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Gravitational Deflection of LIGO Optics in a 9-Point Hindle Mount

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Detector

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Abstract

The deflection, due to self weight, of a LIGO test mass optic in a mount used for metrology measurement at CSIRO is calculated with a finite element model. The optic is oriented with its axis vertical and is placed on a 9-point Hindle mount.

Keywords: core optics, deflection, wavefront error

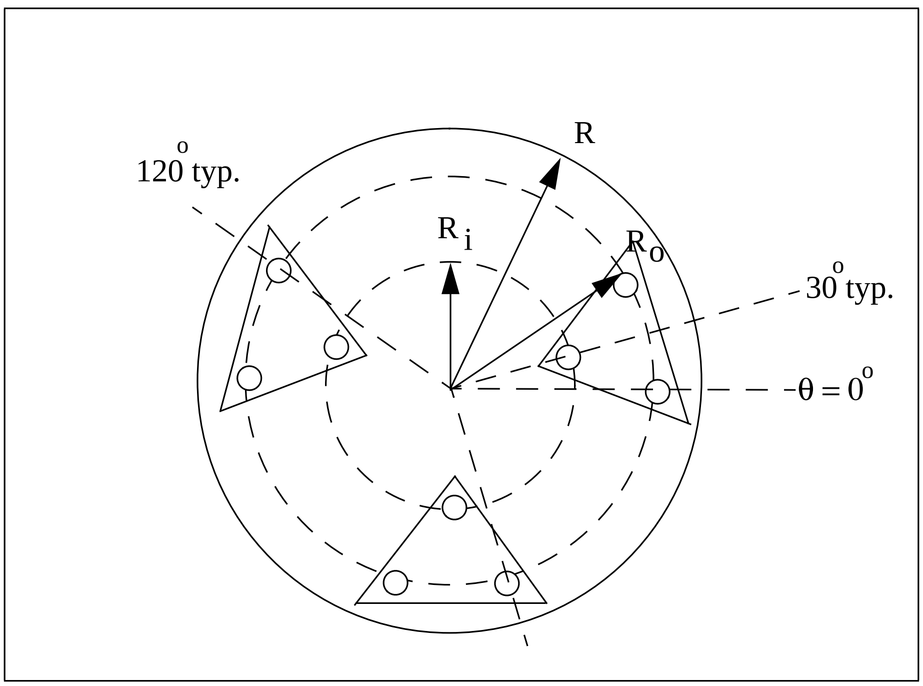
1 OVERVIEW

CSIRO is polishing a number of LIGO core optic components (COC). Interferometric measurement of the surface error is accomplished with the optic axis oriented vertically. CSIRO proposes to use a 9-point hindle mount to support the optic. The self-weight of the optic (due to gravity) will cause the optic to distort. A finite element analysis has been conducted to predict the magnitude and shape of the gravitationally induced deflection of a LIGO test mass optic.

2 HINDLE MOUNT

The details of the mirror mount which CSIRO proposes to use in their metrology system is described in [1]. The vertical axis mount is known as a nine point Hindle mount [2],[3],[4]. The nine-point mount is a two level mount in which three points are supported from a triangular, or delta plate (also known as a “whiffle tree”) at each of three locations. The three locations are located equidistant in azimuth position and located at the radius which divides a constant thickness mirror into a central disk of one-third the total weight and an annulus of two-thirds of the total weight (Figure 1).

Figure (1) Hindle Support Geometry



If the radius of the optic is R, the radius of the inner support points are at:

$$R_i = \left(\frac{\sqrt{6}}{6}\right)R$$

and the radius of the outer supports are at:

$$R_o = \left(\frac{\sqrt{6}}{3}\right)R$$

For the LIGO COC, R = 125 mm, R_i = 51.0 mm and R_o = 102.1 mm. The CSIRO mount has R_i = 51.8 mm and R_o = 103.6 which are quite close to the nominal Hindle mount locations.

In the CSIRO mount, each of the nine support points is comprised of a 11.2 mm diameter pad covered in velveteen.

Hindle mounts are often used for metrology, sometimes with many more than 9 points if the optic has a small thickness to diameter ratio. In general the more support points (including in the limit, continuous support) the better in terms of reducing gravity induced sag. However metrology mounts also generally have stringent alignment (and alignment repeatability) requirements which often preclude the use of soft support materials for continuous support interface to the (non-flat) support table.

