Smart X-ray Optics

Smart X-ray Optics for the next generation of X-ray telescopes.

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ACTOP08 Workshop

9 – 11 October 2008, Trieste, Italy

Presentation Outline

Introduction

- Smart X-ray Optics Consortium
- The design of an active X-ray prototype

Prototype manufacture

- Mandrel production
- Electroforming procedure
- Actuator bonding/harnessing

Actuator influence functions

- Influence function measurements
- Hysteresis within the piezoelectric actuators

Software development

- Finite element analysis of actuator influence functions
- An iterative algorithm to control actuator voltages

X-ray testing of the active prototype

- The X-ray tunnel test facility at the University of Leicester

The Smart X-ray Optics Project

<u>The Smart X-ray Optics Consortium</u>

- University College London
- University of Leicester
- University of Birmingham
- King’s College London
- STFC Daresbury Laboratory
- University of Edinburgh
- Mullard Space Science Laboratory (MSSL)

Goals of the Smart X-ray Optics Consortium

To develop a prototype X-ray telescope with sub arc second resolution and potentially large filling factor whose optical form is actively controllable.

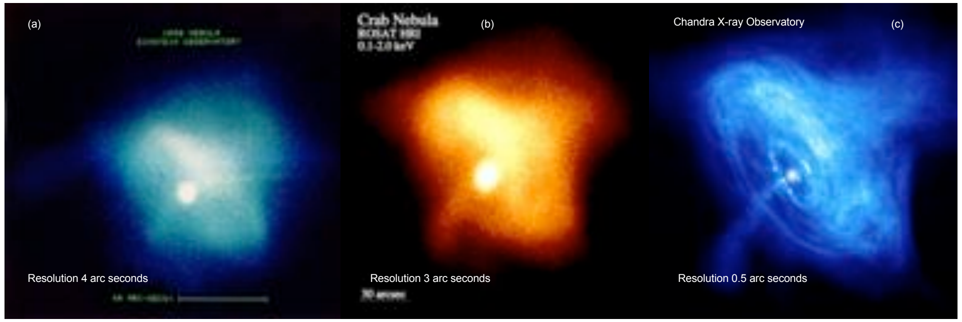
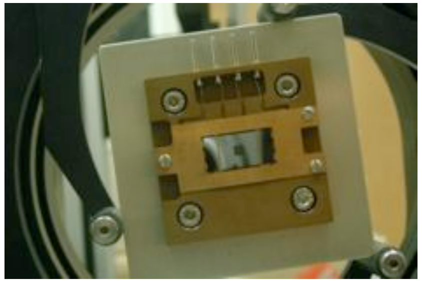
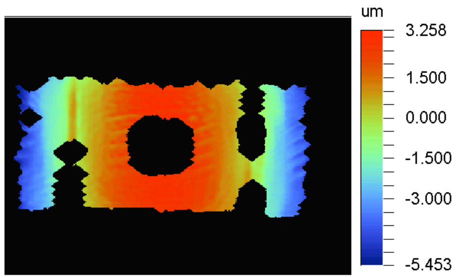


Figure 1: The Crab Nebula as imaged by three different x-ray telescopes, a) The Einstein Observatory (courtesy of NASA), b) ROSAT (courtesy of S. L. Snowden USRA, NASA/GSFC) and c) Chandra (courtesy of NASA/CXC/SAO)

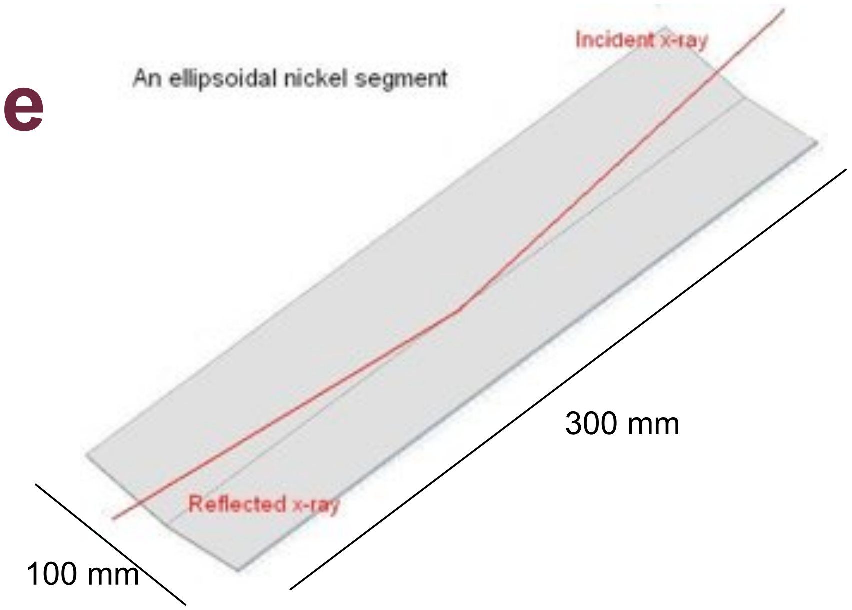
To improve the resolution beyond that of the Chandra X-ray Observatory while increasing the available collecting area.





