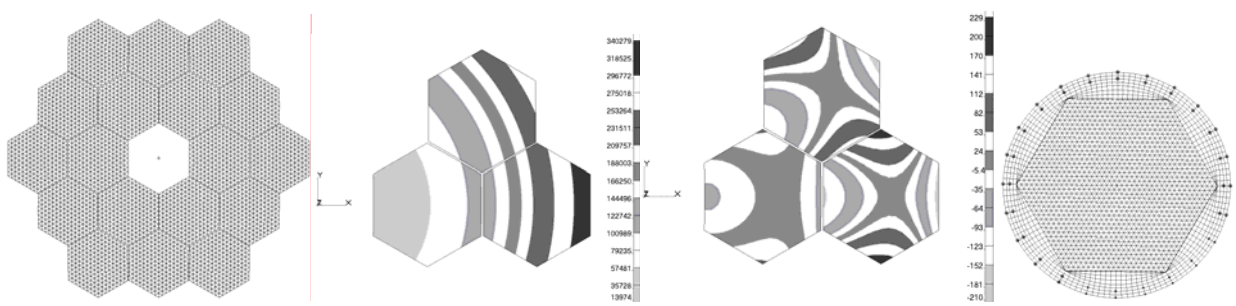
*genberg@sigmadyne.com, phone: 585-235-7460

The local deformation under the grinding force is the data needed to correct the grinding operation. The remaining information is not particularly useful. If this process is repeated for every point on the surface and then collected into a single file, the result is shown in Figure 1c which is the plot of influence functions over the full surface. SigFit[1] can fit Figure 1c with Fourier-Legendre polynomials or a uniform grid array to pass to the grinding machine control program. With the local surface deformation information, the control program can modify the machine parameters to achieve the desired removal profile.

Another issue in the grinding process is the Twyman effect generated on the ground surface. This effect can be modeled as an effective thermal load[2]. In Figure 1d, the full outside surface has a uniform Twyman stress. The surface normal deformation of the ogive blocked at 3 points around its base is shown in Figure 1d. A Fourier-Legendre polynomial fit (N=10, M=6) can represent 99.7% of the deformation. If during the grinding process, only a 1/3 section of the surface has the Twyman stress, the resulting surface normal deformation shown in Figure 1e has twice the surface RMS as Figure 1d. The polynomial fit (N=10, M=6) of Figure 1e only represents 94.7% of the response.

2.0 STRESSES-OPTIC POLISHING OF FREE FORM OPTICS

One method for making off-axis segments of aspheres is through stressed-optic polishing. A segmented primary mirror is shown in Figure 2a with the aspheric sag of the A, B and C segments shown in Figure 2b. Each segment is individually fit with Zernikes in SigFit. After best-fit plane and power are removed, the residual surface is shown in Figure 2c. The circular substrate shown in Figure 2d can be bent to the negative of the desired shape within 1% using the 24 edge actuators. After polishing, the actuators are removed and the desired shape is obtained within 1% error. This shape then goes to a final figure operation. SigFit's genetic optimization capability[3,4] can find the best actuator locations to deform to any single shape, or in this case, the best single set of locations to fit all three shapes.



(a) (b) (c) (d)

Figure 2: Off-axis asphere segments

3.0 ANAYSIS IN SUPPORT OF TEST

During the testing of optics during fabrication, many factors influence the test results. Optomechanical analysis can be used to model these effects to help understand the test results. Figure 3a shows the sag away from flat of an elliptic optical window which is a complex free-form surface.

(a) (b) (c)

Figure 3: Free form elliptic window

Figure 3b shows a simulated test interferogram of the window sitting in 1g on-edge on a kinematic test support. A test chamber window with both radial and axial temperature gradient has a thermo-optic effect caused by index change due to temperature. The dn/dT effect of the test chamber window was analyzed in SigFit and subtracted from the test data as shown in Figure 3c. The resulting surface could be interpolated to a grid array by SigFit for passing to an interferometer or to optical design software.

4.0 SIGFIT CAPABILITIES

SigFit offers a wide variety of surface geometries as shown in Table 1. The conic geometry may add any of the polynomial types listed. For each surface shape the optical segment may represent an arbitrary off-axis portion of the parent geometry, allowing a wide variety of 'free form' optics to be analyzed. Disturbances to be analyzed (fit) include the types listed plus arbitrary linear combinations. SigFit writes the polynomials to files for direct input to the optics programs listed. In addition to fitting polynomials, SigFit can interpolate disturbances to rectangular grid arrays for input to optics programs or interferometers.

Surface Shapes	**Polynomials**	**Disturbances**	**FE Programs**	**Optics Programs**
Flat	Zernike	Finite element results	Nastran (all)	CodeV
Conic	Fringe Zernike	Polynomials	Ansys (all)	Zemax
Biconic	Annular Zernike	Vector data	Abaqus	Oslo
Anamorphic	Asphere	Interferogram arrays	Cosmos	Interferometers
Grazing conic	Forbes QCON	Combinations of above		
Ogive	Forbes QBFS			
Conic+any poly	XY			
Offset segments	Legendre			
	Fourier-Legendre			

Table 1: Summary of SigFit fitting capabilities

5.0 SUMMARY

Standard finite element thermal and structural results are not in a useful form for the integrated test-analysis correlation. This paper has presented a commercially available program SigFit[4,5] which provides the necessary links to pass the thermal and structural data to popular optical analysis and test codes. Surface distortions can be passed as polynomial coefficient tables or interferogram arrays accounting for proper sign conventions, units, and coordinate transformations. The wavefront effects of dn/dT and dn/dσ, as well as stress birefringence effects can also passed from structural programs to optical programs. SigFit also calculates the behavior of adaptive optics and presents the results in optical code format. The interface tools discussed allows test and analysis correlation to be conducted effectively.

REFERENCES

[1] SigFit Reference Manual, Sigmadyne, Inc., Rochester, NY, 2011. (2011)
[2] Doyle, K., Genberg, V.,Michels, G., Integrated Optomechanical Analysis, SPIE, TT58, (2002)
[3] Michels, G., Genberg, V., Doyle, K., and Bisson, G., "Design optimization of actuator layouts of adaptive optics using a genetic algorithm," Proc. SPIE 5877-22, (2005).
[4] Genberg, V., Doyle, K. and Michels, G., "An optical interface for MSC Nastran," MSC Conference Proc VPD04-31, (2004).
[5] Michels, G., Genberg, V., and Doyle, K., "Integrating ANSYS mechanical analysis with optical performance analysis with SigFit," ANSYS User Conference Proc., (2008).