

Mechanical study of the ITF for ponderomotive squeezed light

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UNIVERSITÀ DI ROMA



Suspended Optical Bench



UPPER BENCH

Bench diameter: 960 *mm*

Height:
800 *mm*

Cavity length:
440 *mm*

LOWER BENCH

Material:
Al Anticorodal

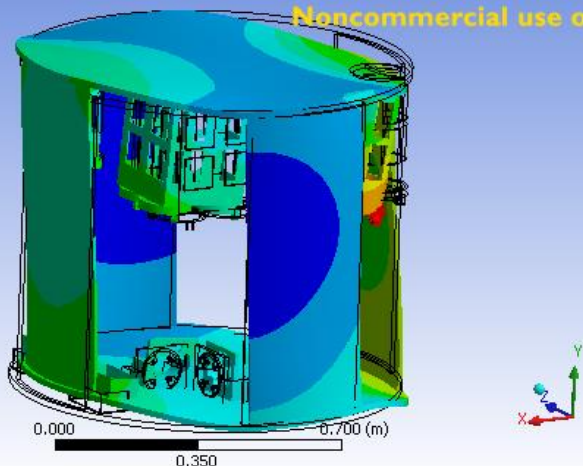
TOTAL WEIGHT
≈ 100 kg



Optical Bench vibration modes

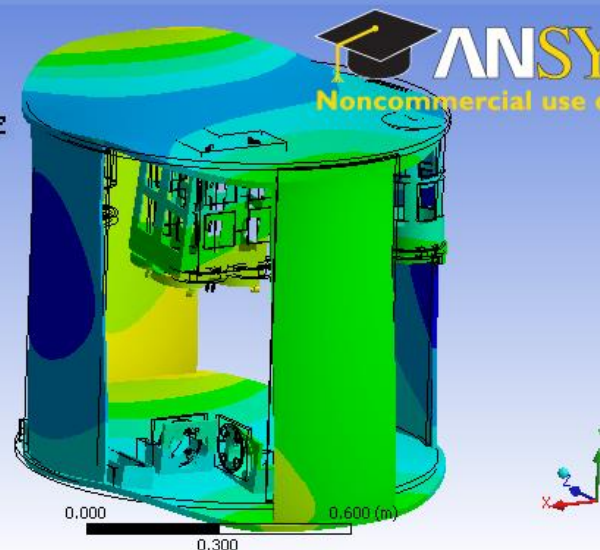
Total Deformation 7

T: SQ ITF 14-04-2014
Total Deformation 7
Type: Total Deformation
Frequency: 63.64 Hz
Unit: m
Time: 63.64
6/26/2014 3:30 PM



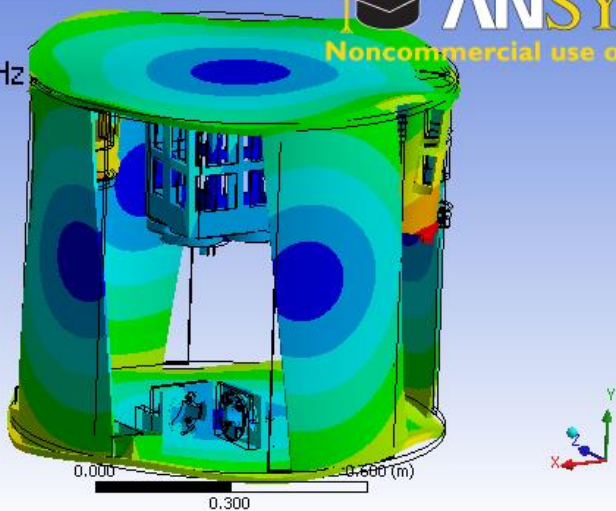
Total Deformation 8

T: SQ ITF 14-04-2014
Total Deformation 8
Type: Total Deformation
Frequency: 64.031 Hz
Unit: m
Time: 64.031
6/26/2014 3:30 PM



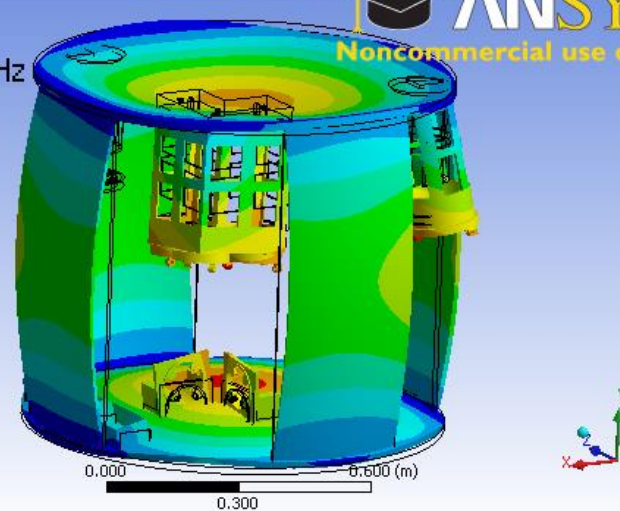
Total Deformation 9

T: SQ ITF 14-04-2014
Total Deformation 9
Type: Total Deformation
Frequency: 74.972 Hz
Unit: m
Time: 74.972
6/26/2014 3:30 PM

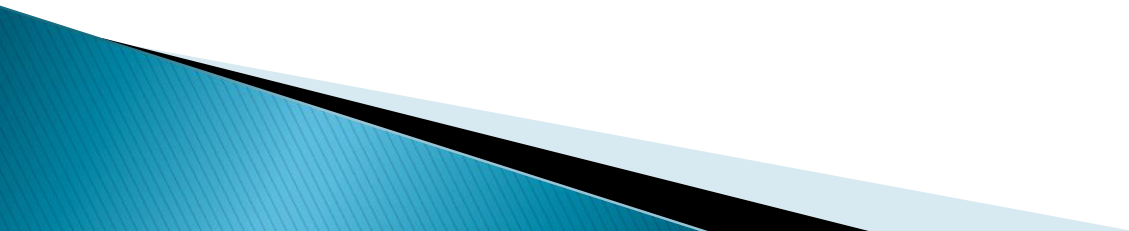


Total Deformation 10

T: SQ ITF 14-04-2014
Total Deformation 10
Type: Total Deformation
Frequency: 86.437 Hz
Unit: m
Time: 86.437
6/26/2014 3:30 PM