smart x-ray optics

An Active X-ray Prototype

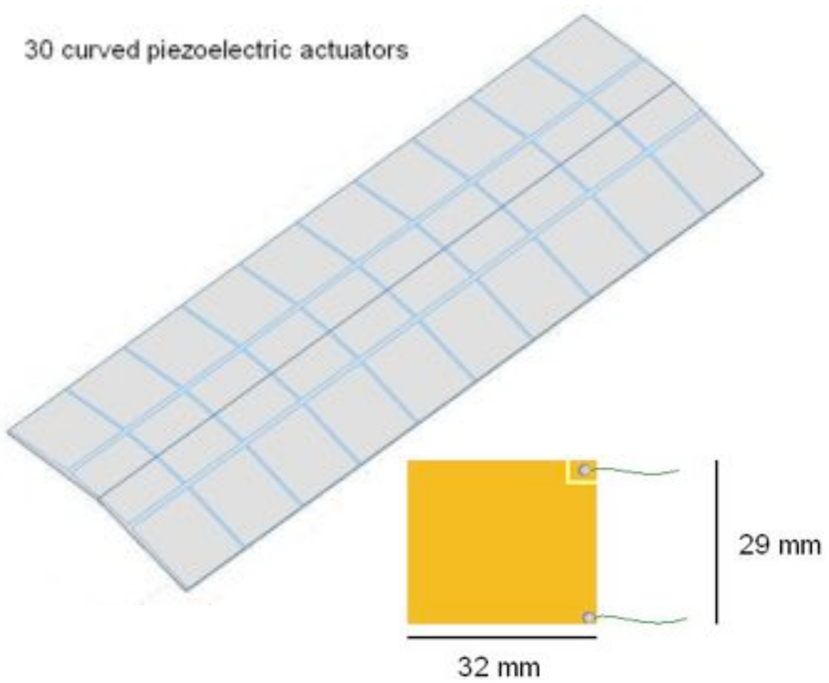


<u>Point-to-point X-ray focussing prototype</u>

- Nickel ellipsoid (semi major axis ~14m) segment (300 x 100 mm)
- 30 curved piezoelectric actuators, developed by the University of Birmingham
- To be tested in the X-ray Tunnel Test Facility at the University of Leicester.
- Support of the optic within X-ray facility is designed by MSSL.

<u>A cylindrical pre-prototype</u>

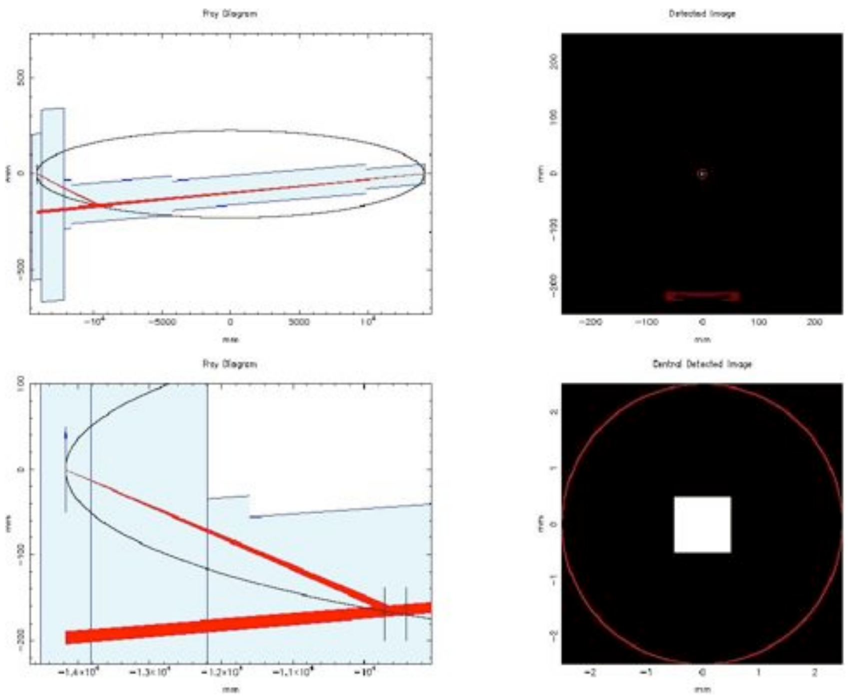
- Nickel cylindrical segment (200 x 100 mm)
- Radius of curvature 154 mm
- Thickness 0.4 mm
- To be tested optically to determine actuator influence functions.

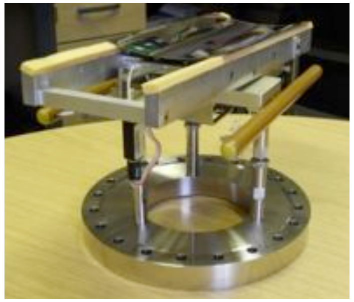


An Active X-ray Prototype

- Optical testing and prototype functionality to be tested at University College London
- X-ray testing to be performed at the University of Leicester's X-ray Tunnel Test Facility

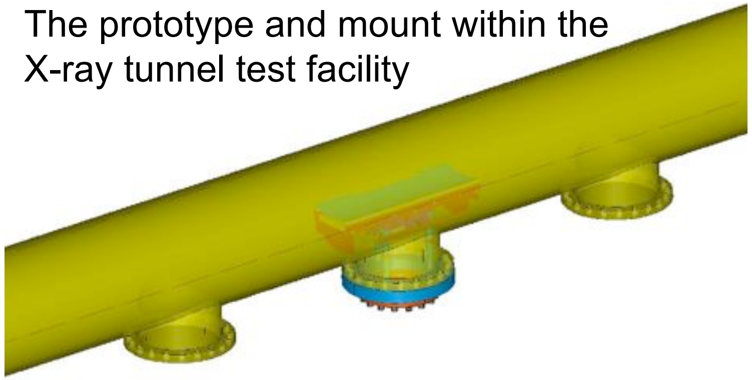
Ray tracing of the optic within the test facility at Leicester, the majority of the X-rays miss the optic, however those incident upon the surface are reflected to the detector.





