LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Beam Splitter Optical Surface Deformation due to Gravity

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Distribution of this document:
LIGO Scientific Collaboration

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1 Revisions

Revision 01 – includes added section from a note from Hiro and a set of jpgs of the figures.

2 Introduction

The gravitational load (body force) on the Beam Splitter Optic is supported in the Advanced LIGO suspensions by wire loops which go round the barrel of the optic breaking off from prisms on the side of the optic. The stress field created by the gravitational load and the resulting ear bond reaction forces will cause a deformation of the optic. We are concerned with the deformation of the optical surfaces, which are polished in a horizontal orientation.

3 Model

The fused silica Beam Splitter dimensions are 370 mm diameter by 60 mm thick. There are no flats on this optic. The optic nominally weighs ~ 14 kg. A three-dimensional finite element model, Static Structural Analysis, created with the ANSYS Workbench version-11.1 software, depicted in Figure-1, represented this geometry. The bevels and the wedge angle of the optics were not included in this model. The mesh consists of 62,00 solid elements (SOLID187) and 100,000 nodes. In the analysis reported here only a vertical gravity vector is considered and the boundary conditions are as follows: -

1) Cylindrical support applied to two areas on bottom of barrel rep wire loop (radial: fixed, axial: fixed ,tangent: free)

2) Displacement applied to centre location on bottom to remove clocking motion (X: 0 , Y: free , Z:0). The clocking was observed when I only used boundary condition #1.

