Direct Polishing of Full-Shell, High-Resolution X-Ray Optics

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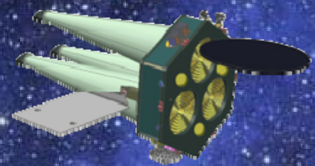
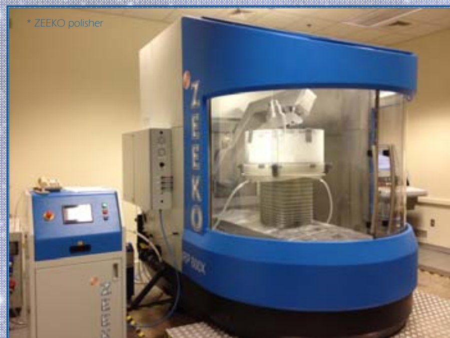


Abstract: Future x-ray telescopes will likely require lightweight mirrors to attain the large collecting areas needed to accomplish the science objectives. Understanding and demonstrating processes now is critical to achieving sub-arcsecond performance in the future. Consequently, designs not only of the mirrors but of fixtures for supporting them during fabrication, metrology, handling, assembly, and testing must be adequately modeled and verified. To this end, MSFC is using finite-element modeling to study the effects of mounting on thin, full-shell grazing-incidence mirrors, during all processes leading to a flight mirror assembly. Here, we report initial results of this study.



* ZEEKO polisher

Fabrication

- Fabrication of thin, lightweight, sub-arcsecond optics requires innovative technology
- NASA MSFC procured a Zeeko polisher to aide in technical advancement; its capabilities include corrective polishing on the order of nanometers.

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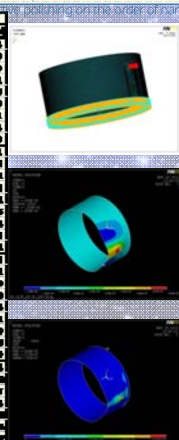


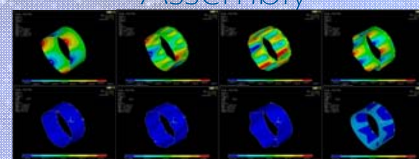
2mm cylinder thickness, 1 atm bonnet pressure							
#	r(mm)	F(N)	%	d(m)	d(μm)	σ(Pa)	σ(psi)
1	5	0.053	10	1.93E-08	0.019	586352	85
2	5	0.053	20	7.79E-07	0.779	1.40E+06	203
3	5	0.053	30	1.06E-06	1.06	1.39E+06	202
4	5	0.053	40	1.32E-06	1.32	1.50E+06	218
5	5	0.053	50	1.71E-06	1.71	1.71E+06	248
6	5	0.053	60	2.12E-06	2.12	1.86E+06	270
7	5	0.053	70	2.63E-06	2.63	1.99E+06	289
8	5	0.053	80	3.19E-06	3.19	2.05E+06	297
9	5	0.053	90	4.51E-06	4.51	2.34E+06	339
10	10	0.4385	10	1.60E-07	0.16	4.85E+06	703
11	10	0.4385	20	6.44E-06	6.44	1.16E+07	1682
12	10	0.4385	30	8.75E-06	8.75	1.15E+07	1668
13	10	0.4385	40	1.10E-05	11	1.24E+07	1798
14	10	0.4385	50	1.41E-05	14.1	1.41E+07	2045
15	10	0.4385	60	1.75E-05	17.5	1.54E+07	2234
16	10	0.4385	70	2.18E-05	21.8	1.65E+07	2393
17	10	0.4385	80	2.64E-05	26.4	1.69E+07	2451
18	10	0.4385	90	3.73E-05	37.3	1.93E+07	2799
19	15	0.9575	10	3.49E-07	0.349	1.06E+07	1537
20	15	0.9575	20	1.41E-05	14.1	2.54E+07	3684
21	15	0.9575	30	1.91E-05	19.1	2.50E+07	3626
22	15	0.9575	40	2.39E-05	23.9	2.71E+07	3931
23	15	0.9575	50	3.08E-05	30.8	3.09E+07	4482
24	15	0.9575	60	3.82E-05	38.2	3.36E+07	4873
25	15	0.9575	70	4.76E-05	47.6	3.60E+07	5221
26	15	0.9575	80	5.77E-05	57.7	3.70E+07	5366
27	15	0.9575	90	8.15E-05	81.5	4.22E+07	6121
28	20	1.5135	10	5.51E-07	0.551	1.67E+07	2422
29	20	1.5135	20	2.22E-05	22.2	4.01E+07	5816
30	20	1.5135	30	3.02E-05	30.2	3.96E+07	5743
31	20	1.5135	40	3.78E-05	37.8	4.28E+07	6208
32	20	1.5135	50	4.87E-05	48.7	4.88E+07	7078
33	20	1.5135	60	6.04E-05	60.4	5.31E+07	7702
34	20	1.5135	70	7.52E-05	75.2	5.69E+07	8253
35	20	1.5135	80	9.11E-05	91.1	5.84E+07	8470
36	20	1.5135	90	1.29E-04	129	6.67E+07	9674

