LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Natural Vibration Modes of ITM number 11

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LIGO Science Collaboration

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1 Introduction

As part of the research to support an advanced LIGO, core optic material selection decision, Phil Willems is measuring the mechanical loss factors associated with some of the natural modes of a polished, uncoated fused silica optic of approximately initial LIGO dimensions. The optic is designated ITM number 11. It has an initial LIGO diameter (250 mm), but has no wedge angle and is slightly thicker than an initial LIGO test mass optic (108 mm thick versus 100 mm at the thickest point for an initial LIGO test mass). Finite element calculations of the unconstrained, natural mode frequencies and mode shapes are presented in this memo.

2 Frequencies and Strain Energy Fractions

Frequencies and strain energy ratios for the first 25 modes (to 22 kHz) are summarized in the Table below. The strain energies[1] are for unit (1 mm) peak displacement of the mode. The strain energy is partitioned into the fraction associated with the barrel and with the overall surface (barrel plus faces). These ratios are rather approximate. The strain energy of all elements with a face on the barrel (or face) is simply added, i.e. there is no explicit boundary layer thickness associated with the surface. The typical element dimensions are about 15 mm, so the surface related strain energies are associated with a volume extending from the surface into the right circular cylinder a distance of about 7 mm.

Note the very low strain energy associated with the barrel for modes 4 and 5 (11.2 kHz). This mode is a radial compression/expansion mode (depicted in the next section). The frequency of this mode is same (to 3 significant figures) as that for the initial LIGO end test mass, with a 2 degree wedge angle and 100 mm thickness (see LIGO-T970191-03).

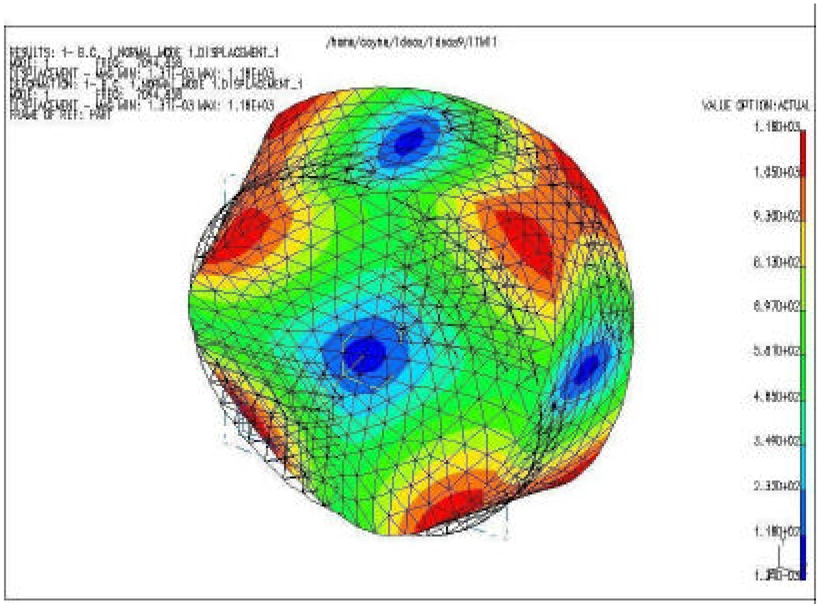
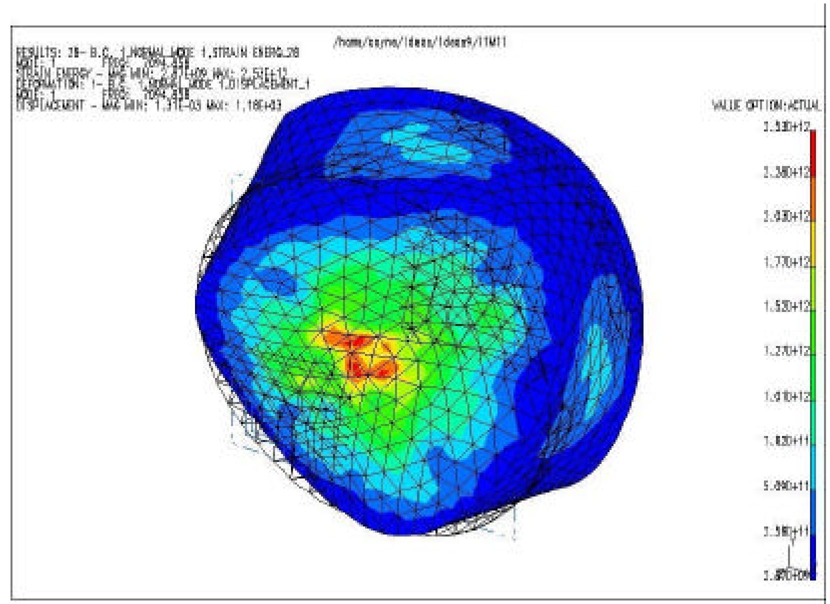
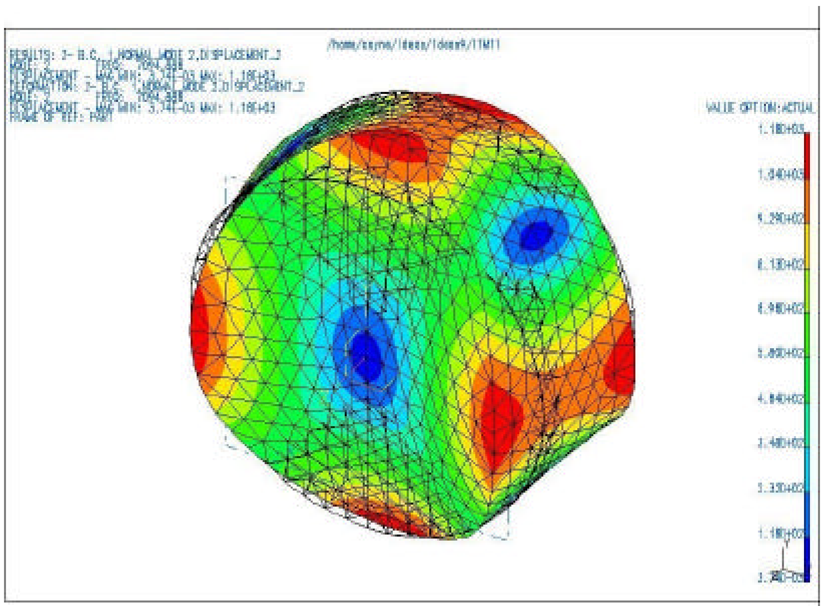
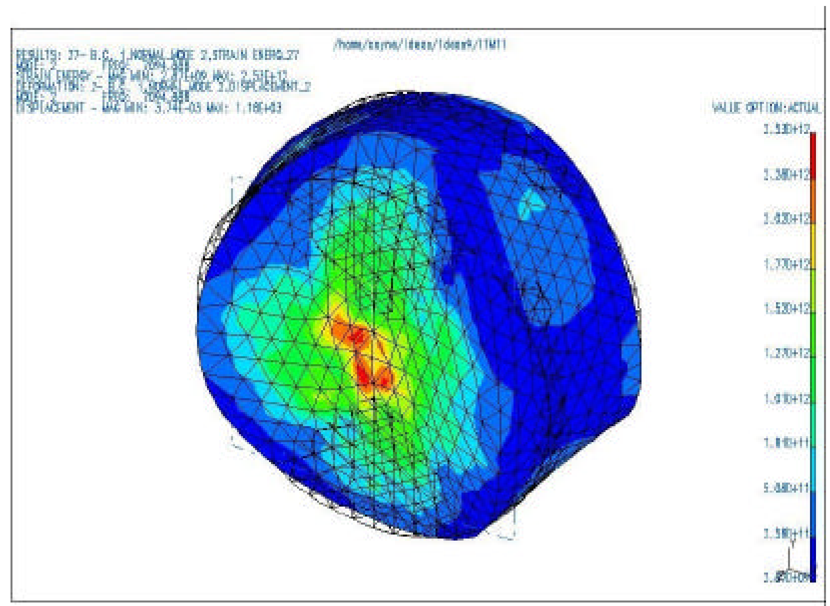
[1] Based on the I-DEAS documentation, the strain energy should be in units of Joules and normalized to unit dsplacement – in this case 1 mm. However, this has not been confirmed by independent check and it is known that the normalized mode shapes reported by I-DEAS, are in fact not normalized to unit amplitude even when this option is selected. For the relative (% of total) results reported here, this point is probably not important.