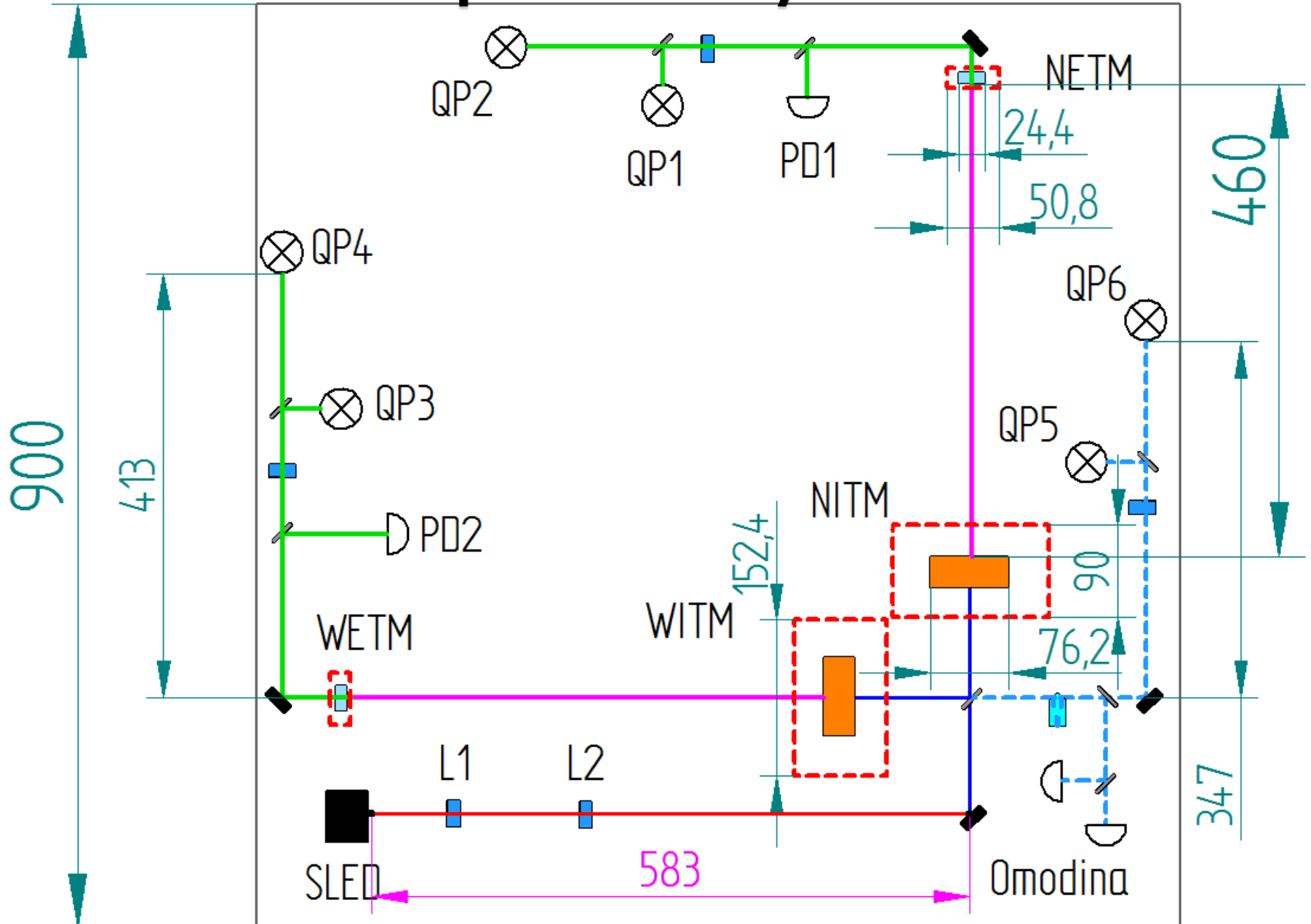


Optical Layout



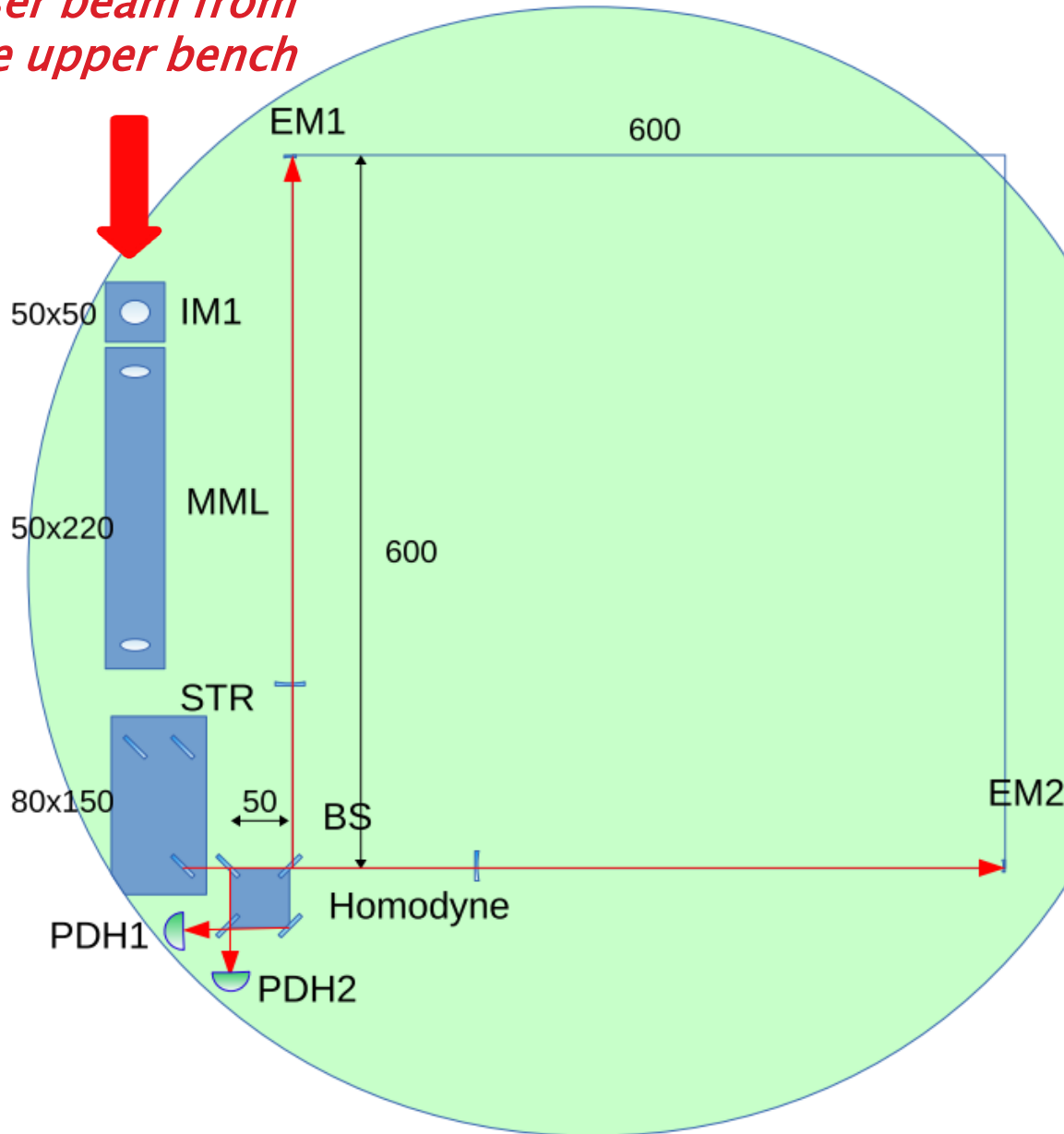
Optical Layout

Designed by
A. Rocchi



Optical Layout

laser beam from the upper bench



Main components

LEGENDA

IM1: input mirror

E' lo specchio che porta il fascio dal piano superiore sul banco