- Top center: finite-element model of cylinder (height=0.300m, diameter=0.610m, thickness= 0.002m and 0.006m) held at base with polishing force applied
- Middle center: displacement results
- Bottom center: von Mises stress results
- Left: stress and displacement results for finite-element model of polishing forces on a 6mm-thick shell, varying the contact area of polisher
- Right: results for finite-element model of 2mm-thick shell, varying contact area

- 6mm cylinder mounted into hardware to attach to the Zeeko polisher

* Chandra mirror shell

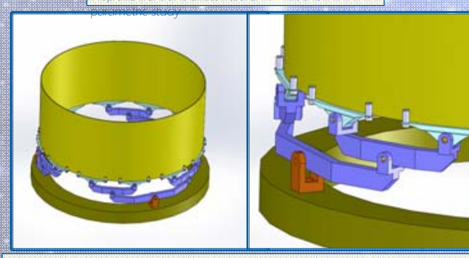
Assembly



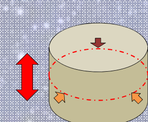
- Top: using FEM shown in Fabrication, distortion due to gravity in the axial direction, mounted at base. Left to right: 3-point, 6-point, 9-point, and 12-point mount
- Bottom: stress due to gravity in axial direction, mounted at base. Left to right: 3-point, 6-point, 9-point, and 12-point mount

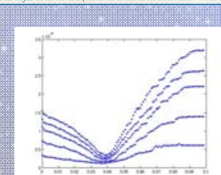
run#	#pts	disp(microns)	stress(psi)
1	3	8.35	227
2	6	0.16	83
3	9	0.02	54
4	12	0.01	41

Displacement and stress results from above parametric study

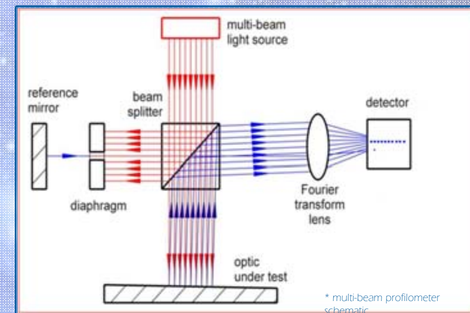


Whiffletree design based on parametric study, where 6 points is minimum number of points necessary





- Left: finite-element model (FEM) of thin cylinder (height=0.198m, diameter=0.226m, thickness=10, 30, 50, 70, and 90 microns) with three equidistant mounting points were created to set mounting tolerances. The placement of these points was then varied longitudinally.
- Right: imaging half-power diameter is plotted for FEMs described above, varying thicknesses and axial location of mounting points. As the thickness gets smaller, the mounting location becomes more significant; thicknesses from top of figure to the bottom are 10, 30, 50, 70, and 90 microns



* multi-beam profilometer schematic

Metrology

- Because lightweight mirrors are flimsy, they are susceptible to significant distortion due to mounting errors, including gravitational sag, machining errors and assembly distortions
- Blocking fixtures are necessary to fabricate sub-arcsecond grazing-incidence optics on the order of 2mm thick, however, with the added strength comes added error in the optic
- Metrology in a "free form" is required before adding a blocking fixture
- A subtraction between the blocking error and the "free form" is applied to the corrective polishing

- Left: grazing-incidence optic mounted in blocking fixture
- Right: stiffening ring to hold optic for metrology

The Vertical Long-Trace Profilometer (VLTP, from Continental Optics) vertically scans the surface under test (sitting on a rotary table) and is best suited for metrology of full-cylinder mirror shells and large-diameter mandrels