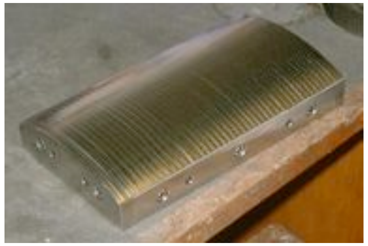
The optic mount used to hold and manoeuvre the optic within the X-ray tunnel test facility

The prototype and mount within the X-ray tunnel test facility



Prototype Manufacture: production method I

Mandrel production



Mandrel polishing

Electroforming preparation

Cylindrical Mandrel
- Material: stainless steel
- Ground to a radius of curvature of 0.154m
- Surface roughness: 5nm rms

Elliptical Mandrel
- Material: aluminium coated with Kanigen
- Ground to a radius of curvature between 0.165m and 0.169m
- Expected surface roughness: 1nm rms
- Gold will be vacuum deposited upon the Kanigen surface to provide an passivation layer for the nickel deposition.

Electroforming Preparation
- Polyester insulating tape used to mask off the undesired regions.
- A thin polypropylene insulator is used to isolate the electroformed optic from the excess over plated regions.
- The electrical connection is via the two stainless steel supporting rods.

Prototype Manufacture: production method II

Electroforming

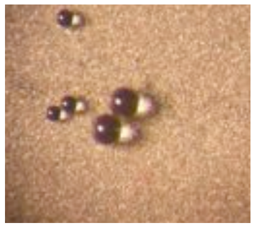
Removal from electrolyte

Release from the mandrel

Actuator bonding

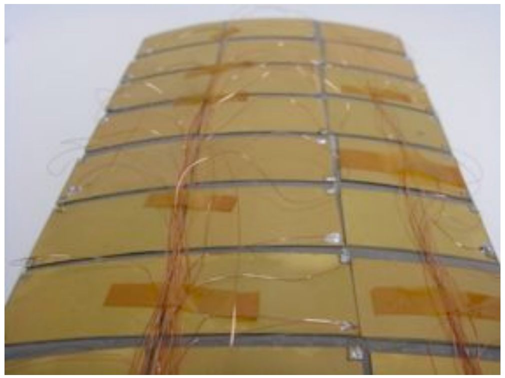
- A nickel sulphamate procedure
- Total plating time 40 hours
- Operated at low current density 0.01A/cm^2
- Mechanical agitation is provided by a filtering pump.

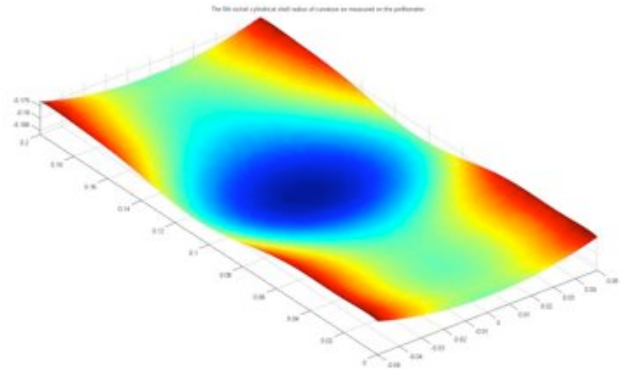
- Actuators are bonded using a low shrinkage adhesive
- The adhesive contains small glass beads, which ensure that a minimum thickness layer is maintained.
- The glass beads are available in either 80µm or 150 µm diameters



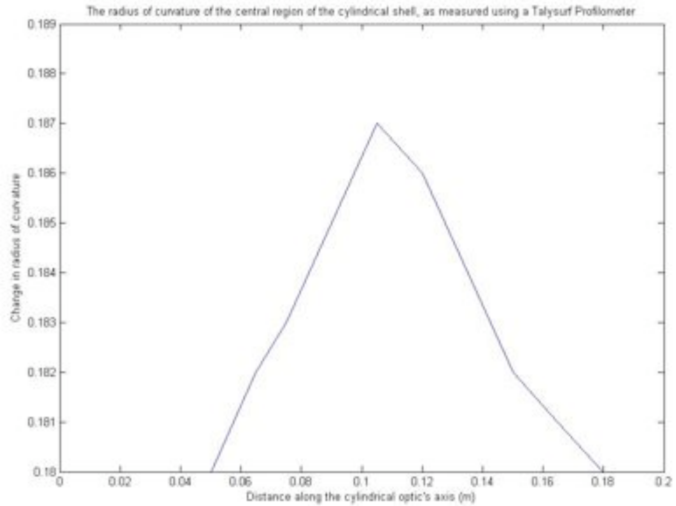
The completed cylindrical prototype

• Actuators harnessed to a 37 pin connector.
• Vacuum compatible acrylic adhesive tape is used to bind the wires.
• All 30 actuators have a common ground that can be set between a voltage range of -200 to 200 V.