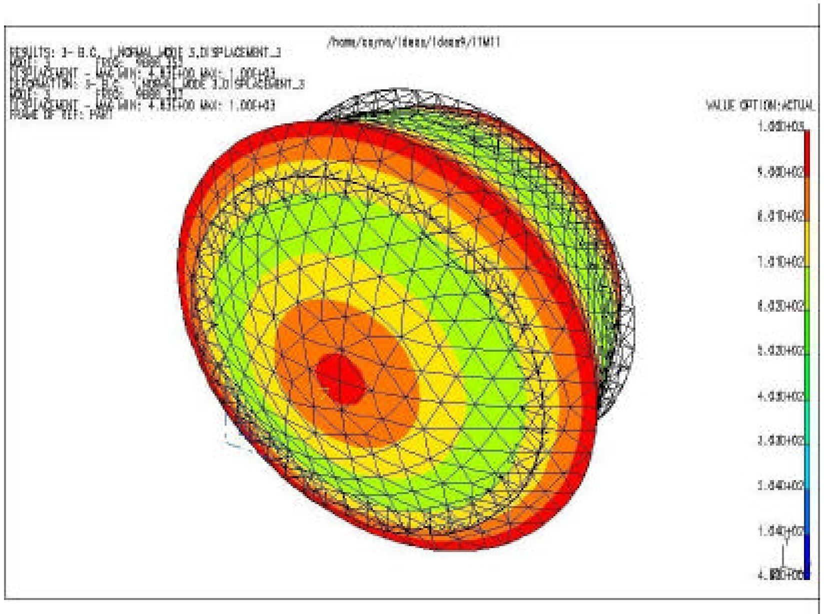
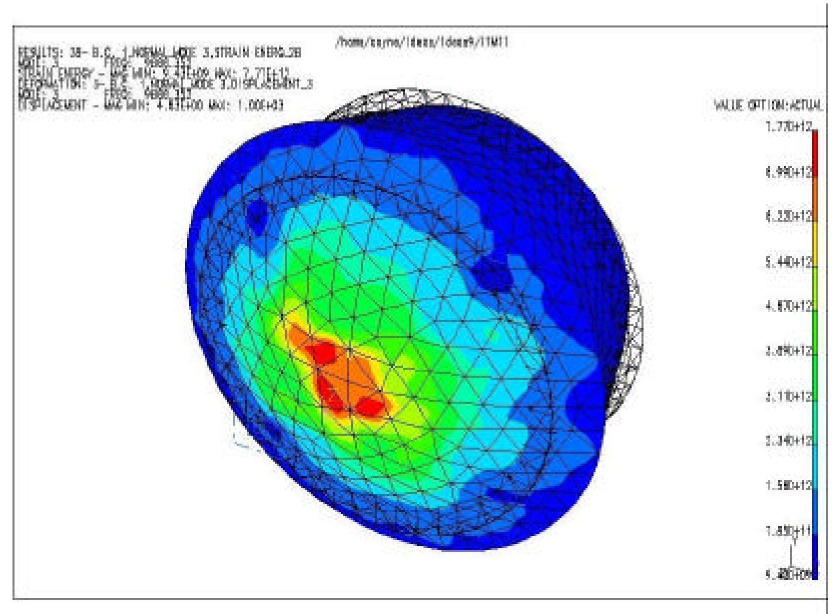
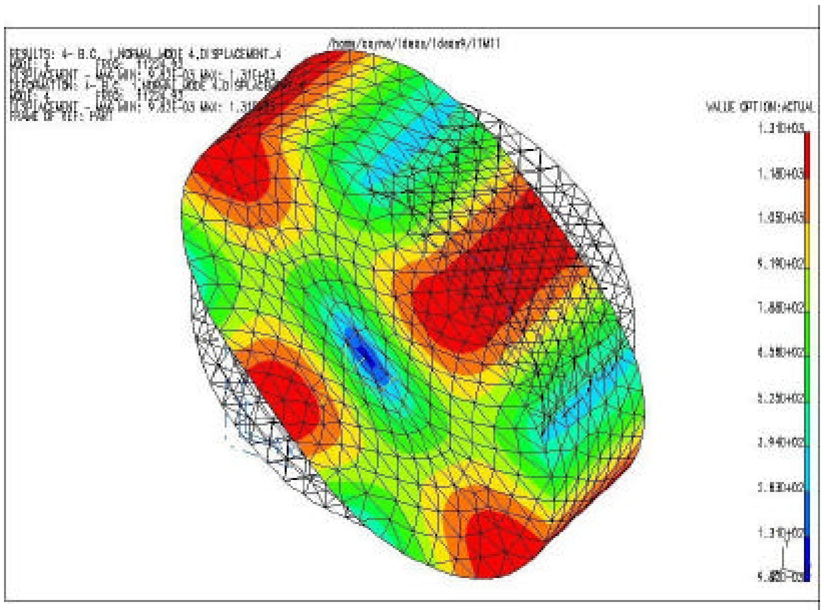
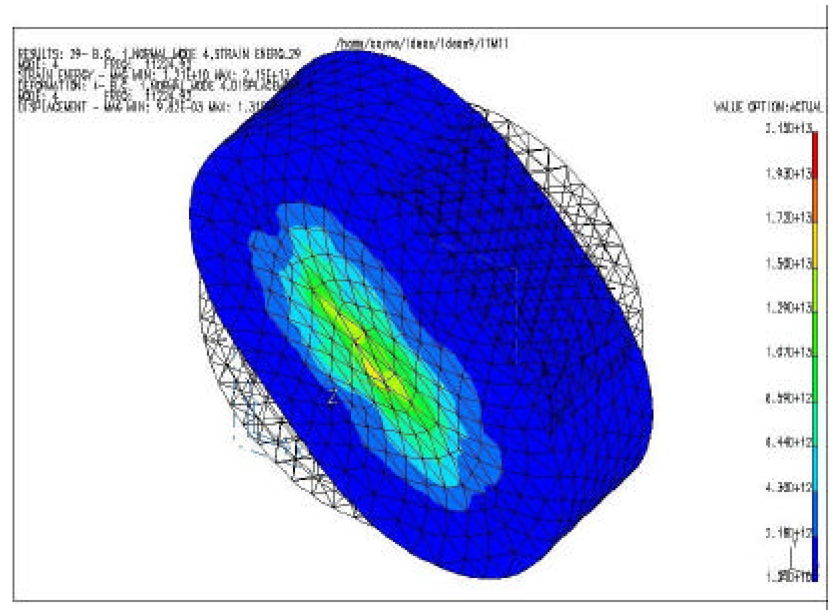
date	23-Apr-03
FEA code	I-DEAS, version 9; filename: ITM11
run time	0:11
converged?	probably, based on previous experience, to ~0.2% frequency, ~4% strain energy (not checked)
material model	isotropic, linear
element type	parab., tetra.
# nodes	11716
# elements	7481
FEM name	fem2
mesh type	free mesh (15mm? size)
	Note: mapped mesh (fem1) failed during analysis; singularity?