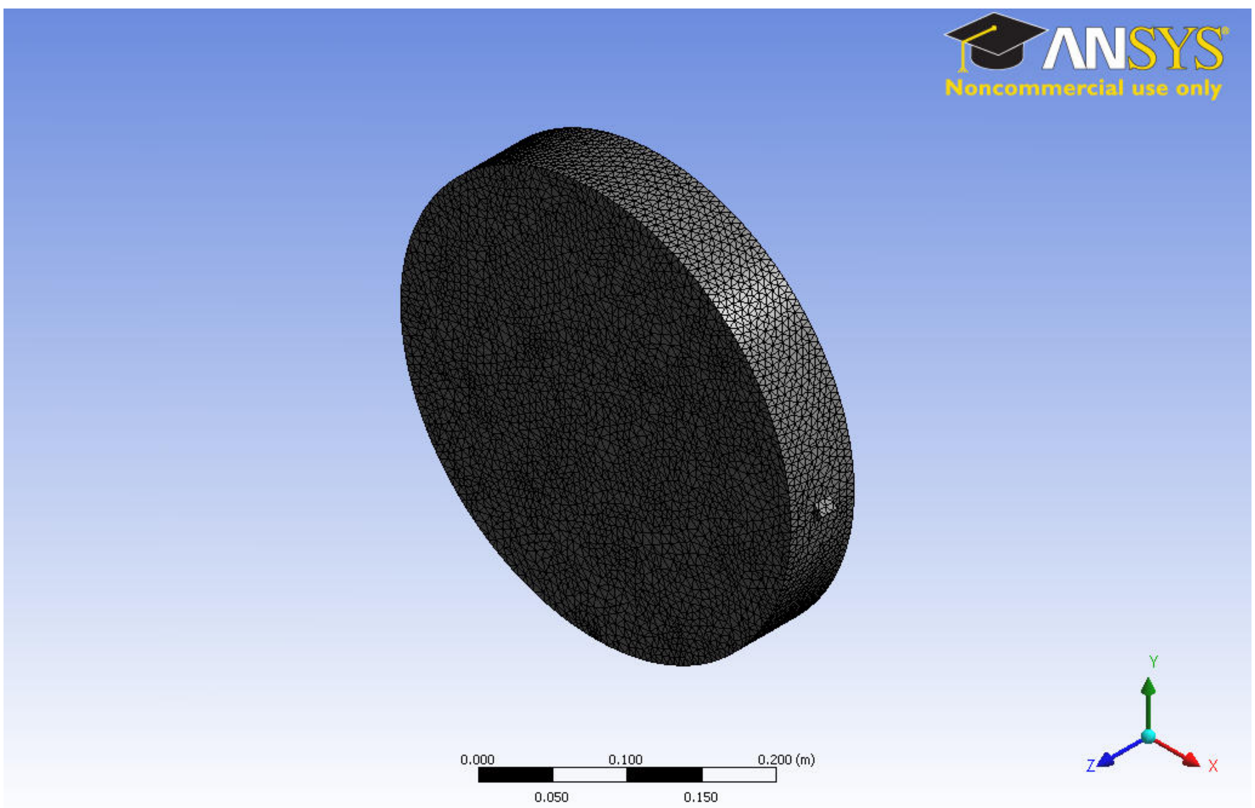


Figure 1: Finite Element Mesh (The mesh consists of 62,000 solid elements and 100,000 nodes.)

As well as the boundary conditions described above gravity is applied in the vertical direction, Y direction in the model.

4 Deformation Field

The finite element analysis indicates a peak transverse (normal to the optic face) deformation of ~ 3 nm total as shown in figure 2 below.

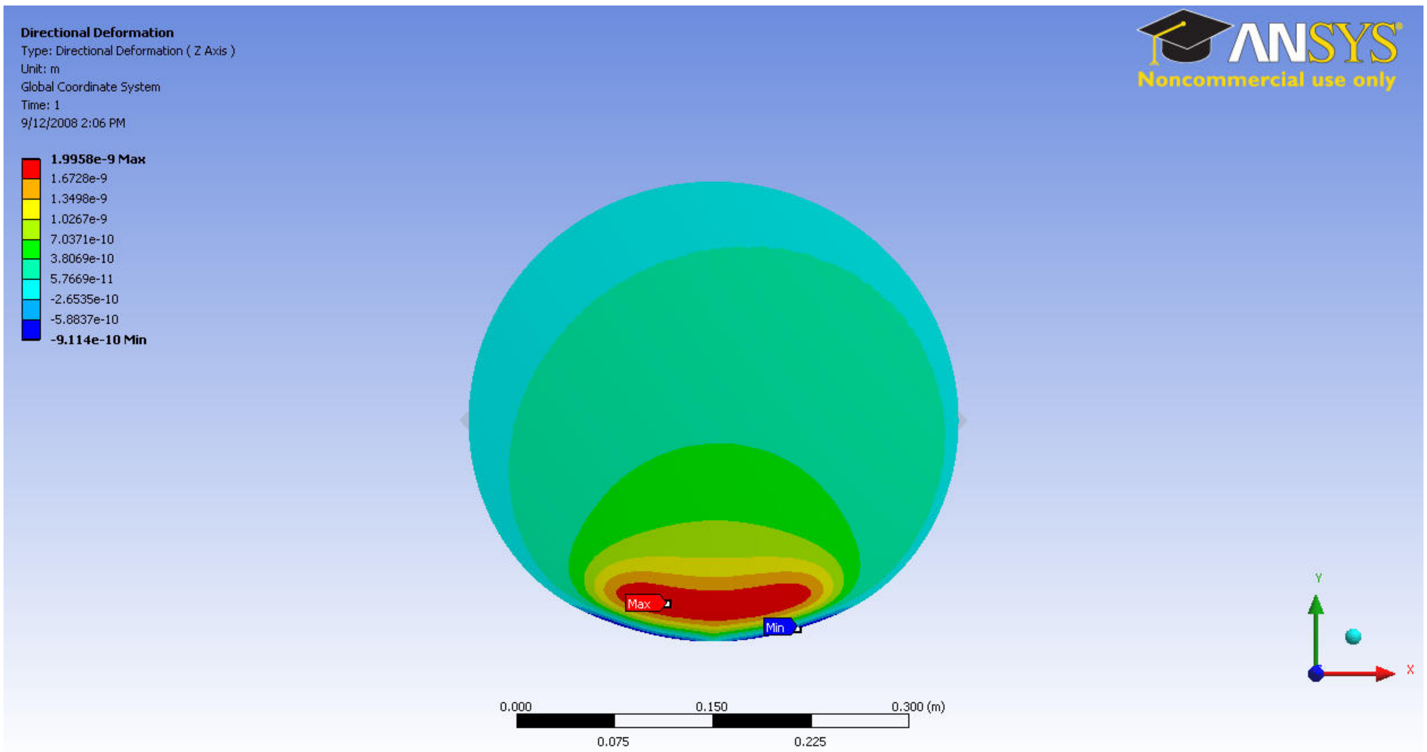


Figure 2: Front Surface Normal Displacement (see note below)

Figure 2 and figure 7 show peak positions at off center, and it looks like left-right symmetry is broken. The actual distribution has two peaks at the symmetric positions and, due to numerical precision, it happened that one of the peak was infinitesimally larger than the other.

