A stainless-steel mandrel for slumping glass x-ray mirrors

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ABSTRACT

We have fabricated a precision full-cylinder stainless-steel mandrel at Marshall Space Flight Center. The mandrel is figured for a 30-cm-diameter primary (paraboloid) mirror of an 840-cm focal-length Wolter-1 telescope. We have developed this mandrel for experiments in slumping—thermal forming at about 600°C—of glass mirror segments at Goddard Space Flight Center, in support of NASA’s participation in the International X-ray Observatory (IXO). Precision turning of stainless-steel mandrels may offer a low-cost alternative to conventional figuring of fused-silica or other glassy forming mandrels. We report on the fabrication, metrology, and performance of this first mandrel; then we discuss plans and goals for stainless-steel mandrel technology.

INTERNATIONAL X-RAY OBSERVATORY

The International X-ray Observatory (IXO), next-generation astronomical X-ray Mission, requires extremely large collecting area (5 square meters of effective area at 1 keV and 1 square meter at 6 keV) combined with good angular resolution (5 arcsec half power diameter) in order to achieve unprecedented sensitivities for the study of the high-z Universe and for high-precision spectroscopy of bright X-ray sources. Slumping glass technology is one of the fabrication techniques considered for producing the x-ray mirror segments for a single large x-ray mirror assembly. This mirror fabrication approach requires massive number of the forming mandrels. Stainless-steel mandrels may offer a low-cost alternative to conventional figuring of fused-silica or other glassy forming mandrels.

Stainless Steel Mandrel

Goal:

Find commercially available material applicable for manufacturing of the forming mandrels to significantly reduce cost of the glass replication process

Mandrel description

– 8400 mm focal length
– 155.080 mm intersection plane radius
– 304.8 mm overall length (12.000 inches)
– 200 mm optical length (50 mm zone at each end for polishing overstroke)
Performance prediction requirement – 15 arc seconds (HPD)

Material: 304L Stainless Steel
– 18-20% Cr, 8-12% Ni
– 0.03% C, 1% Mn, 1% Si, 0.045% P, 0.03% S, 0.1% other

Mandrel Fabrication

– Rough machining – Heat Treatment – Precise machining – Initial Precision turning
– Axial Figure Metrology – Final Precision Turning – Polishing – Final Metrology

– Design of the support structures for machining, turning and polishing - Precision fit.
– Thickness of the mandrel was set to 1 cm based on thermal considerations.

Mandrel Fabrication (cont.)

Pre-machining and precise turning:

– The mandrel was stress relieved at 650°C for one hour. The stress relieving temperature is much lower than annealing temperature (1010 to 1120 °C), so grain growth should not be an issue.
– Rough machining went fine, but the mandrel was warped after heat treatment. Contractor has performed the precise machining;
– “Free standing” mandrel is out of roundness;
– Mandrel was turned on inside to make it to conform to the end rings better;
– All mandrel assemblies were done at the Circularity Test Stand.

Polishing:

– The hardened steel layer has appeared during initial polishing. The mandrel was precision grinded.
– At the point of final polishing pull-outs became visible (possibly the result of the precision turning)
– The mandrel was precision grinded again
– The mandrel is polished to 45A rms

Surface Passivation

– Surface of SS coupon degraded during thermal cycling
– A surface passivation study has been performed. Two techniques have been tested: the electro-chemical passivation and nitric acid passivation.

Results:

Nitric acid passivated stainless steel coupon (left photo) – the surface roughness degraded from 46 to 168 A after the heat treatment;

Electrochemically passivated stainless steel coupon (right photo) – the surface roughness degraded from 23 to 1068 A after the heat treatment.

Future Plans

– Thermally cycle the mandrel. Perform full metrology on the heat treated mandrel to characterize possible changes in mandrels figure, circularity and surface roughness;
– Resume fabrication process study with coupons in order to define an ideal stainless steel for mandrel production;
– Produce hyperbolic mandrel to match the primary mandrel.