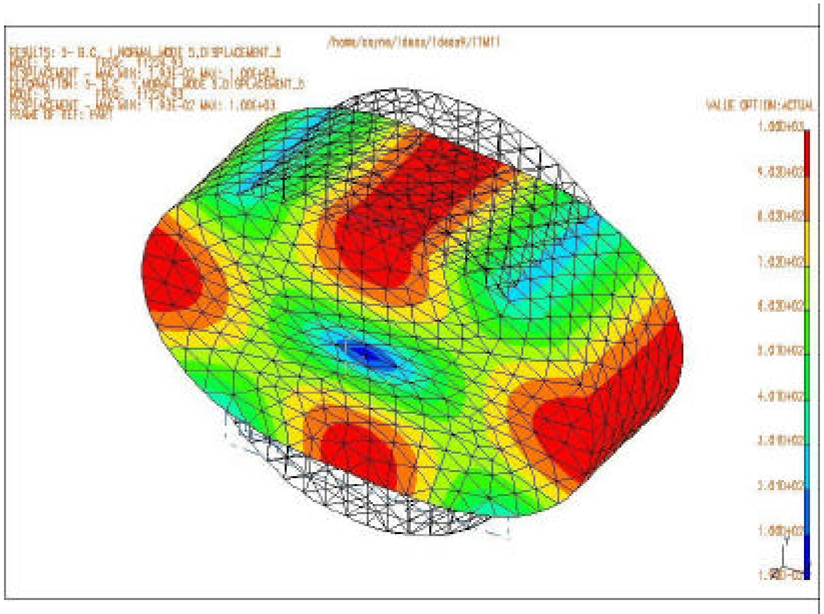
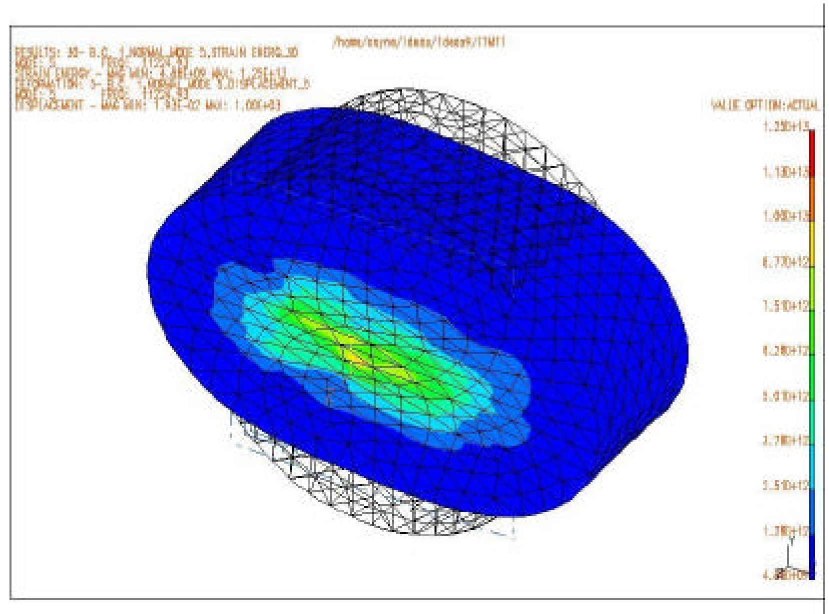
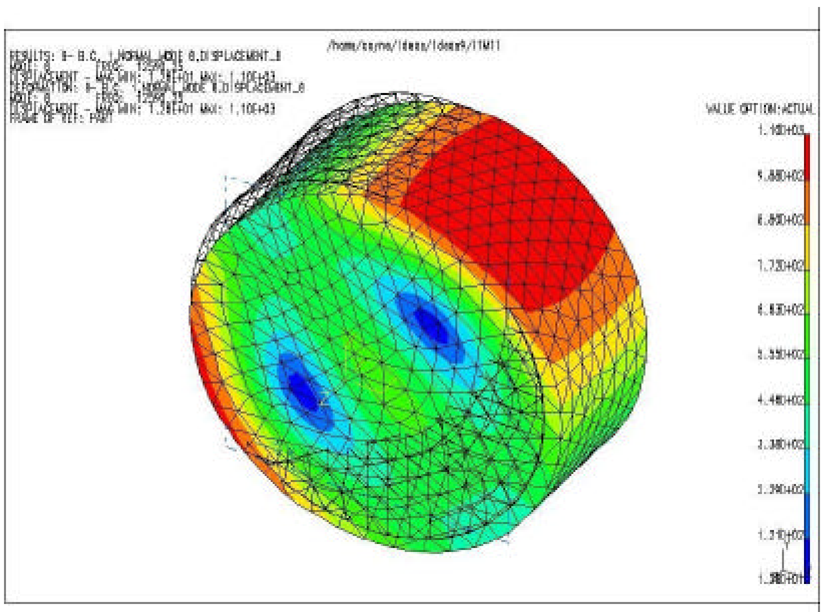
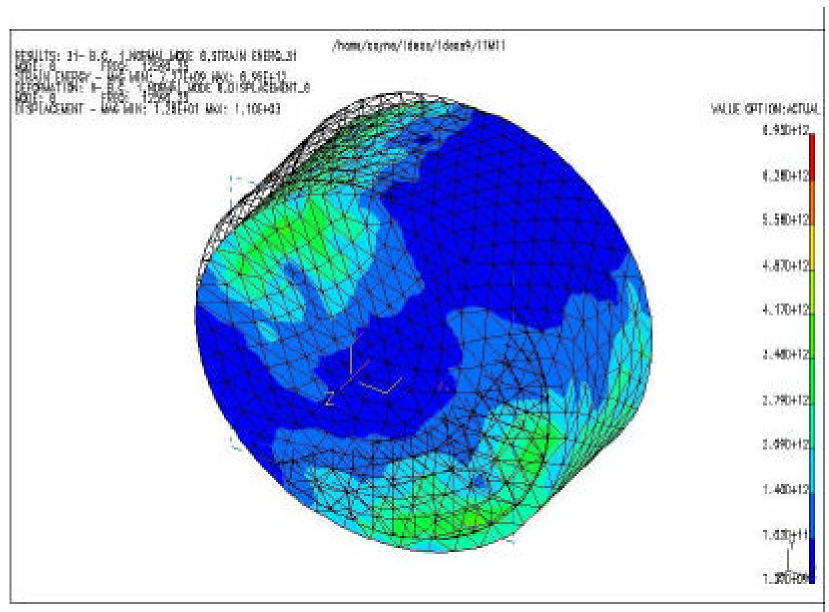
	shape	freq (Hz)	Strain Energy (J for unit displacement?)				
			total	barrel	surface	barrel %	surface %
Mode No 1		7095	3.10E+15	1.61E+14	7.90E+14	5.2%	25.5%
2		7095	3.09E+15	1.63E+14	7.91E+14	5.3%	25.6%
3		9866	7.61E+15	1.78E+14	1.75E+15	2.3%	23.0%
4		11225	2.46E+16	1.14E+14	2.48E+15	0.5%	10.1%
5		11225	1.44E+16	6.69E+13	1.45E+15	0.5%	10.1%
6		12590	1.11E+16	1.03E+15	1.95E+15	9.3%	17.6%
7		12590	1.11E+16	1.03E+15	1.94E+15	9.3%	17.5%
8		12799	8.46E+15	7.40E+14	2.27E+15	8.7%	26.8%
9		12799	8.46E+15	7.38E+14	2.27E+15	8.7%	26.8%
10		14451	3.39E+16	9.99E+14	3.70E+15	2.9%	10.9%