MML: Mode Matching Lens

STR: Beam Steering Mirrors
To alline the interferometers

BS:Beam Splitter

EMi: End Mirror

IMi:Input Mirror

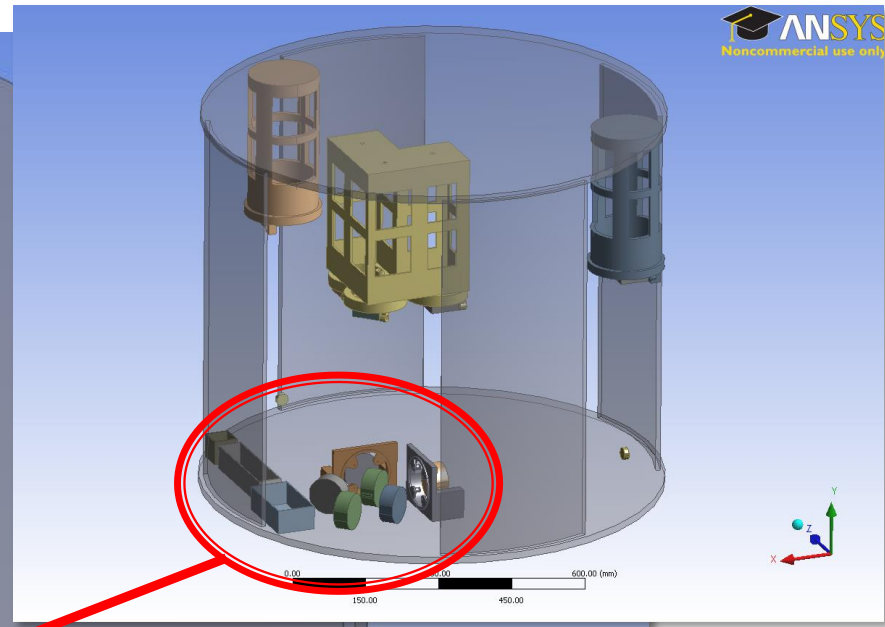
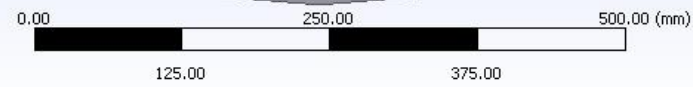
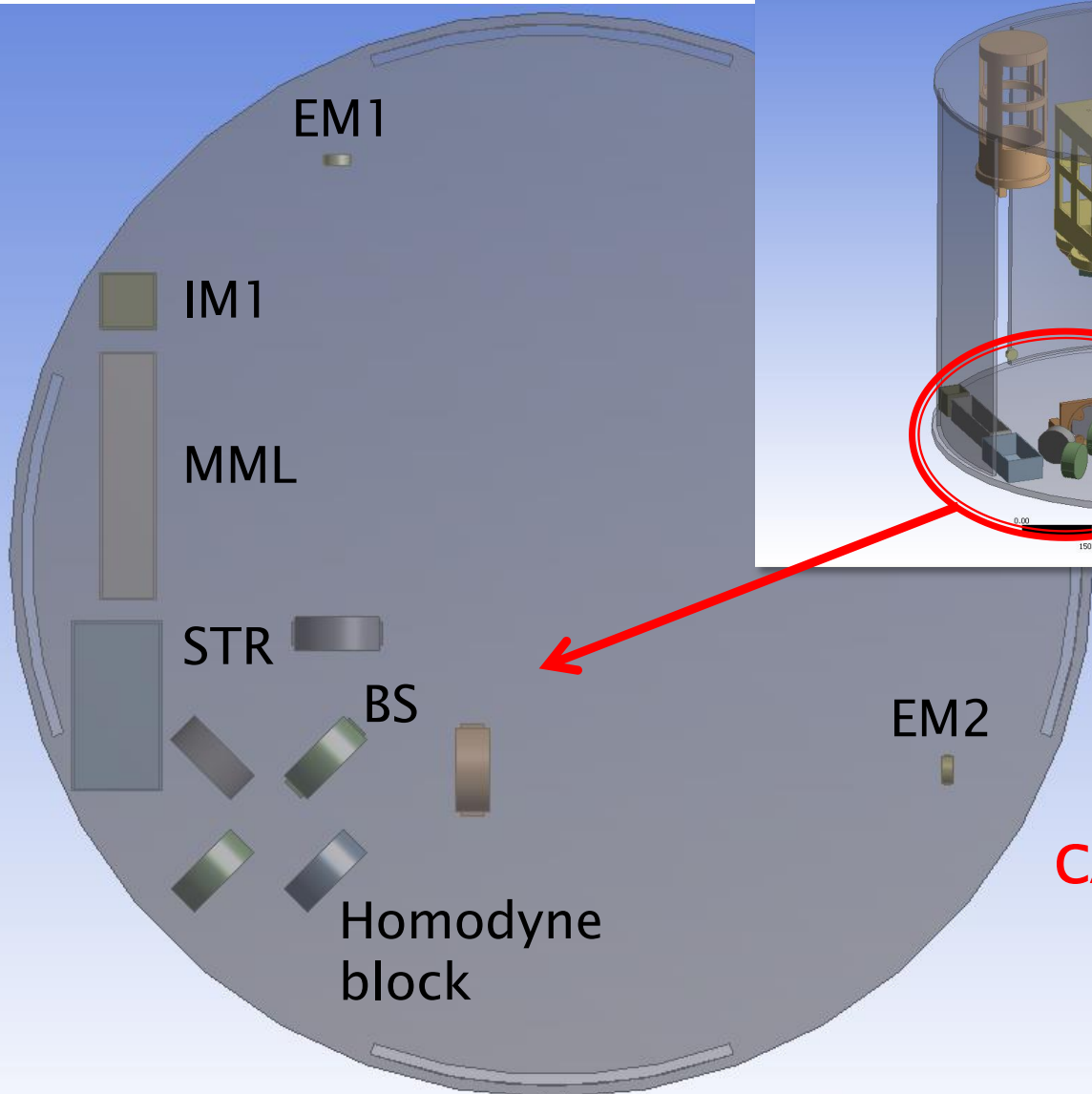
MISURE IN mm