The distribution shows the following (from Hiro Yamamoto).

The sag is < 0.3nm in 100mm radius, which corresponds to 17 x 10^3 km.
The rough tilt in the vertial direction is 1 nm / 37cm = 3e-9 rad.

5 Comparison to ETM work in LIGO-T050184

The finite element analysis indicates a peak transverse (normal to the optic face) deformation of ~ +/- 4 nm, or 8 nm total, which compares with the work done in LIGO-T050184.

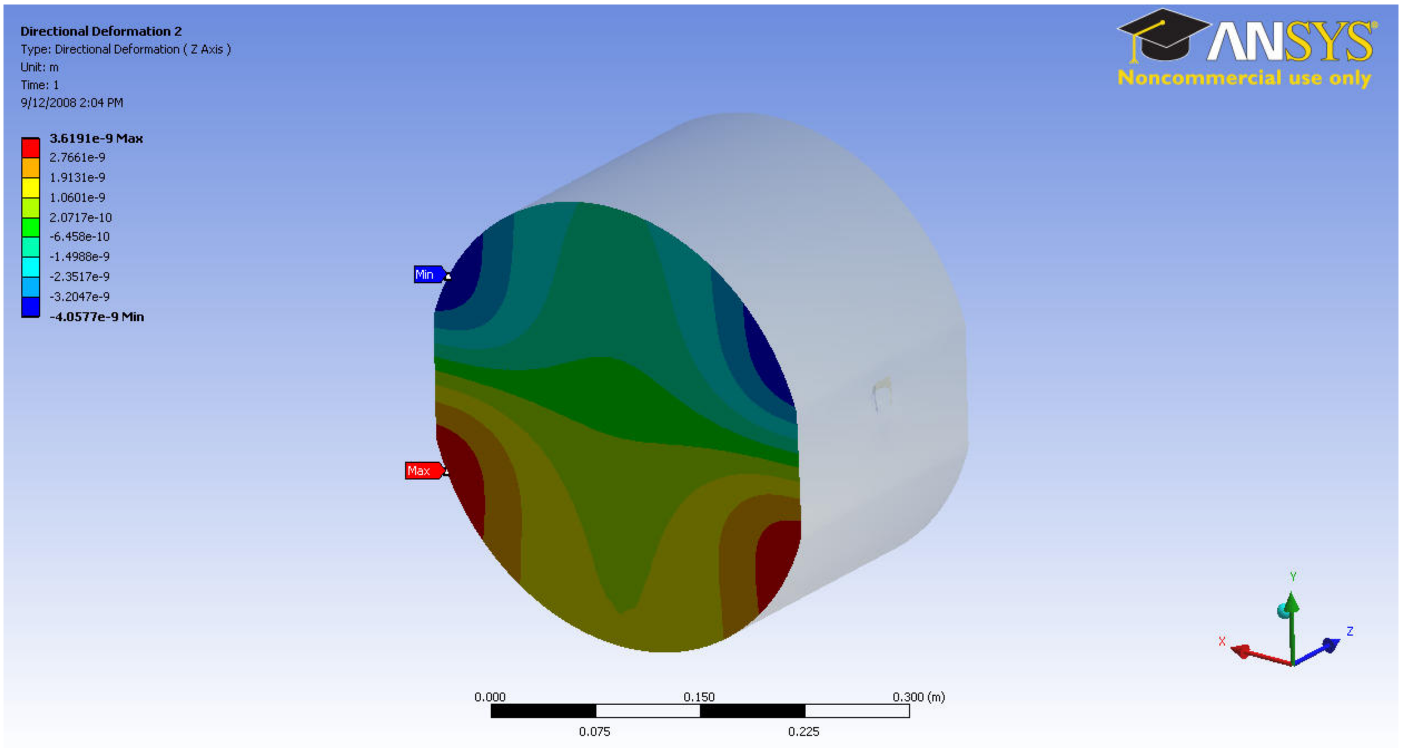


Figure 3: - Front Surface Normal Deformation of the ETM Optic (Isometric)