11		14982	1.29E+16	1.67E+14	1.62E+15	1.3%	12.6%
12		14982	1.29E+16	1.63E+14	1.64E+15	1.3%	12.7%
13		17156	2.27E+16	5.33E+14	2.77E+15	2.3%	12.2%
14		17156	2.27E+16	5.31E+14	2.77E+15	2.3%	12.2%
15		17427	1.75E+16	2.63E+15	2.69E+15	15.0%	15.4%
16		18266	1.42E+16	1.64E+15	4.09E+15	11.5%	28.8%
17		18266	1.43E+16	1.66E+15	4.11E+15	11.6%	28.7%
18		19249	1.48E+16	2.14E+15	3.11E+15	14.5%	21.0%
19		19249	2.28E+16	3.32E+15	4.81E+15	14.6%	21.1%
20		19745	1.64E+16	3.24E+14	1.96E+15	2.0%	12.0%
21		19745	2.13E+16	4.19E+14	2.54E+15	2.0%	11.9%
22		20637	1.59E+16	2.21E+15	3.00E+15	13.9%	18.9%
23		20637	1.59E+16	2.23E+15	3.00E+15	14.0%	18.9%
24		22186	1.47E+16	1.51E+14	1.67E+15	1.0%	11.4%
25		22225	2.81E+16	1.38E+15	4.42E+15	4.9%	15.7%