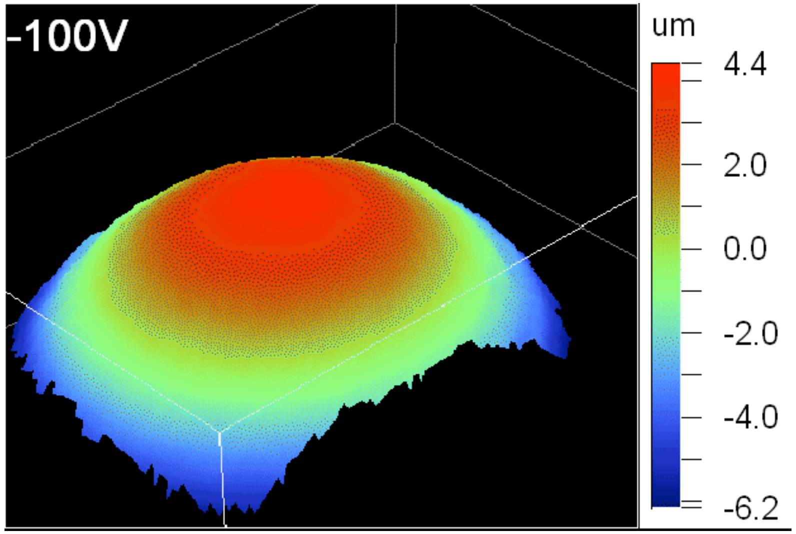




• The mean radius of curvature is 0.182m
• The designed radius of curvature is 0.155m

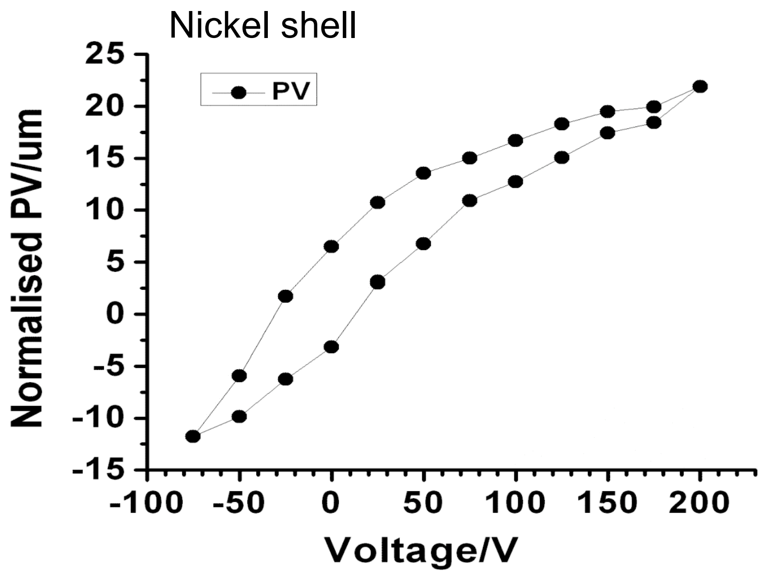


Actuator Influence Functions

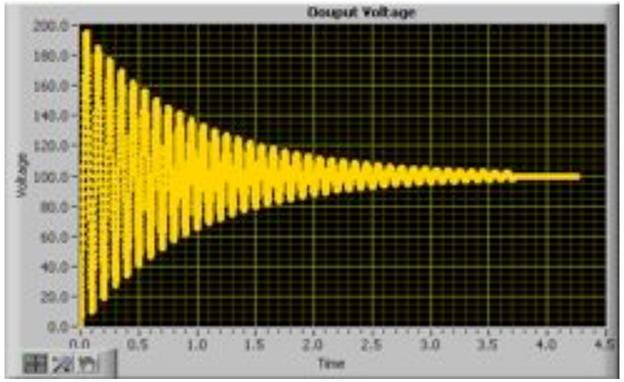


• Initial influence function measurements taken using an optically flat glass slide. On the back of which was bonded an actuator created by the University of Birmingham.
• Measurements were taken using a WYKO infrared interferometer and a Talysurf Profilometer.
• The visible area in the movie is 2.5 cm^2.

Piezoelectric hysteresis
• As the actuators are voltage driven; hysteresis is evident in the measurements.
• This is highly undesirable for precision and repeatability.
• The maximum difference in displacement is approximately 2 µm.