6 Actions and Further Work

I have now given a file with HR surface node deformation results to Hiro and written up the associated draft memo.
I would like to look at use of Cartesian co-ordinates to apply force as an alternative method to that described above (I have been talking to Riccardo DeSalvo about this)) and eventually (not urgent) decompose results into zernikes and include in a revision to this memo.

Appendix 1

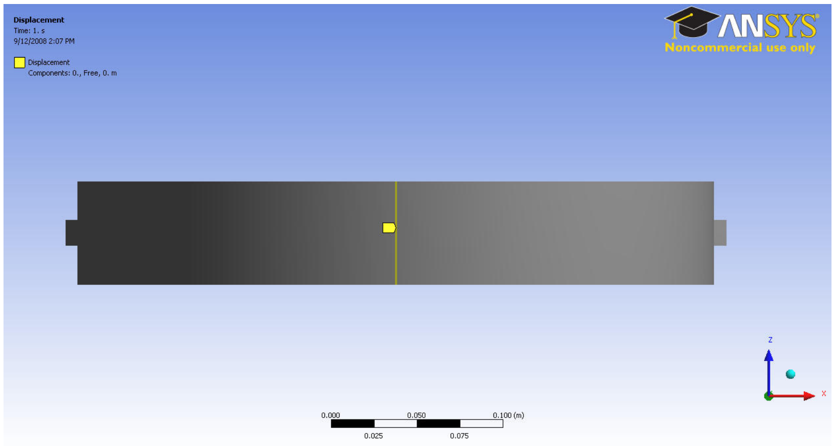