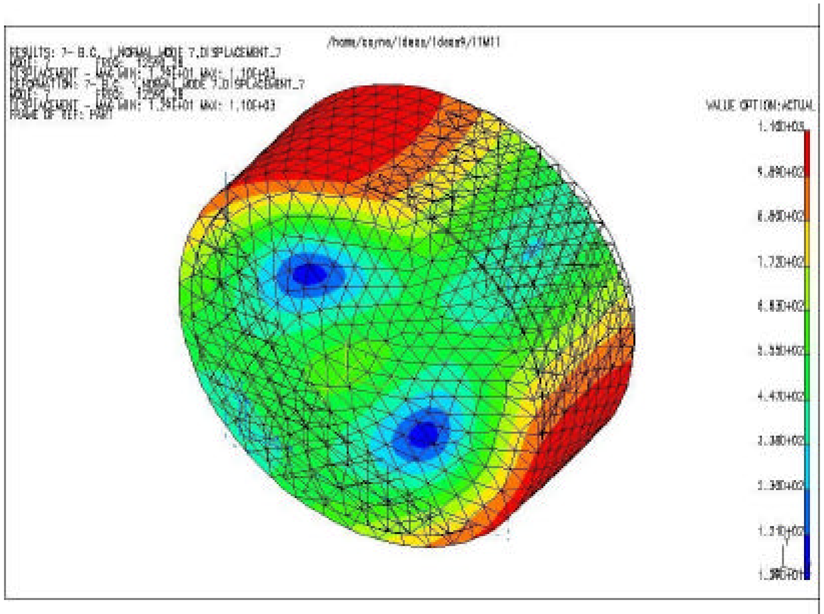
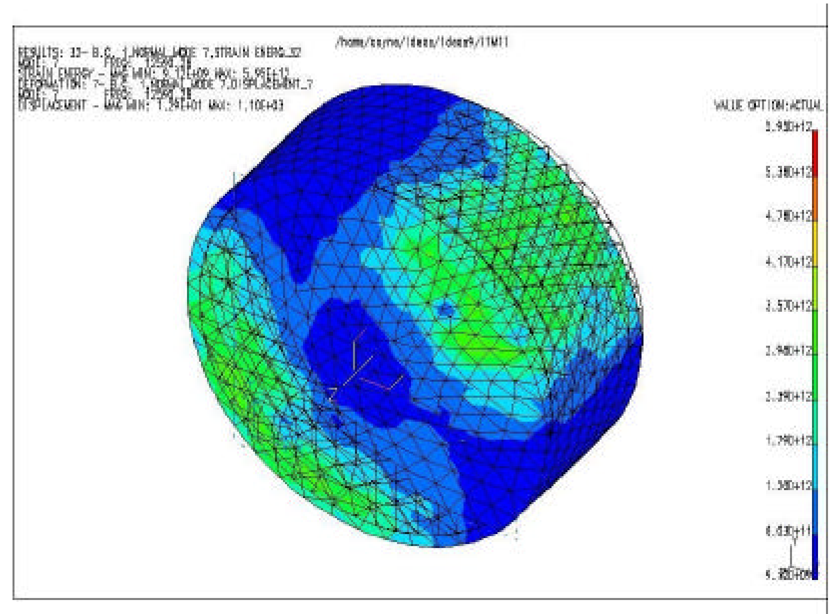
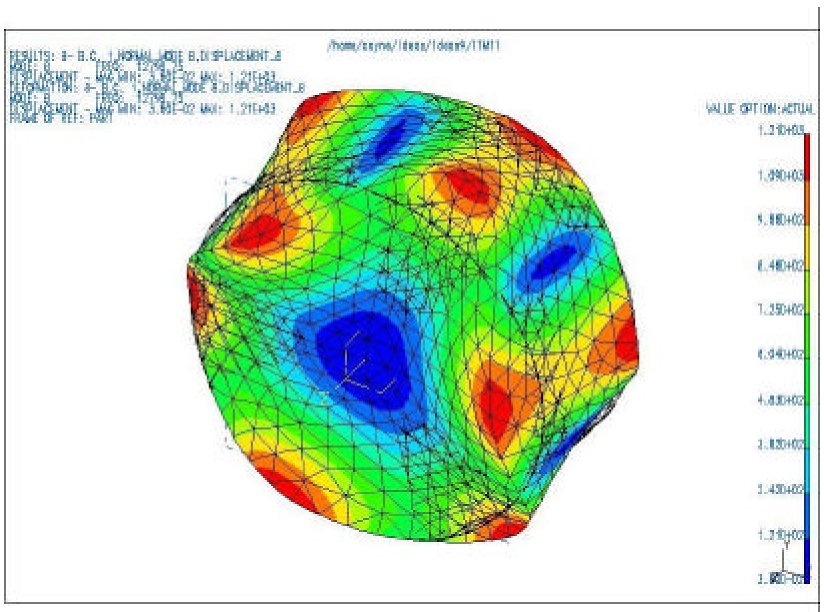
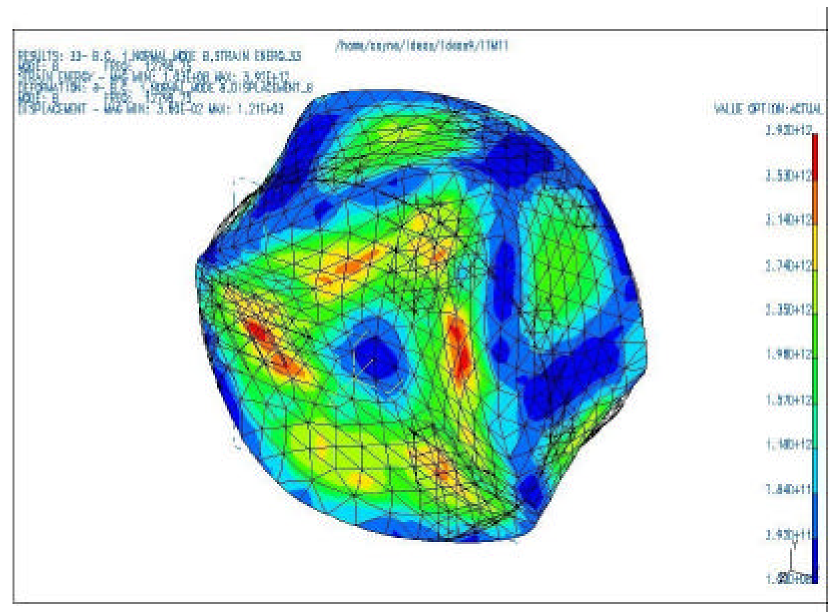
3 Mode Shapes