Lower Bench

**Designed by
M. De Laurentis**

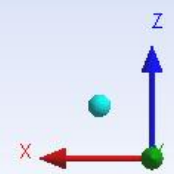
Optical Layout

Main components



Lower Bench

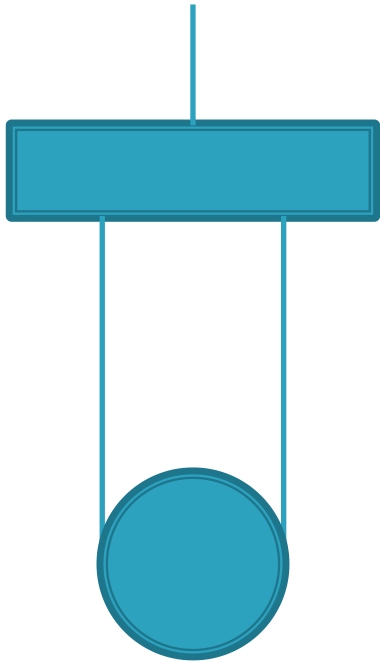
CAD layout



End Payload

End Payload

Double pendulum suspension



▶ **Marionette Mass: 1 kg**

- Wire diameter: 300 μm
- Length: 0.4 m
- Material: Steel c85
- Loss Angle @ 10 Hz: 10^{-4}
- Number of wires: 1

▶ **Mirror Mass (EM): 10 g**

- Wire diameter: 50 μm
- Length: 0.4 m
- Pendulum Frequency: 1.1 Hz
- Vertical Frequency: 42 Hz
- First Violin: 133.7 Hz
- Material: Fused Silica
- Loss Angle @ 10 Hz: 10^{-6}
- Number of wires: 2
- Dilution Factor: 600
- Thermal Noise @ 10 Hz: $2.4 \times 10^{-17} \text{ m}/\sqrt{\text{Hz}}$
- Requirement @ 10 Hz: $10^{-16} \text{ m}/\sqrt{\text{Hz}}$

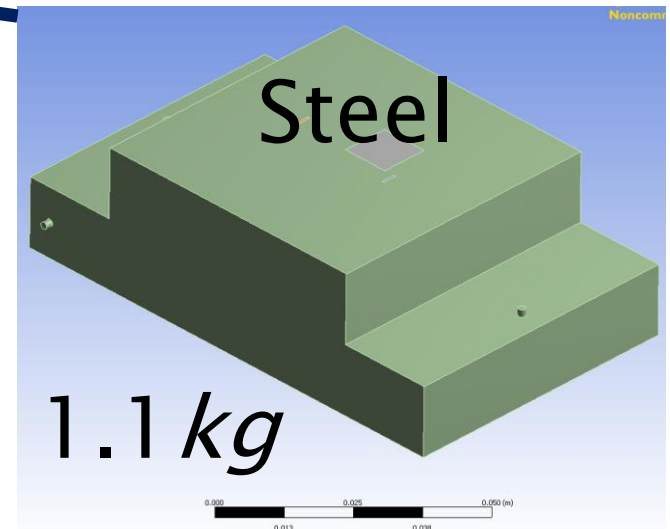
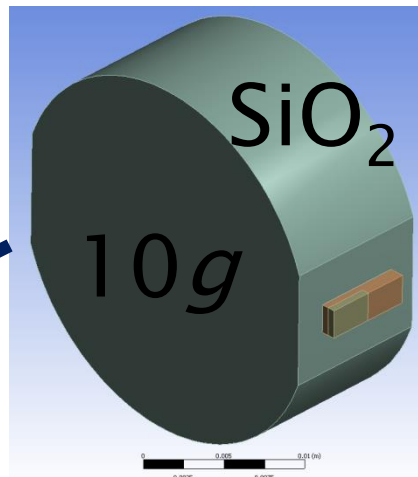
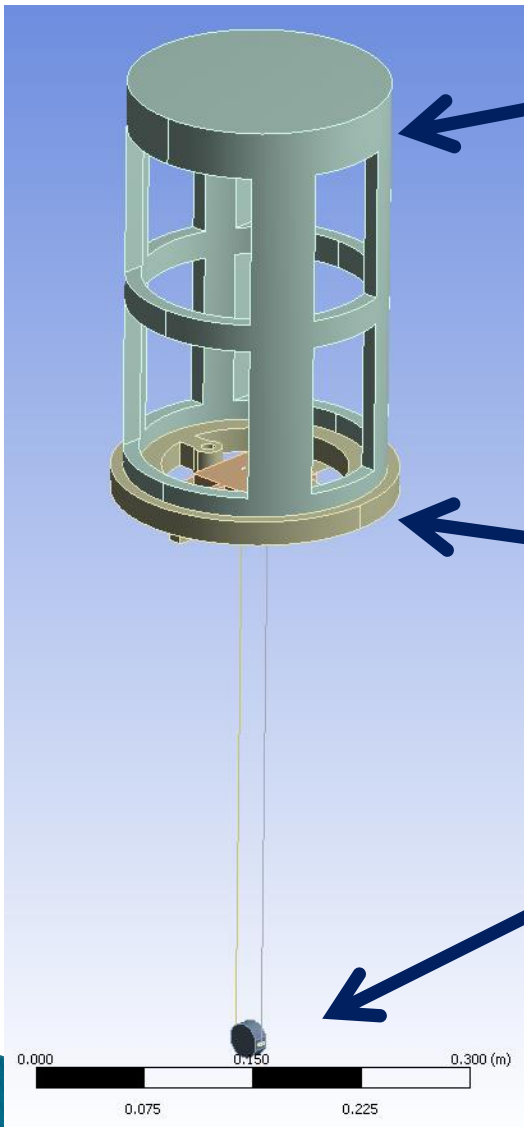
End Payload