3 FINITE ELEMENT ANALYSIS

The LIGO optic substrates are in two different *basic* sizes, one for the beamsplitter (BS per D960793) and one for the recycling mirror (RM), folding mirror (FM), input test mass (ITM) and end test mass (ETM per D960794). After grinding & polishing, both have a diameter of 250 mm. The beamsplitter substrate is 40 mm at it's minimum thickness (after grinding & polishing). The other optics are 100 mm thick at their thickest point (after grinding & polishing).

In all analyses, the acceleration field is defined to be 100 g (980 m/s2) in order to avoid numerical roundoff problems with small displacements.

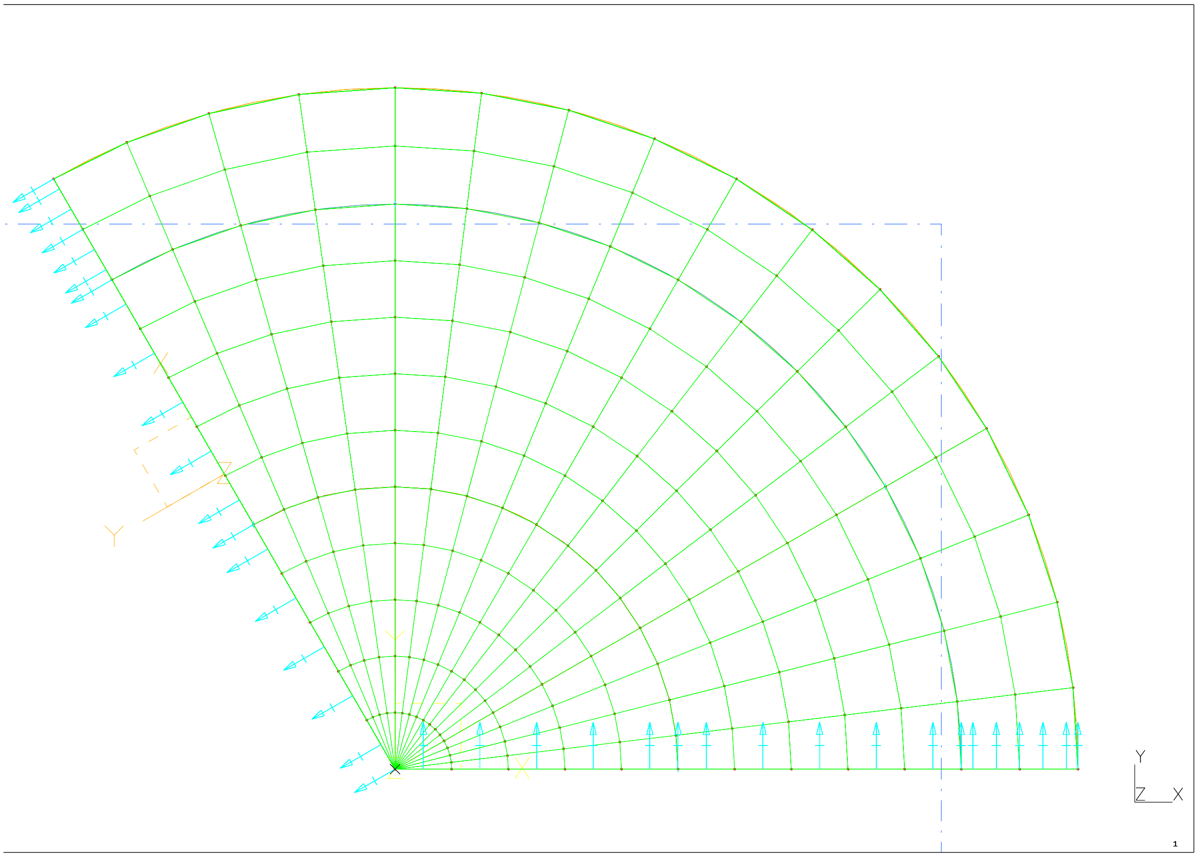
3.1. ETM, ITM, FM, RM

A 120 degree sector Finite Element Model (FEM) with symmetry boundary conditions along the radial faces was prepared (from $\theta = 30^0$ to 150^0, where θ is defined in Figure 1). The support points were modeled as single point vertical restraints, since the small spatial extent of the mount pads would not significantly "print through" the thick optic. The FEM is comprised of 1920 linear, isoparametric, solid brick and wedge elements (2255 nodes) linearly distributed with 12 radially, 16 circumferentially and 10 through the thickness, as shown in Figure 2. The load (100 g) is in the -Z direction, i.e. normal to the optic face. Convergence was checked with a full model (no symmetry boundary conditions) with 2592 elements (18 radial[1], 24 circumferential and 6 through thickness). The wedge angles have been neglected for calculation of the sag of the thick optics. (The maximum 2 degree wedge represents a reduction of only 9 mm from a thickness of 100 mm.)