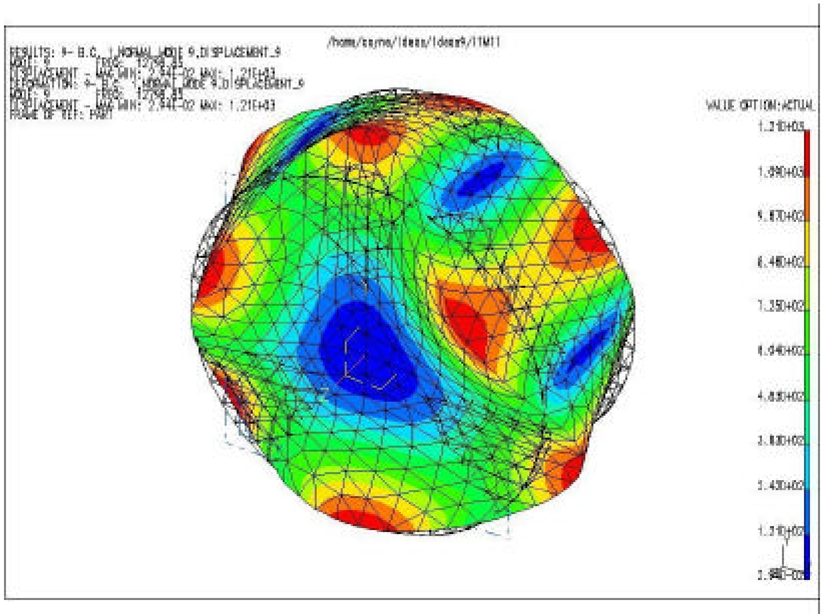
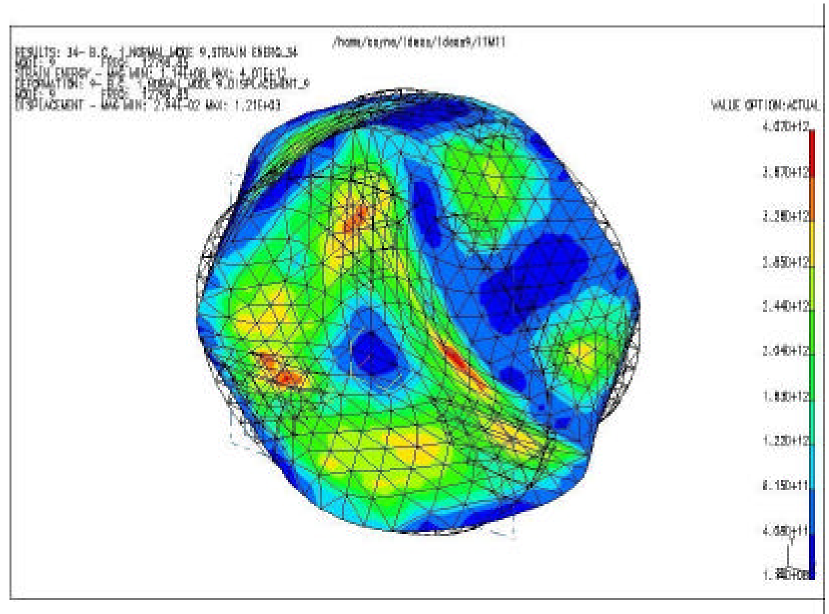
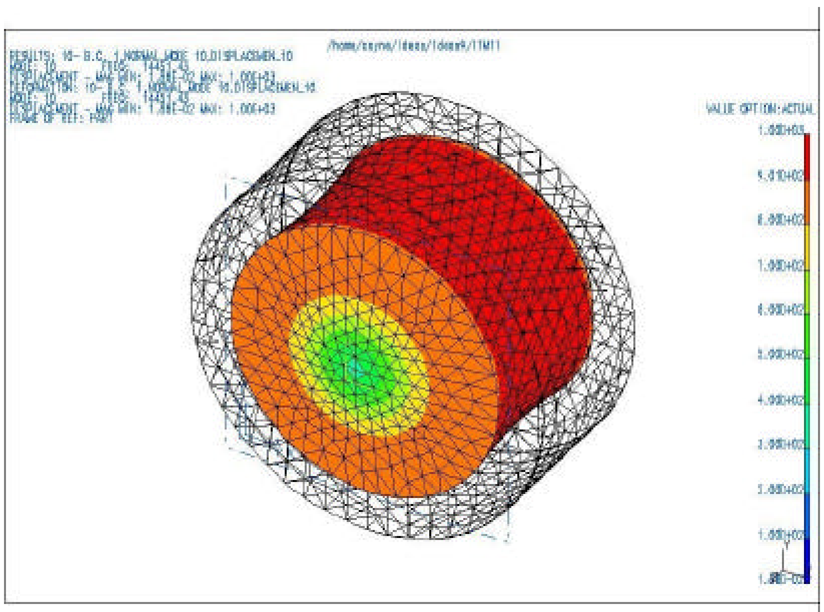
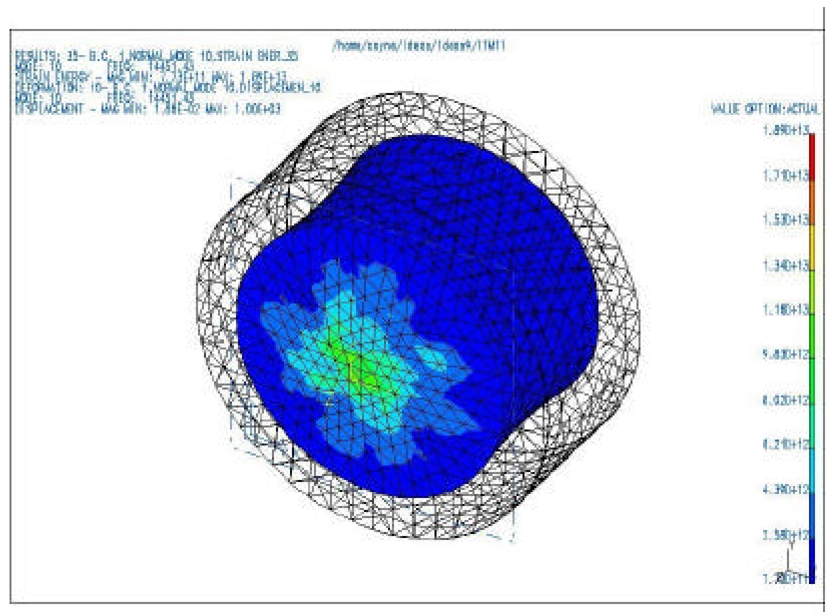
Each of the first 15 mode shapes are depicted as a deformed geometry with contours of displacement and contour of strain energy in the following table.