Figure 4: - Displacement support

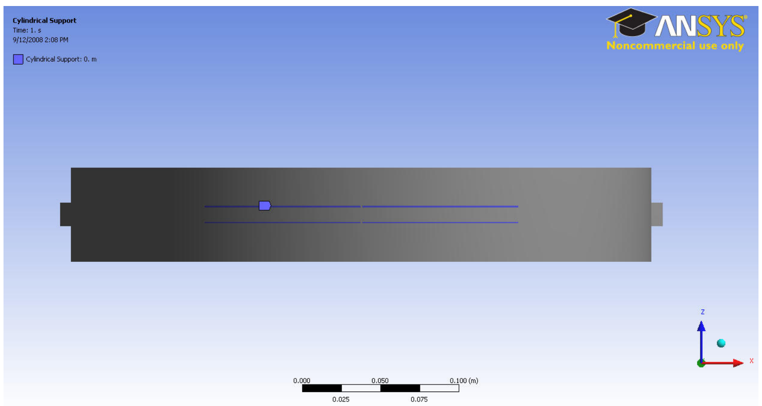


Figure 5: Cylindrical Support

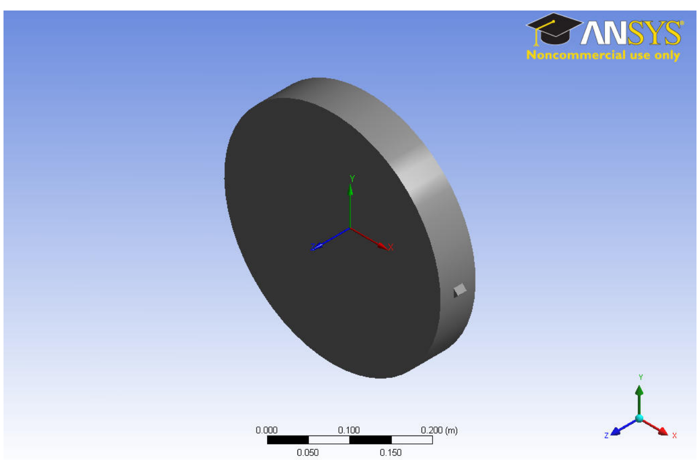


Figure 6: - Co-ordinate System

Appendix 2

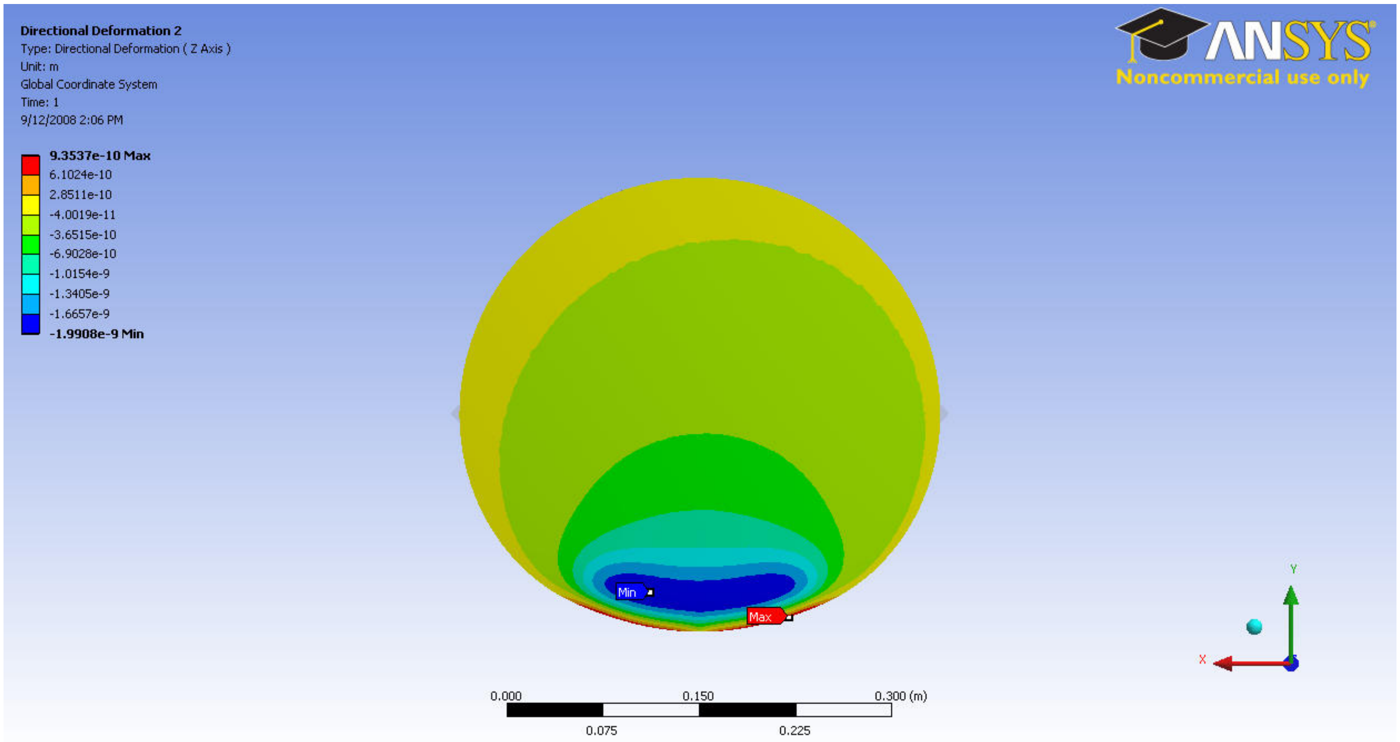


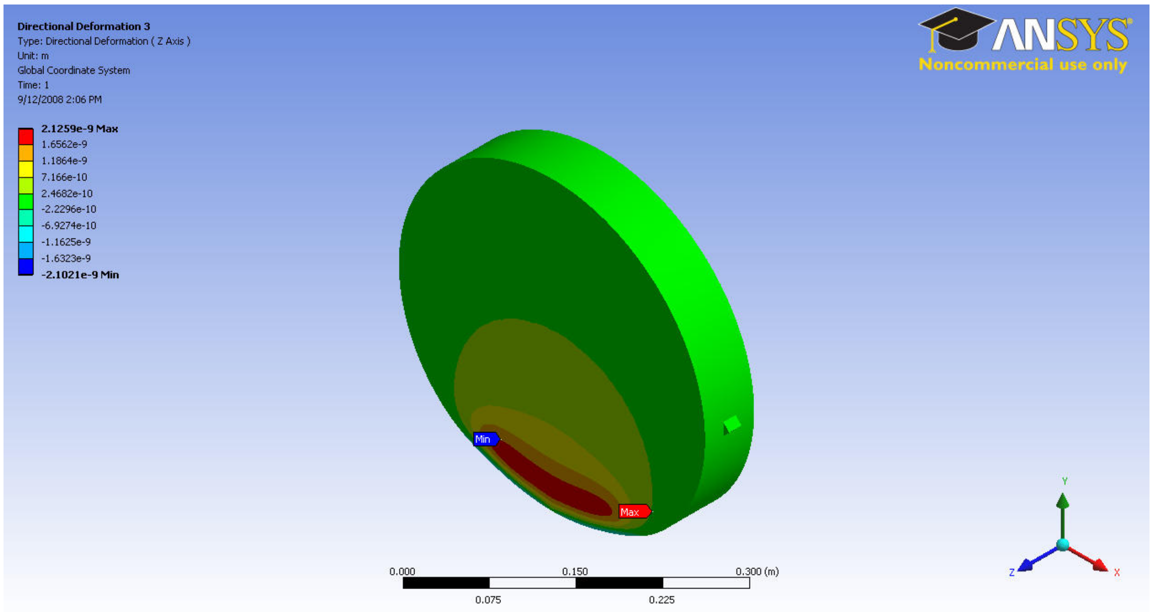
Figure 7: Back Surface Normal Displacement (see note on page 3)

ANSYS Node Number	X Location (m)	Y Location (m)	Z Location (m)	Directional Deformation (m)