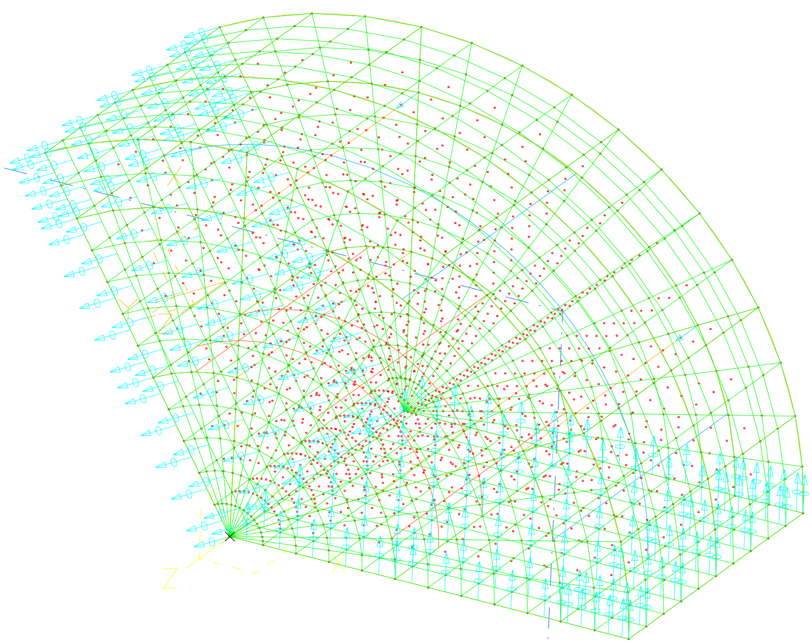
1. The radial distribution was biased to have most of the elements near the center of the optic.