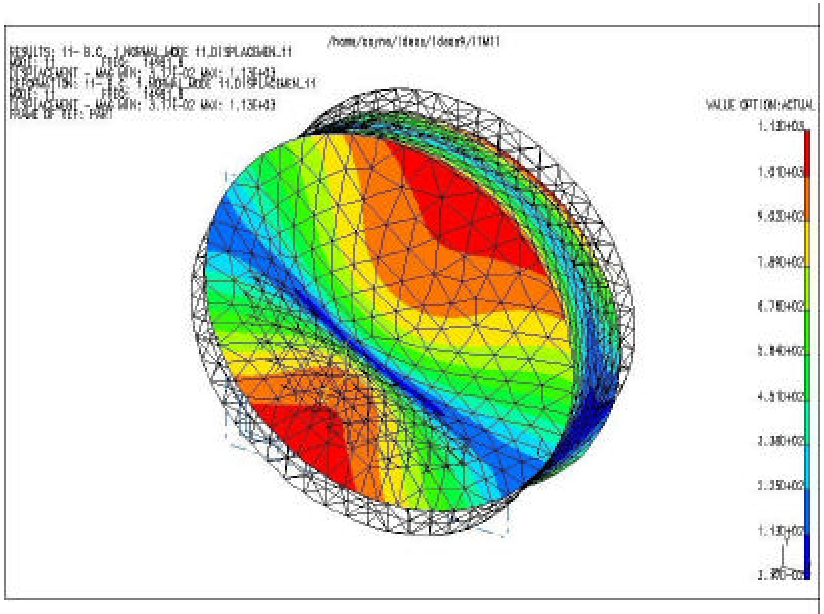
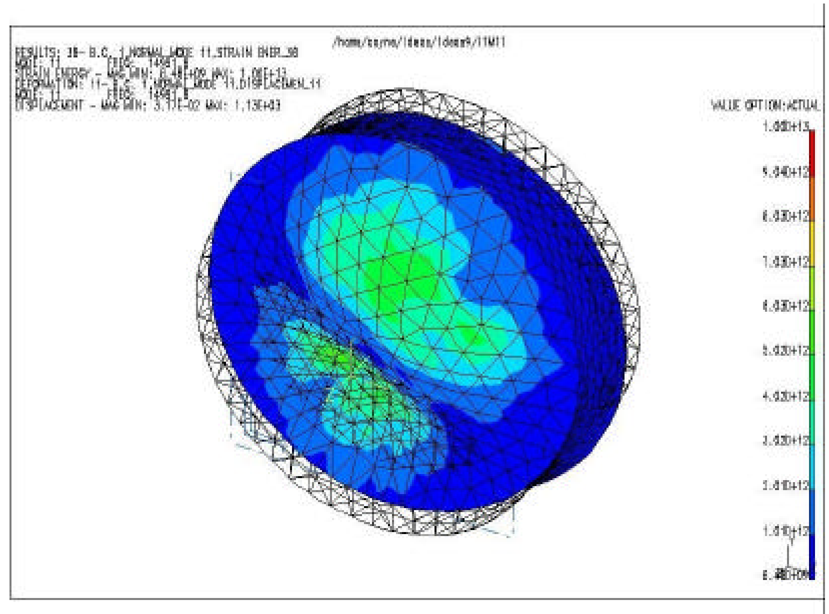
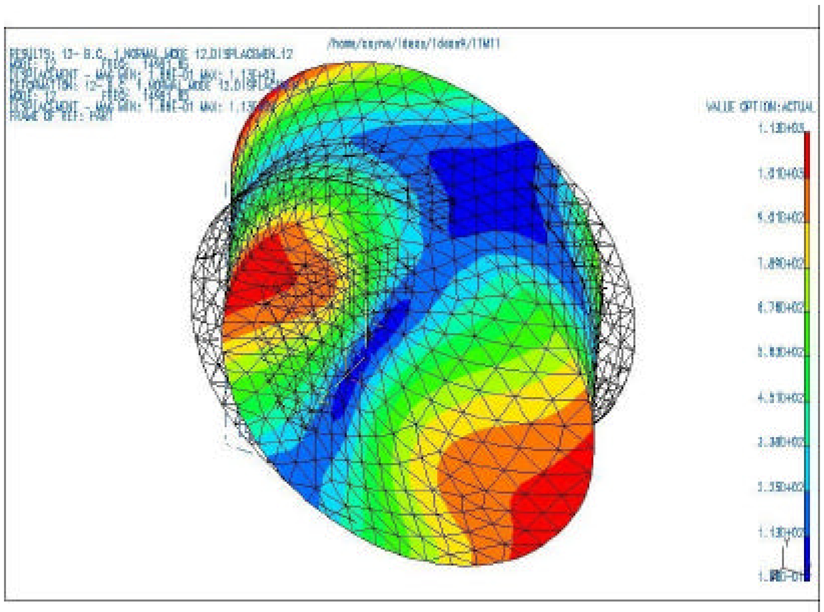
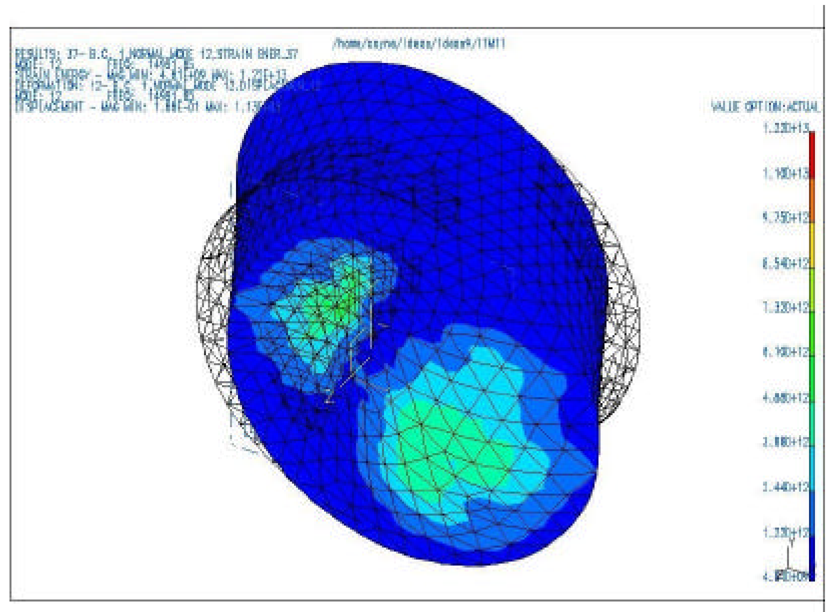
No.	Hz	Displacement Contour	Strain Energy Contour
1	7095		
2	7095		