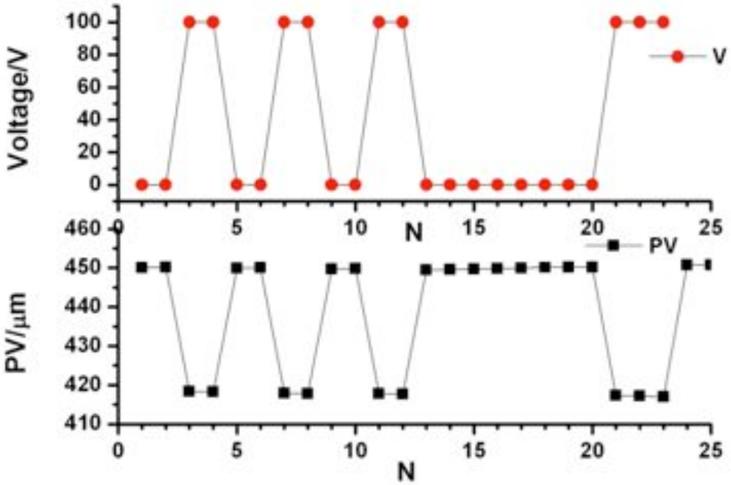


Actuator Influence Functions - Hysteresis

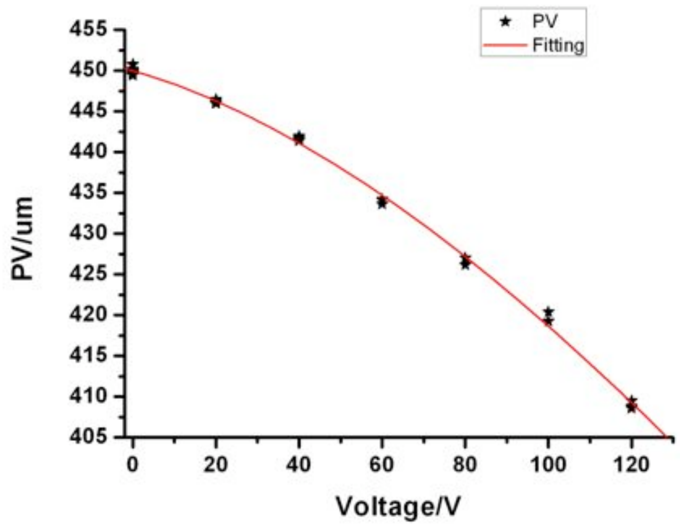


- By oscillating around the desired voltage, the effect of hysteresis is observed to be reduced.
- A control program was designed in LabVIEW to oscillate for approximately 4 minutes before stabilising on the desired voltage.
- Measurements of the displacement against voltage were obtained from actuators bonded upon the nickel shell.
- This method provided repeatability with an error of 1% in measured displacement.

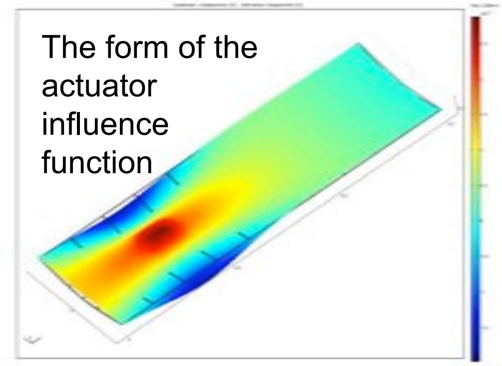
- Voltage varied between 0 and 100V.
- A 30µm displacement was measured at 100V.



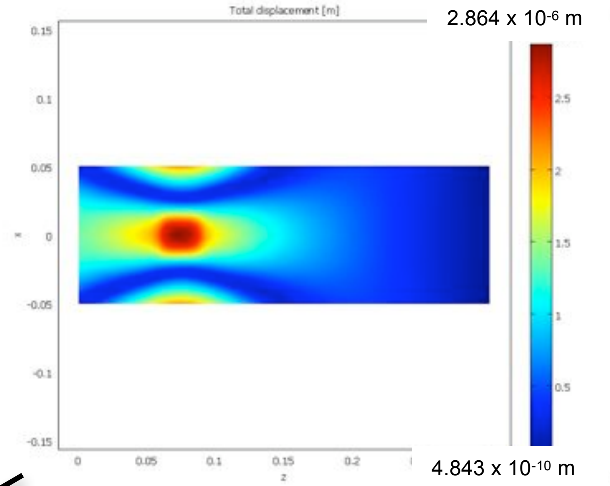
- A non linear relationship was measured for voltage against displacement in 20V steps.

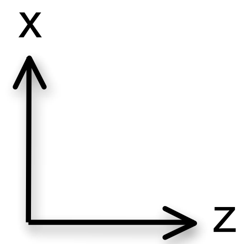


Actuator Influence Functions - FEA



Total Displacement

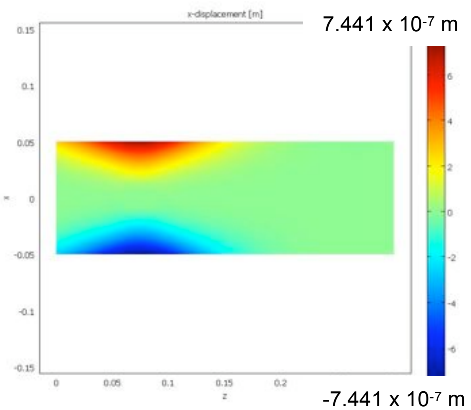




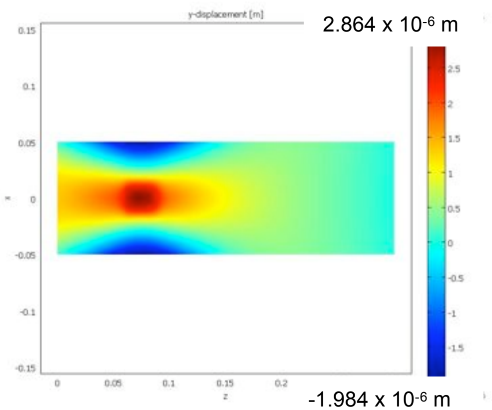
y-axis is directly out of the screen

- FEA Software: Comsol Multiphysics
- Applied Voltage: 10V
- The optic is loosely bounded to mimic its non fixed position on the support structure.