Figure (2) Thick Core Optic FEM

(a) planform



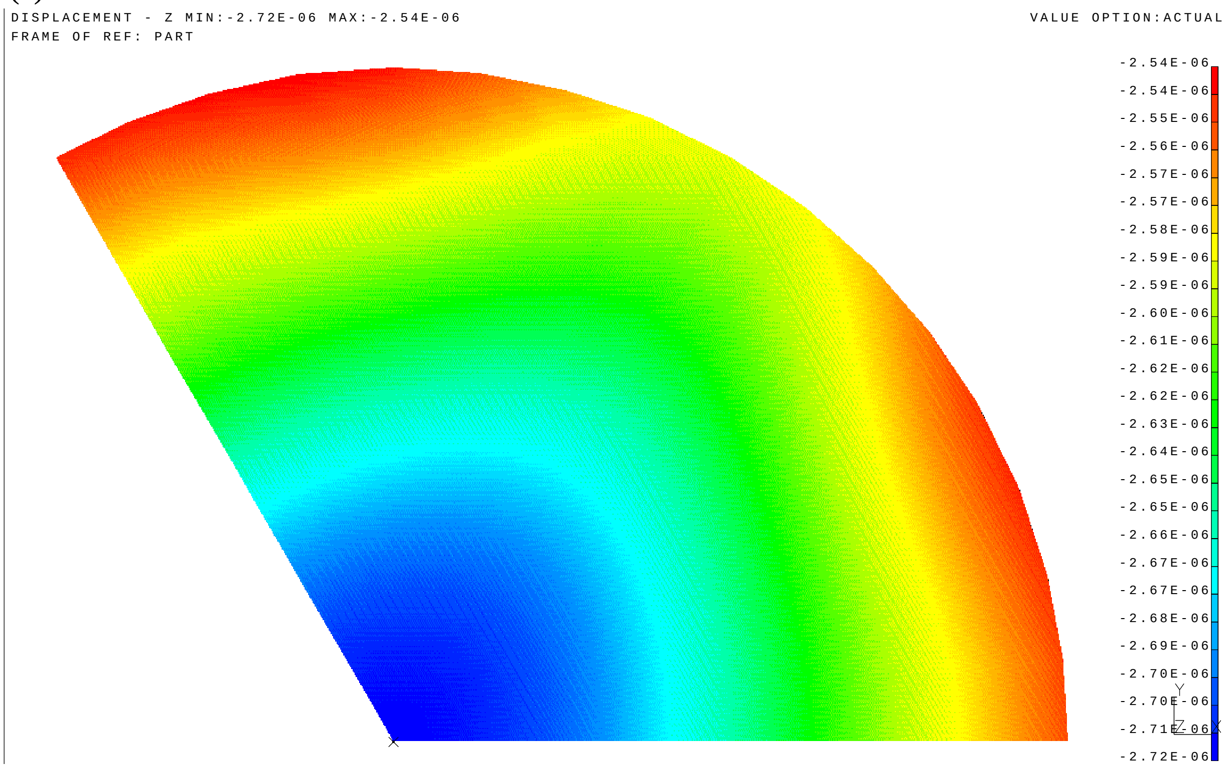
(b) isometric view



The vertical (z) deflection due to the gravitational load is given in Figure 3 (where the units are in cm for a 1 g load). The peak to valley (pv) deflection across the front face of the optic is 1.8 nm. The spatial variation of the deflection is principally focus, but there is a component of deflection with a 120 degree azimuthal period.

Figure (3) Thick Core Optic vertical displacement (cm) due to 1 g

(a) contour



(b) line contour

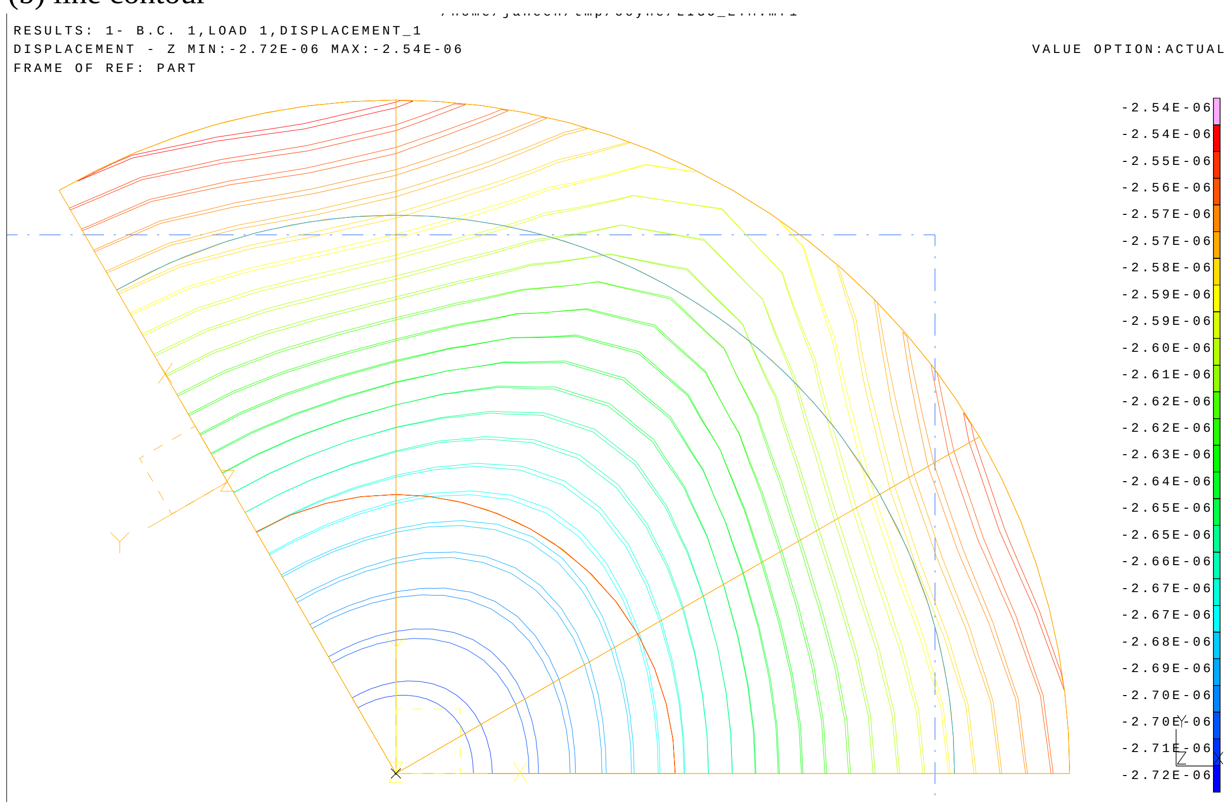
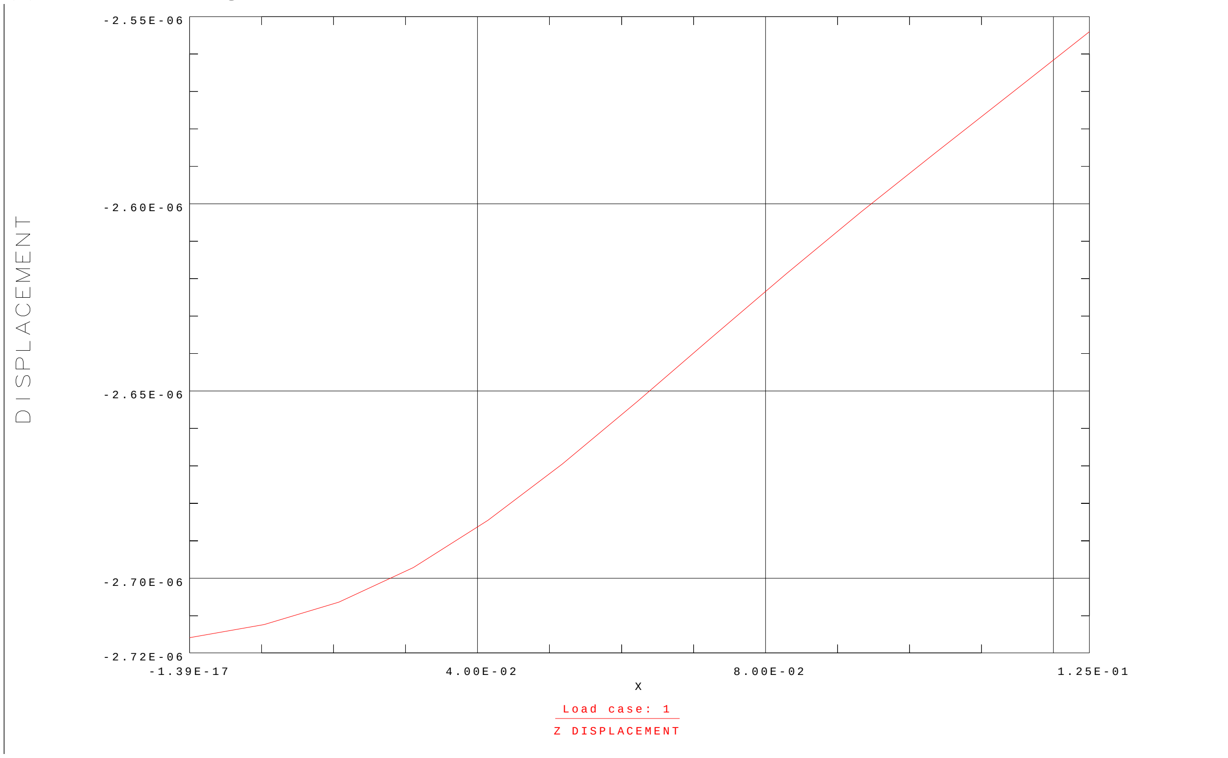