1	5.00E-04	-0.185	3.00E-02	0
419	-5.00E-04	-0.185	3.00E-02	0
420	5.88E-03	-0.18491	3.00E-02	-3.25E-10
421	1.12E-02	-0.18466	3.00E-02	-5.25E-10
422	1.66E-02	-0.18425	3.00E-02	-6.37E-10
423	2.20E-02	-0.18369	3.00E-02	-7.15E-10
424	2.73E-02	-0.18298	3.00E-02	-7.83E-10
425	3.26E-02	-0.18211	3.00E-02	-8.12E-10
426	3.79E-02	-0.18108	3.00E-02	-8.47E-10

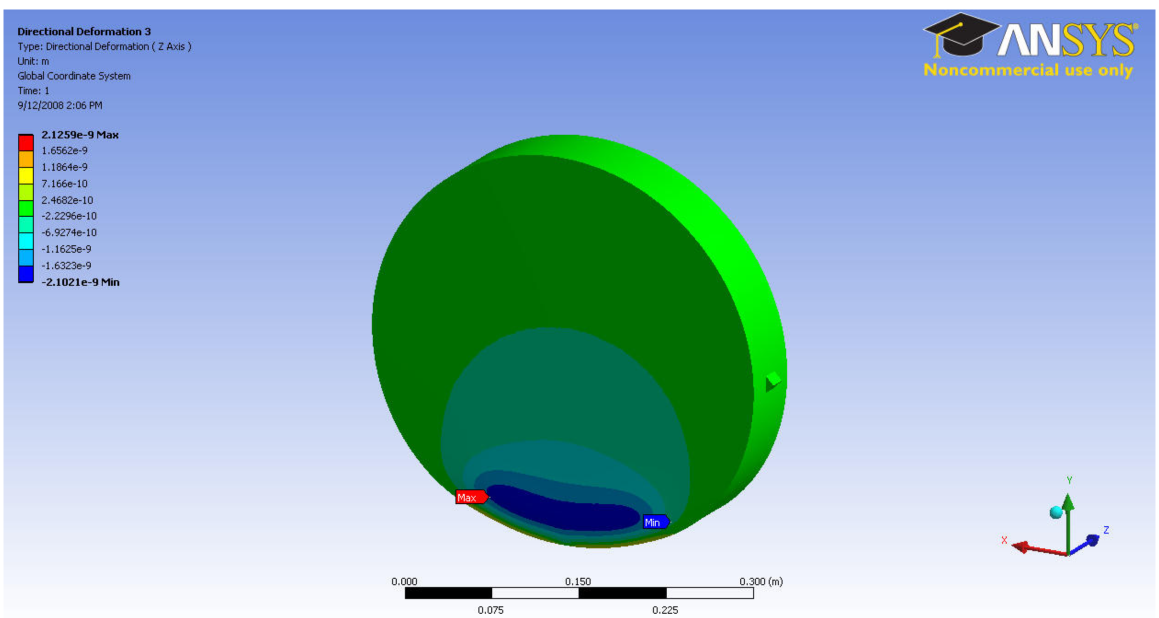
Table 1 : Extract of available output available from ANSYS in ASCII or EXCEL files