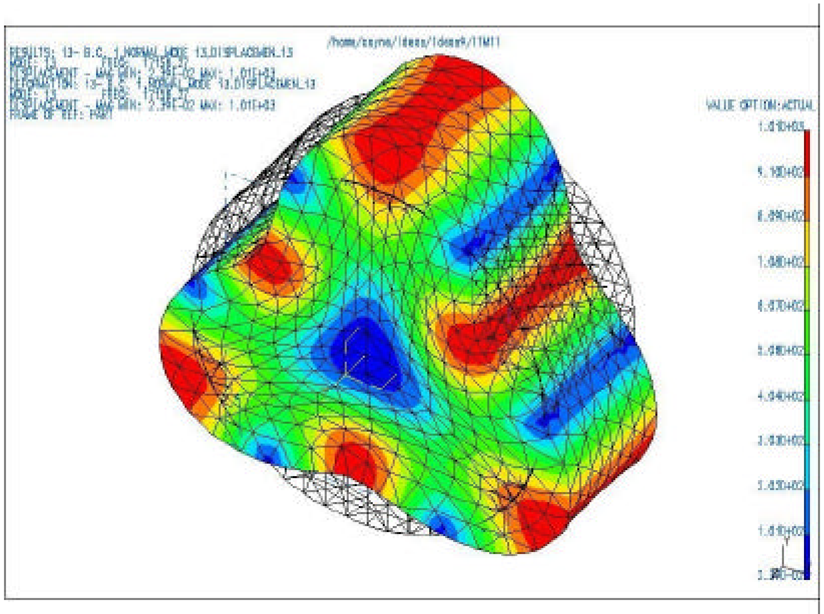
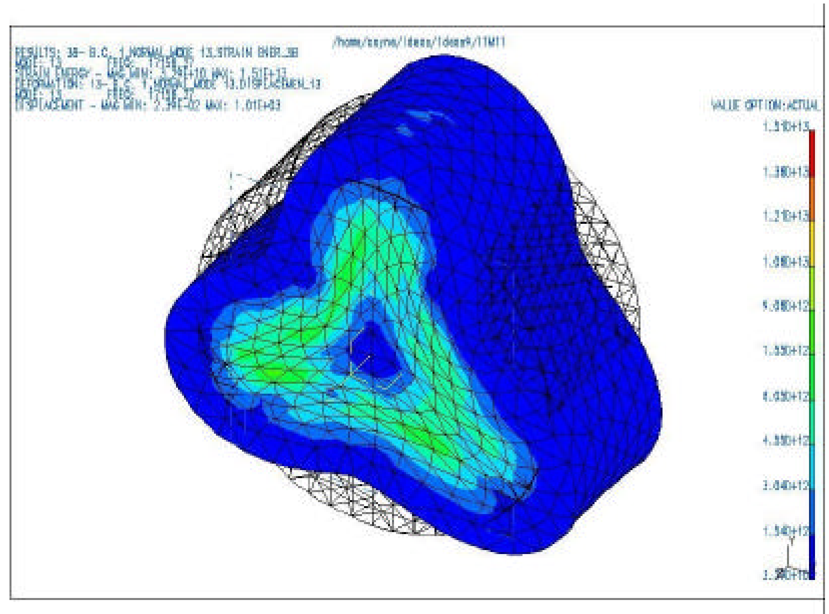
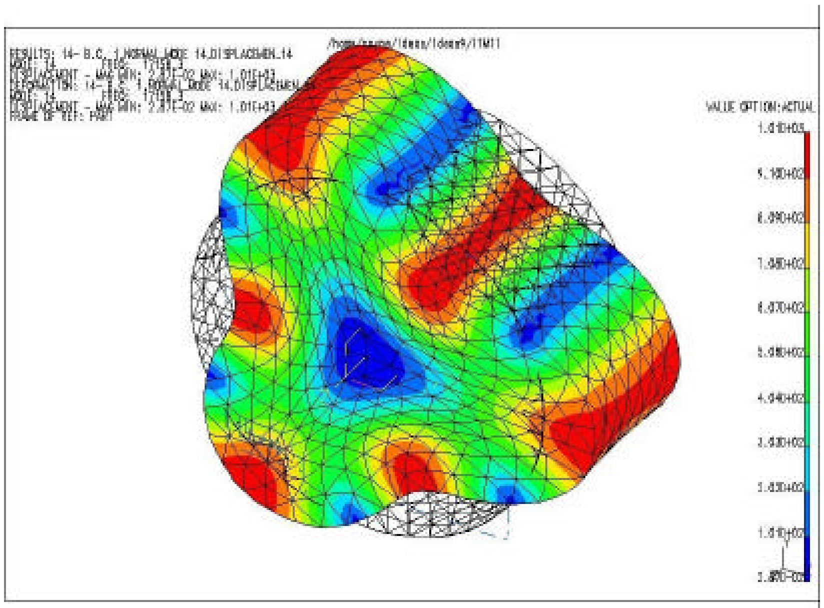
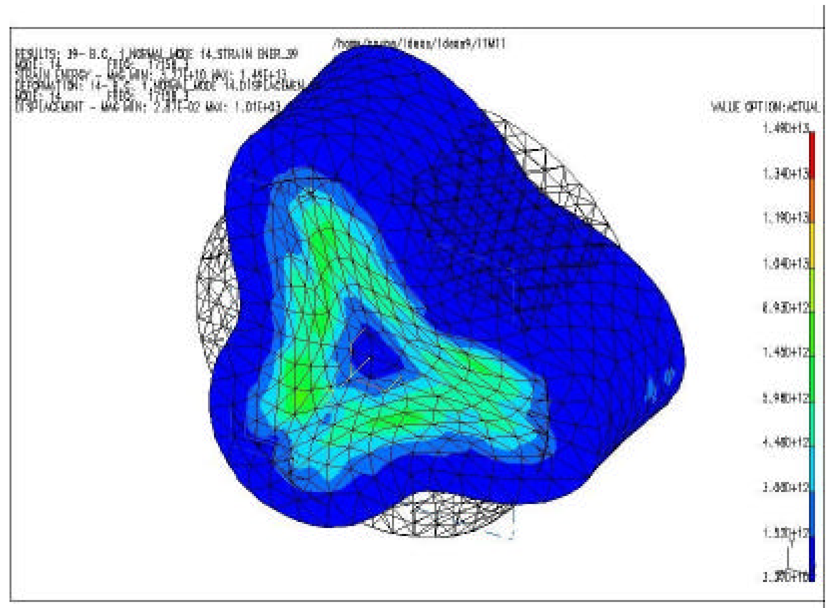
3	9866		
4	11225		

5	11225		
6	12590		

7	12590		
8	12799		

9	12799		
10	14451		

11	14982		
12	14982		

13	17156		
14	17156		

15	17427