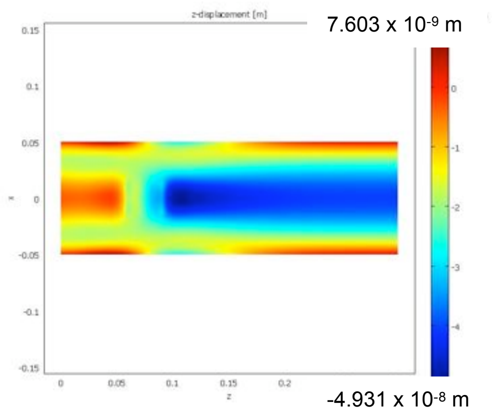
X - Displacement



Y - Displacement

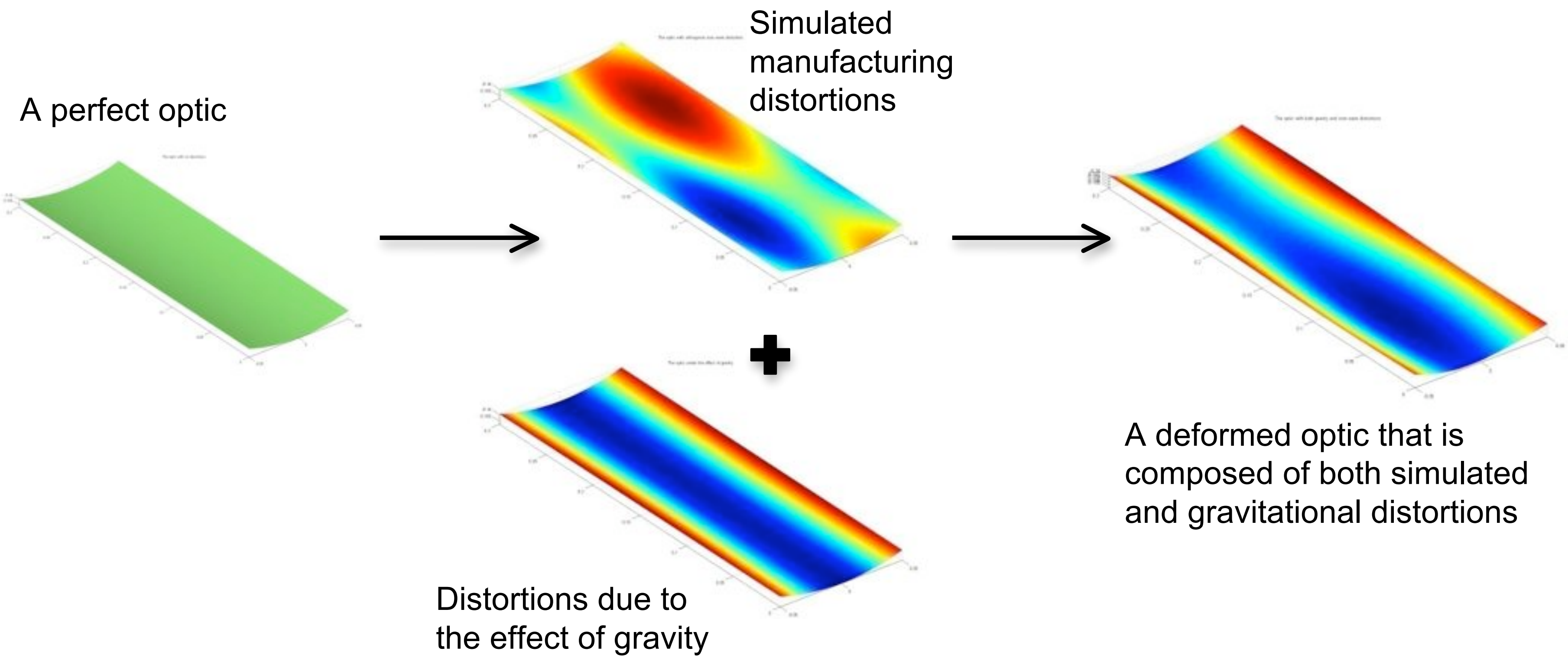


Z - Displacement

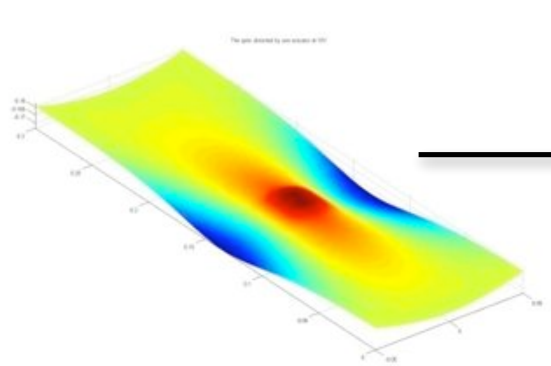


Software Development

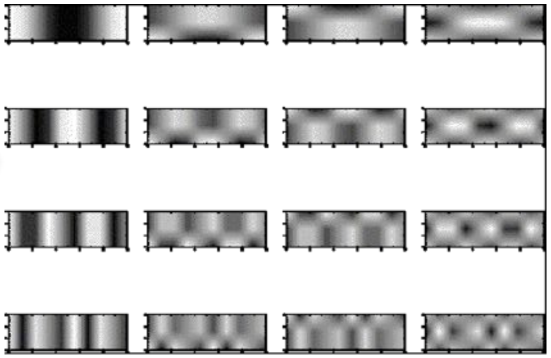
- An approximated simulated annealing method
- Start with a distorted optic
- Try to improve the resolution using actuation