Figure (3) Thick Core Optic vertical displacement (cm) due to 1 g

(c) variation along $\theta = 0^0$



3.2. BS

The FEM is shown in Figure 4. The model has a 1 degree symmetric wedge (i.e. 0.5 degree wedge of each face relative to the cylindrical sides of the optic.). The gravity vector was oriented along the cylindrical axis (Z-direction) so that both the plane defined by the Hindle support points and the front surface of the optic were oriented at 0.5 degrees from the gravity vector. The FEM is comprised of 3456 isoparametric, solid brick and wedge elements linearly distributed with 12 radially, 48 circumferentially and 6 through the thickness.

The Hindle support points were modeled as point (nodal) constraints since (i) the diameter of the pads (11.2 mm) are small relative to the optic dimensions and (ii) to constraint more nodes in this region would artificially add a rotational restraint which is not realistic. Kinematic constraint against lateral sliding was ensured by restraining the central point of the optic (on the assumption of a nearly symmetric response); restraint against rotation about the vertical (Z) axis was achieved by the addition of a tangential restraint at one of the Hindle mounting points.

The vertical (z) deflection due to the gravitational load is given in Figure 5 (where the units are in cm for a 1 g load). The surface deflection is 5.5 nm pv. The deflection pattern shows a clear three-fold azimuthal symmetry reflecting the Hindle mounting arrangement.

4 REFERENCES

[1] B. Oreb to G. Billingsley, LIGO-C970153-00-D Action Item No. 6 Response, 1/31/97.