Appendix 3

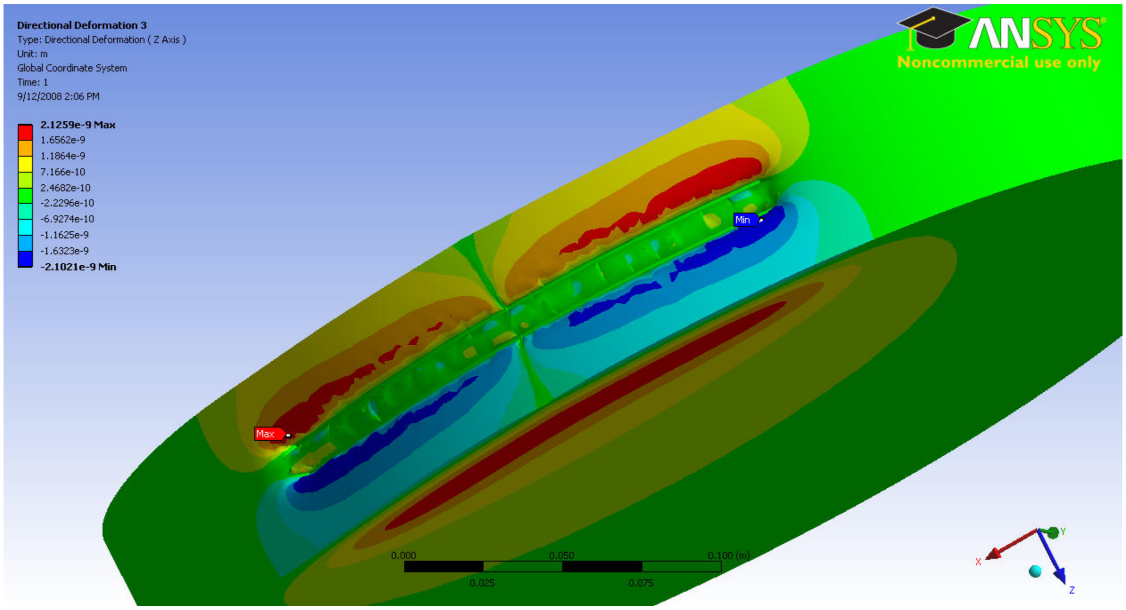
The following images are the total deformation of the optic (front, rear and the from below) in the Z direction



Appendix 3-1 – Isometric front



Appendix 3-2 – Isometric rear



Appendix 3-3 – looking at location of wire on barrel of optic from below

Appendix 4

E-mail from Hiro Yamamoto: -

I suggest you add two informations.

One is about fig2 and fig7. These two figures show peak positions at off center, and it looks like left-right symmetry is broken.
The actual distribution has two peaks at the symmetric positions and, due to numerical precision, it happened that one of the peak was infinitesimally larger than the other. A short comment would relieve unnecessary wonders.

Another is a simple estimation of the effect. The distribution shows the following.

The sag is < 0.3nm in 100mm radius, which corresponds to 17 x 10^3 km.
The rough tilt in the vertial direction is 1 nm / 37cm = 3e-9 rad.

These numbers will give a good intuitive guidance how (not) serious this deformation is.
Probably, another note based on more careful calculation will be worthwhile, but these two numbers, sag and tilt, say 90% of what is needed.