Cage & Coil Holder (Al anticorodal)
CCH weight: 2.2 kg ;

Mirror is suspended from 2 fused silica wires (diameter = $5\text{e-}5\text{ m}$)

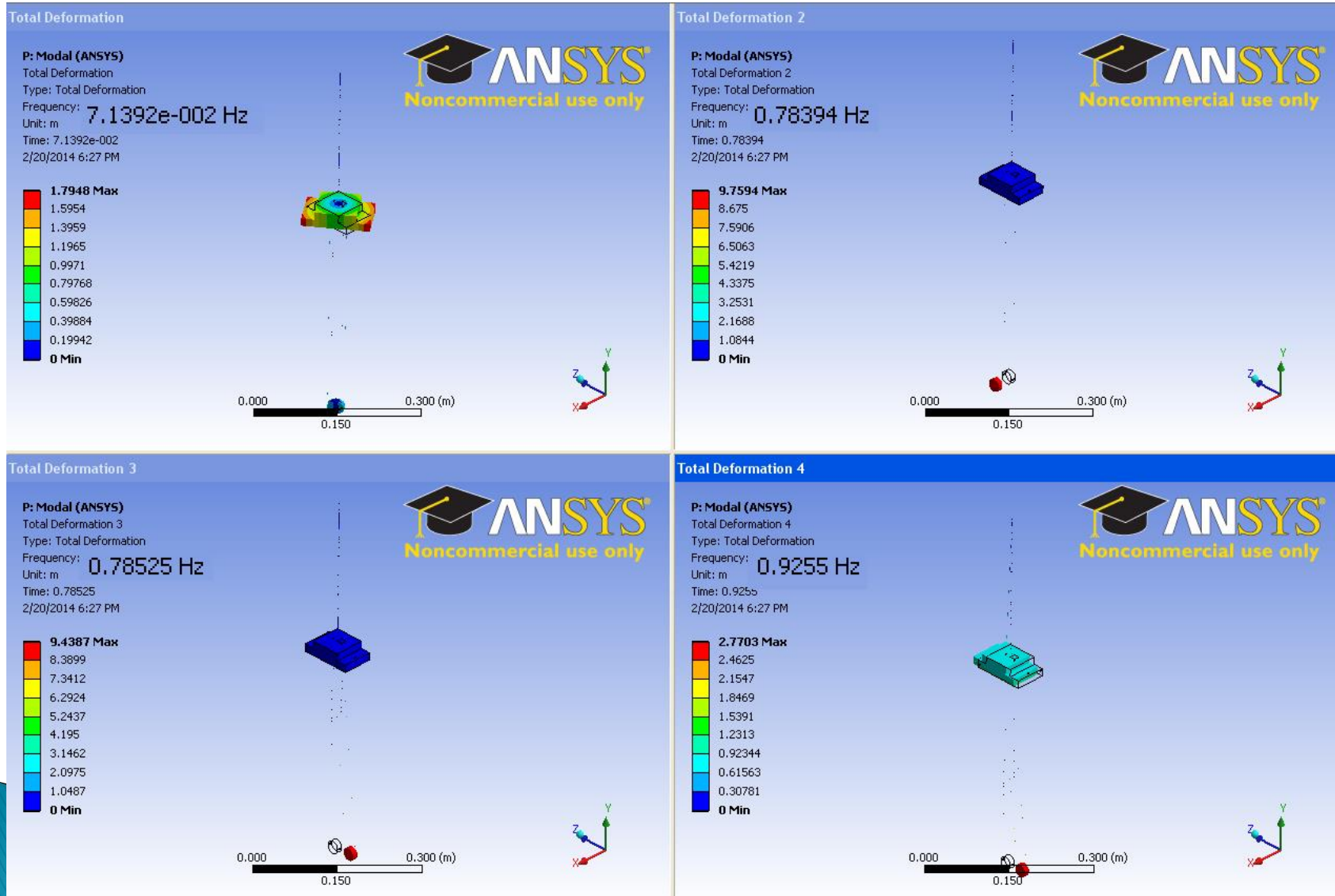
END MIRROR

MARIONETTE



End Payload Vibration Modes

first pendulum



End Payload Vibration Modes

Total Deformation 5

P: Modal (ANSYS)

Total Deformation 5

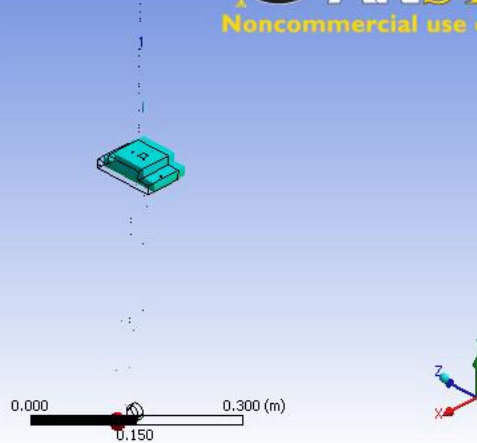
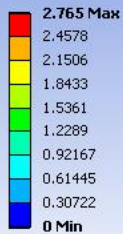
Type: Total Deformation