[2] P. Yoder, Opto-Mechanical Systems Design, Marcel Dekker, 1986, section 10.4.2, pg. 302-305.

[3] J. H. Hindle, Mechanical Flotation of Mirrors, in Amateur Telescope Making, Book One, A.G. Ingalls (ed.), p.229, Scientific American, 1945.

[4] R. Sinnott (ed.), “Telescope Making: Mirror Support: 3 or 9 Points?”, Sky & Telescope, Sep. 94.

Figure (4) BeamSplitter FEM

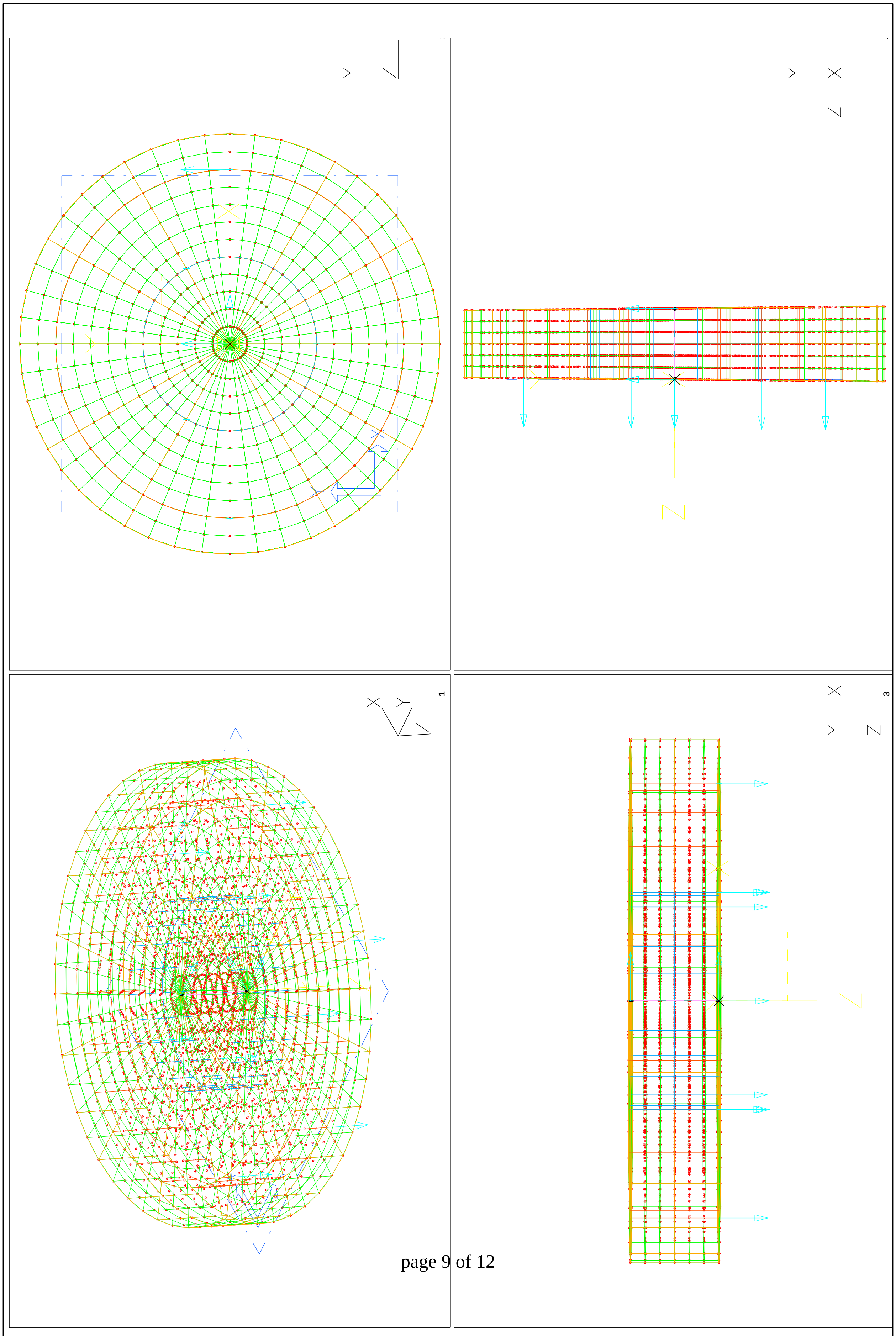


Figure (5) Vertical displacement of the optic surface (cm) due to 1 g

(a) line contours

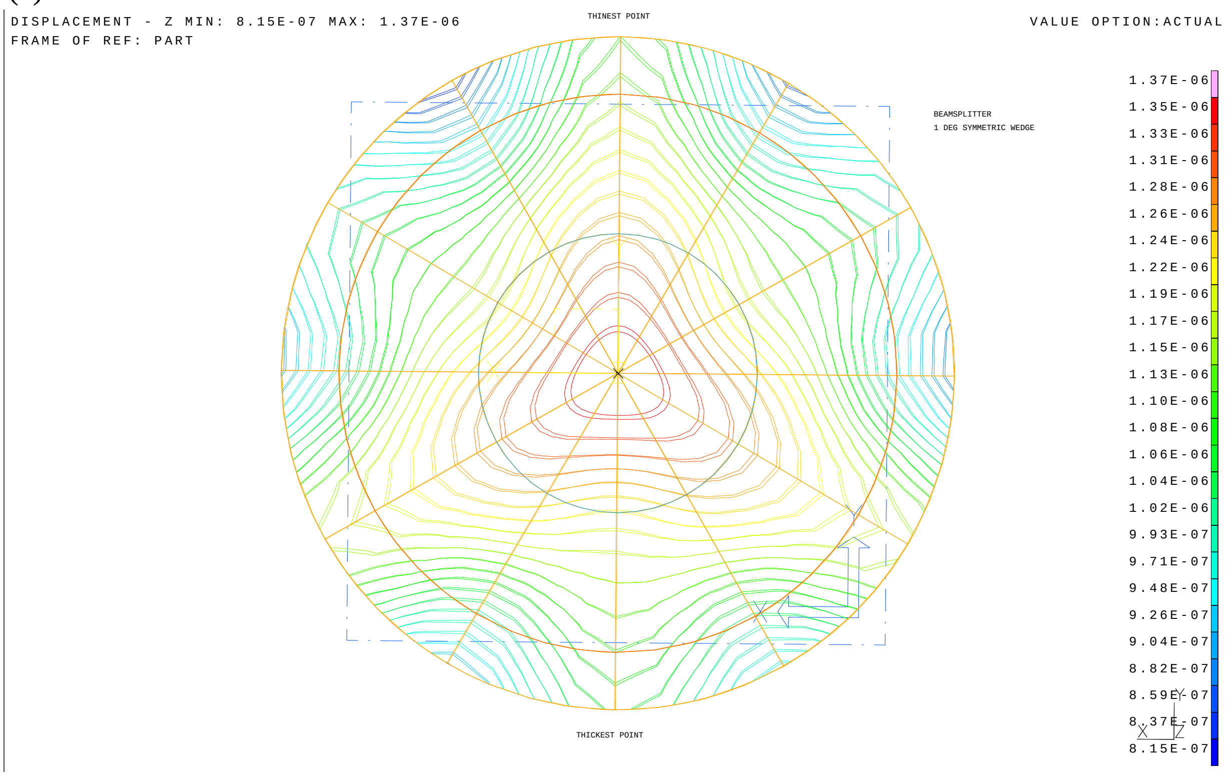
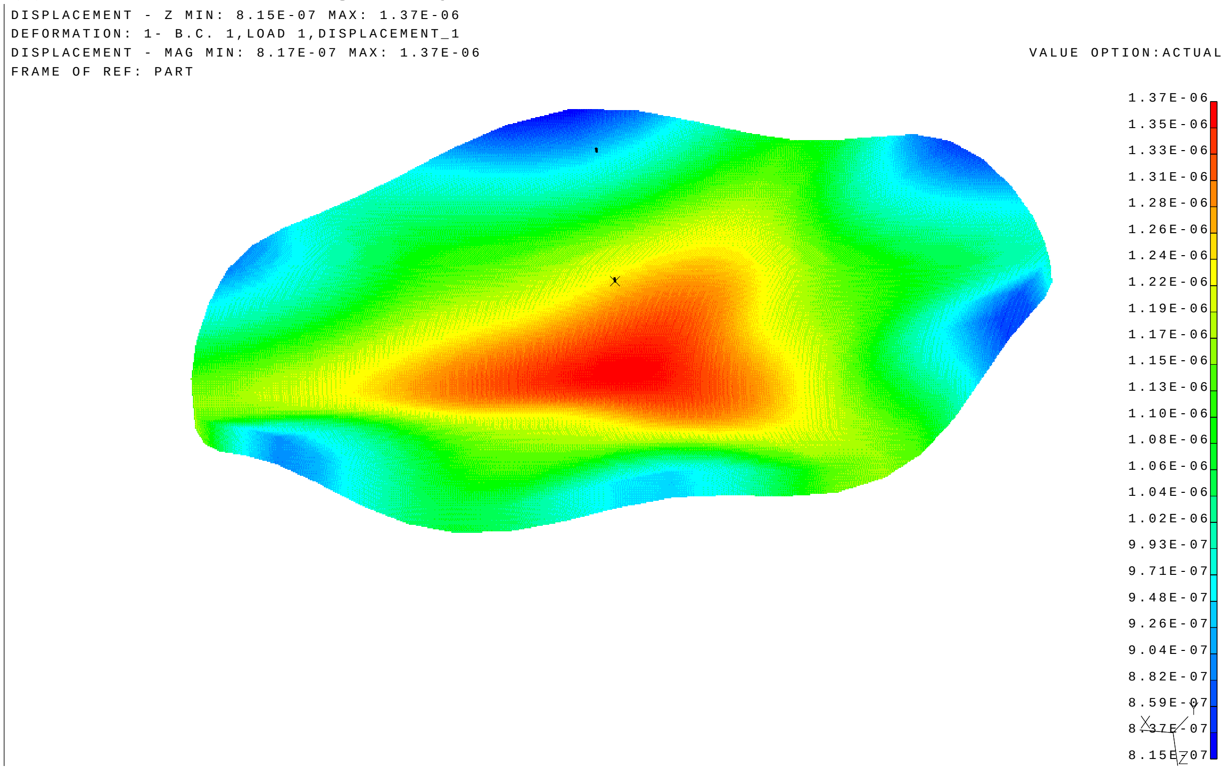