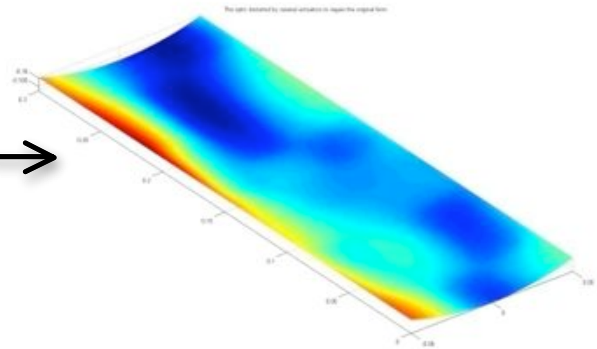
Software Development



Actuator influence function



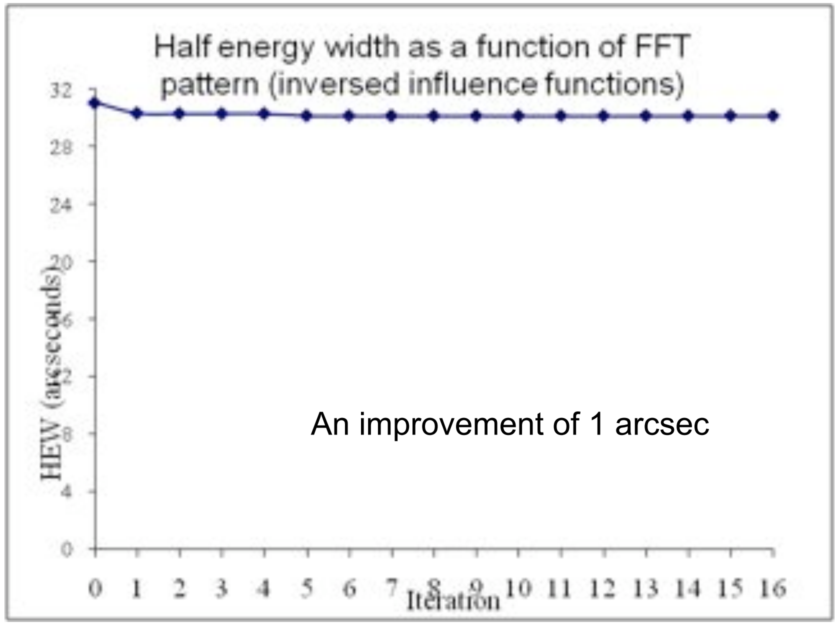
Fourier transform patterns

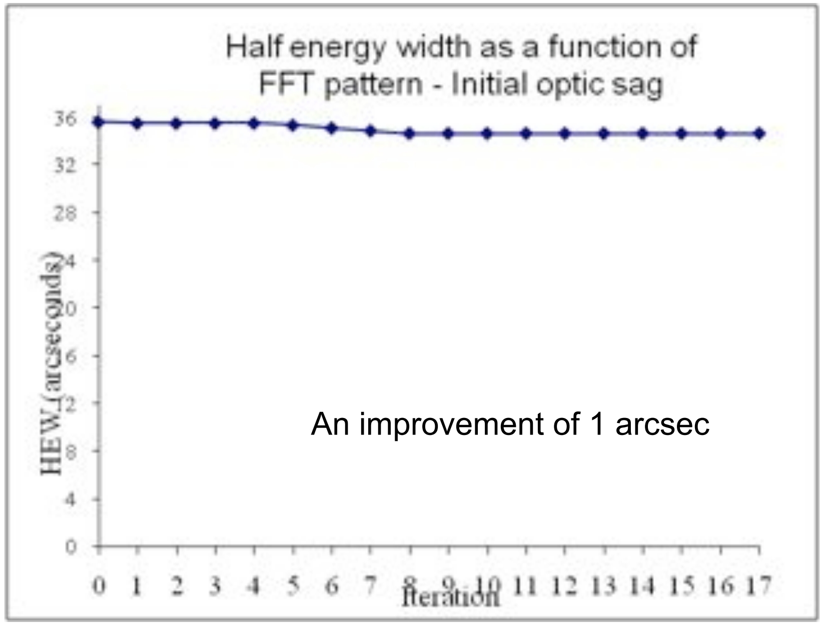


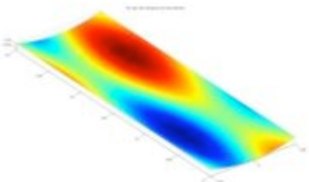
The final actuator pattern composed from the output of the simulated annealing method.