Frequency: 0.92694 Hz

Unit: m

Time: 0.92694

2/20/2014 6:29 PM



Total Deformation 6

P: Modal (ANSYS)

Total Deformation 6

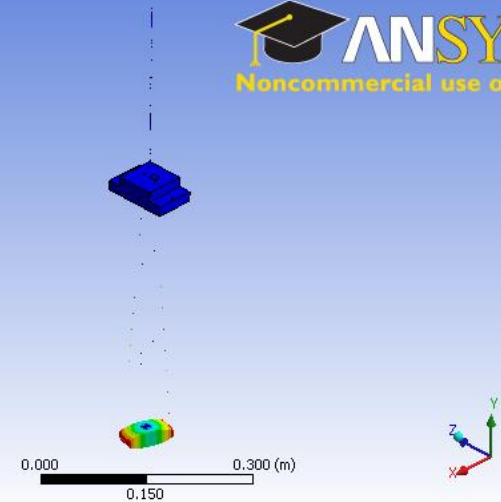
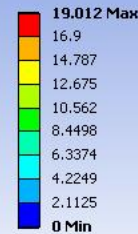
Type: Total Deformation

Frequency: 1.4019 Hz

Unit: m

Time: 1.4019

2/20/2014 6:29 PM



Total Deformation 7

P: Modal (ANSYS)

Total Deformation 7

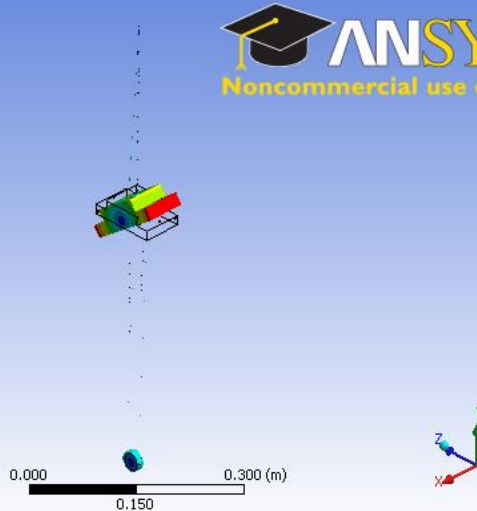
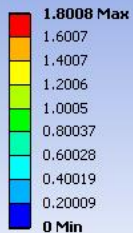
Type: Total Deformation

Frequency: 2.7408 Hz

Unit: m

Time: 2.7408

2/20/2014 6:29 PM



Total Deformation 8

P: Modal (ANSYS)

Total Deformation 8

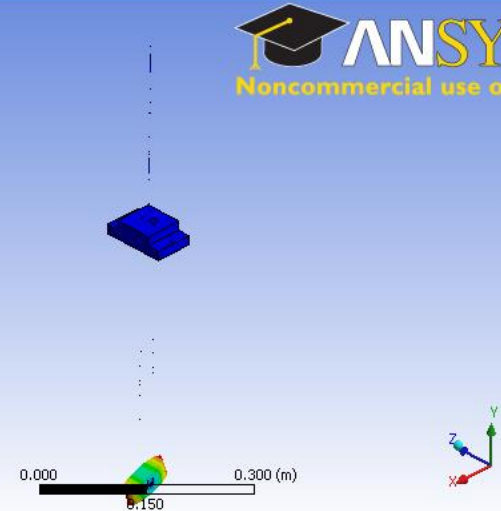
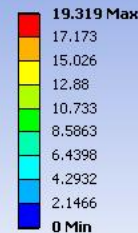
Type: Total Deformation

Frequency: 2.9797 Hz

Unit: m

Time: 2.9797

2/20/2014 6:29 PM



End Payload Vibration Modes

Total Deformation 9

W: Modal (ANSYS)

Total Deformation 9

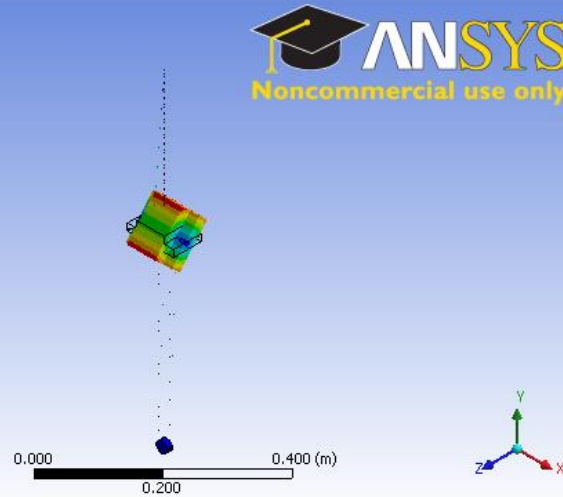
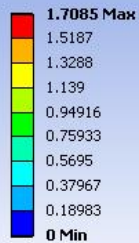
Type: Total Deformation

Frequency: 3.7665 Hz

Unit: m

Time: 3.7665

6/27/2014 11:57 PM



Total Deformation 10

W: Modal (ANSYS)

Total Deformation 10

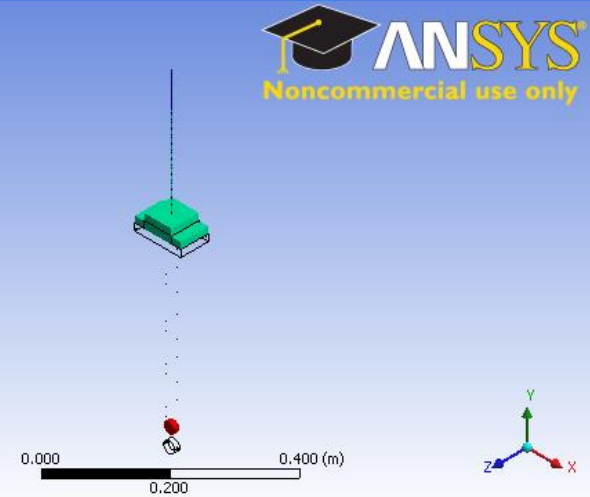
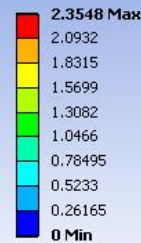
Type: Total Deformation