Figure (5) Vertical displacement of the optic surface (cm) due to 1 g

(b)contours on deformed geometry



(c) variation along $\theta = -90^0$ (through support at R_i)

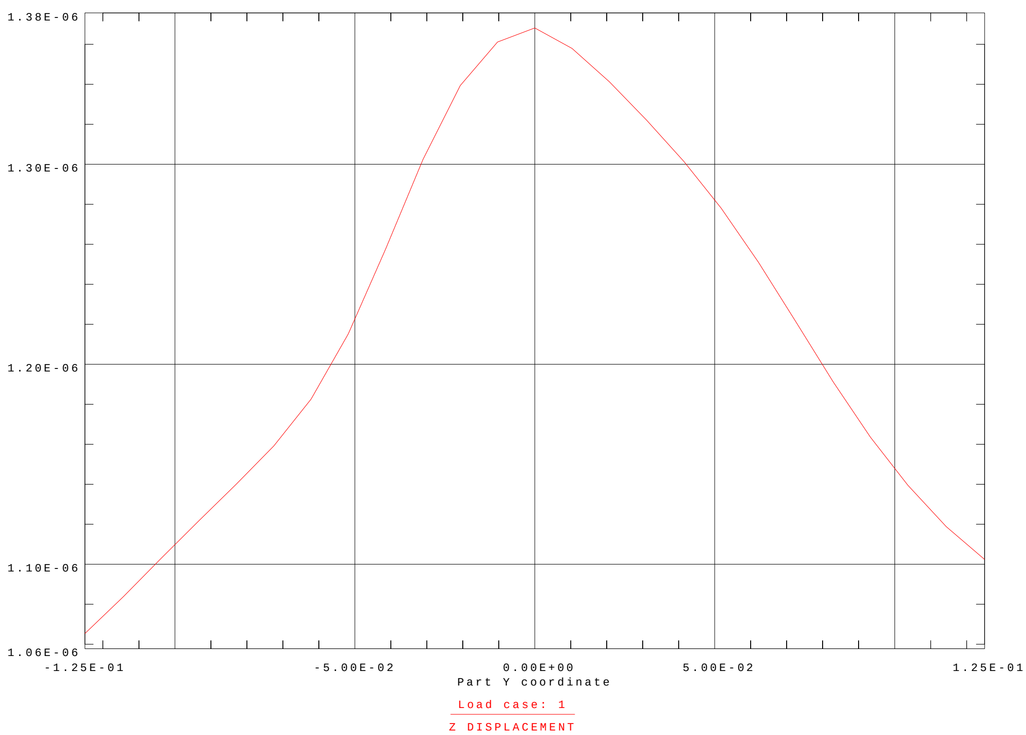


Figure (5) Vertical displacement of the optic surface (cm) due to 1 g

variation along $\theta = -60^0$ (through support at R_o)