- A series of basis patterns are created using a Fast Fourier transform.
- These are then combined with the actuator influence functions to create the optic distortion.
- The routine iterates through the basis patterns and calculates the best combination.
- This creates the final actuator distortion of the optic.

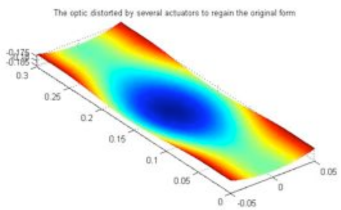
Software Development







- Using simulated distortion of two orthogonal sine waves.
- Sine wave amplitude: 3 μm
- Initial HEW: 31.1 arcsec
- Final HEW: 30.1 arcsec
- number of iterations: 16



- Using radius of curvature measurement data from the cylindrical prototype scaled for the elliptical prototype.
- Initial HEW: 35.62 arcsec
- Final HEW: 34.65 arcsec
- number of iterations: 17

Operation within the X-ray environment

Apply the first FFT actuator pattern using a randomly selected initial voltage

X-ray measurement
HEW is calculated from the MCP detector

The HEW is inputted into the iteration program and the next set of voltages is calculated

New voltages set and allowed to stabilise

After 16 iterations the final voltages and HEW of the optic are attained

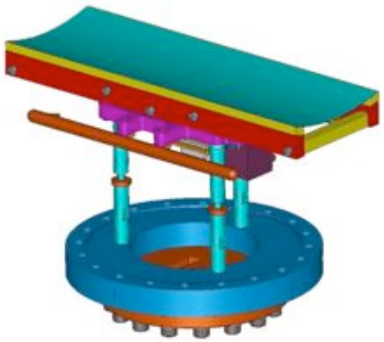
Leicester's X-ray Tunnel Test Facility

Testing at Leicester

- Test date: November 2008 for 4 weeks
- Test facility specifications: 28m in length
  Energy range 0.1KeV to 100KeV
  Optional addition of a laser for alignment purposes
  MCP detector with 0.8m travel

Source end of the test facility

Optic mounting and a CAD drawing with the optic in place



Summary

The Smart X-ray Optic Consortium Goals

- To produce an active X-ray focussing optic with a resolution of 0.1"

Summary

- Completion of all the components of the X-ray tunnel facility mount.
- The cylindrical prototype has been fabricated and is awaiting testing.
- Actuator influence functions and the effects of hysteresis have been investigated.
- A simulated annealing method has been combined with simulated and measured data to provide the control of the actuators.

Current and Future Work

- The elliptical mandrel is in the final stages of completion
- Further tests in the investigation of hysteresis.
- Cylindrical prototype actuation testing.
- Elliptical prototype manufacture and completion.

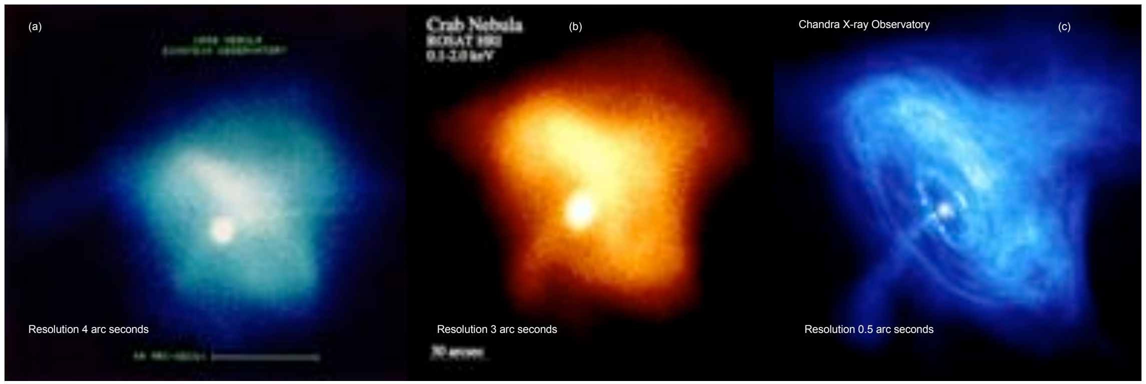
Target

- To produce the active elliptical prototype by the 1st Nov 2008, ready for testing in the University of Leicester's X-ray beam facility

Acknowledgements

SXO Consortium: Carolyn Atkins, David Brooks, Tim Button, Peter Doel, Camelia Dunare, Charlotte Feldman, Melvyn Folkard, David Hart, Ady James, Alan Michette, Graeme Morrison, William Parkes, Slawka Pfauntsch, Daniel Rodriguez Sanmartin, Shahin Sahraei, Andy Smith, Tom Stevenson, Craig Theobald, Samantha Thompson, Boris Vojnovic, Hongchang Wang, Richard Willingale, Dou Zhang.

This work has been funded by a basic technologies grant from the UK Engineering and Physical Sciences Research Council (EPSRC)



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