Frequency: 32.786 Hz

Unit: m

Time: 32.786

6/27/2014 11:57 PM



Total Deformation 11

W: Modal (ANSYS)

Total Deformation 11

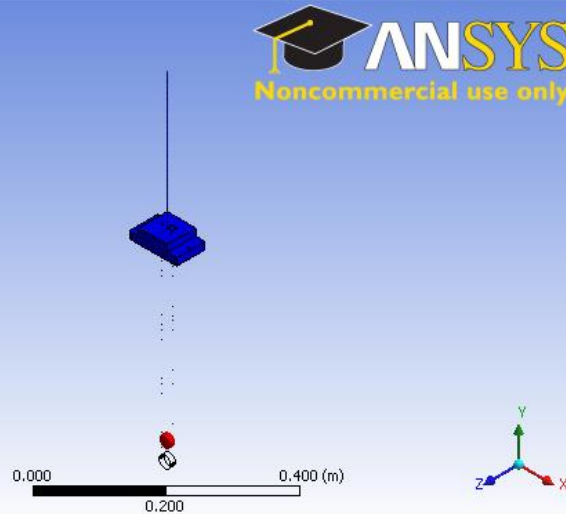
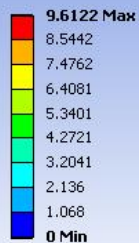
Type: Total Deformation

Frequency: 42.513 Hz

Unit: m

Time: 42.513

6/27/2014 11:57 PM



Total Deformation 12

W: Modal (ANSYS)

Total Deformation 12

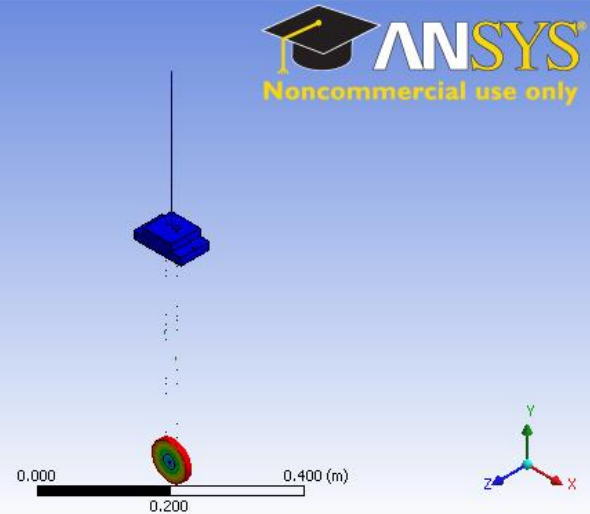
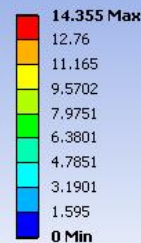
Type: Total Deformation

Frequency: 58.972 Hz

Unit: m

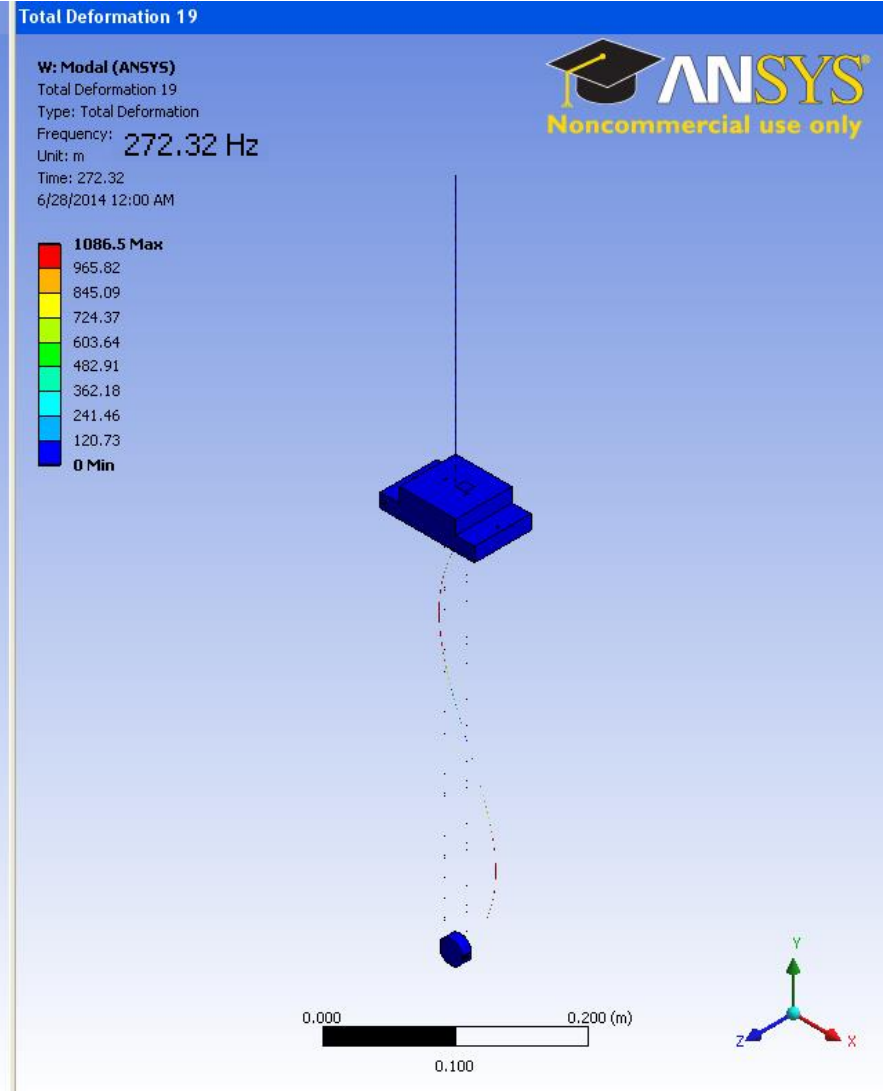
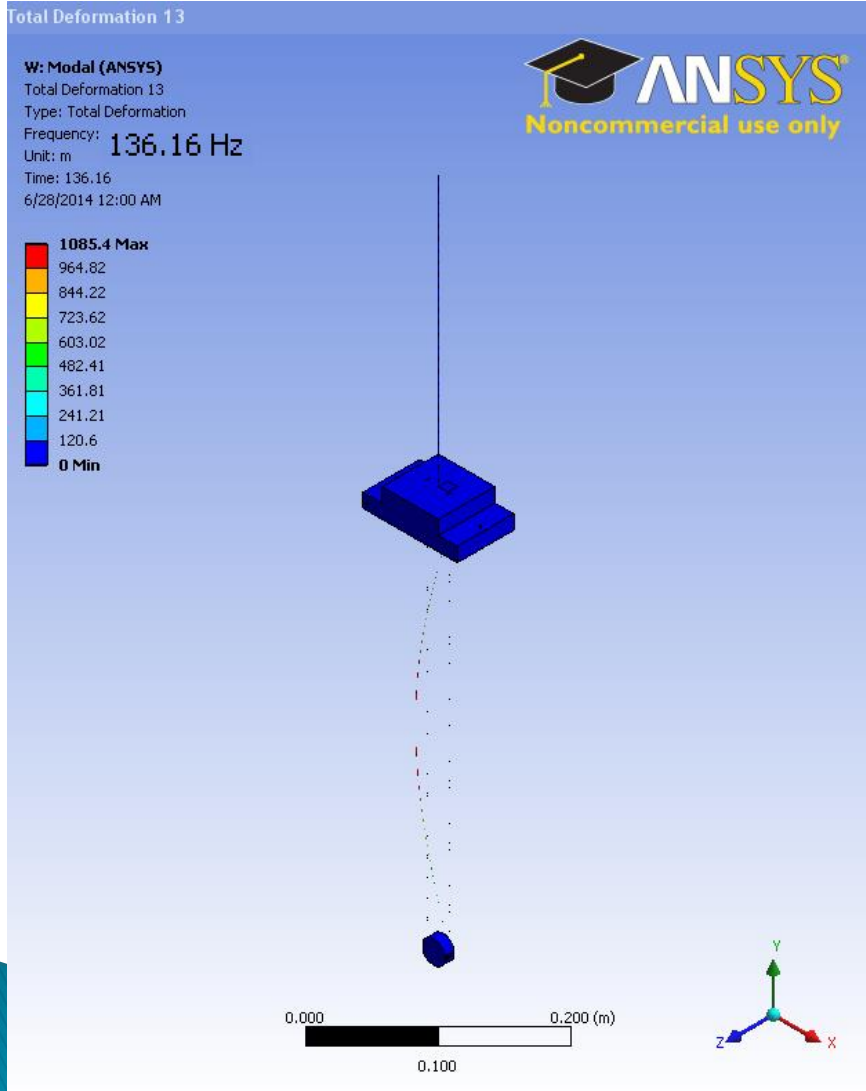
Time: 58.972

6/27/2014 11:57 PM



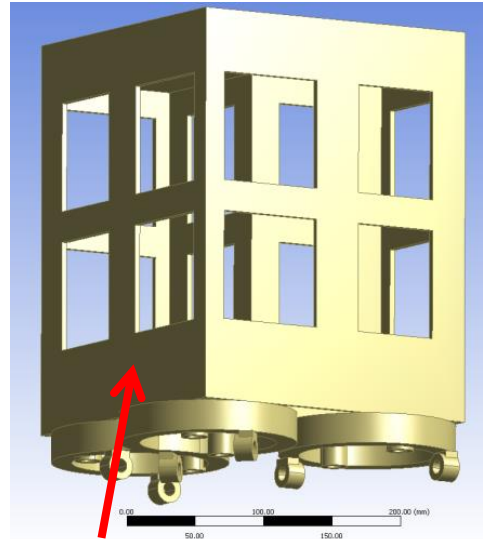
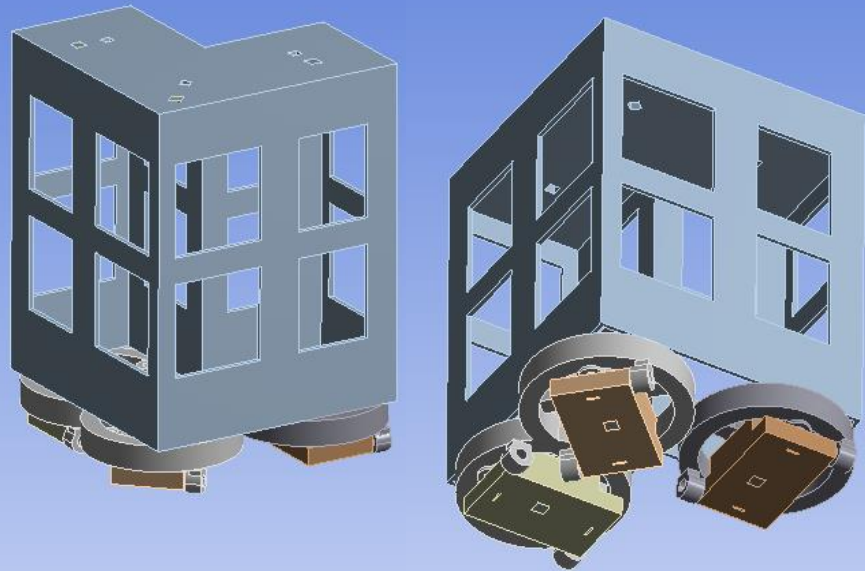
first violin

End Payload Vibration Modes

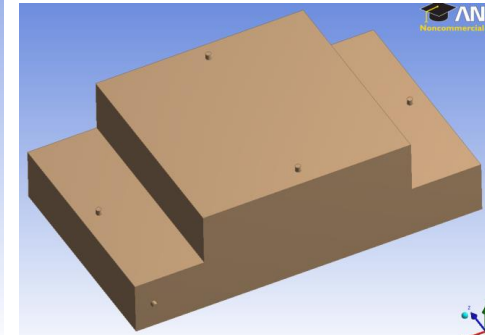


Input Payload

Input Payload

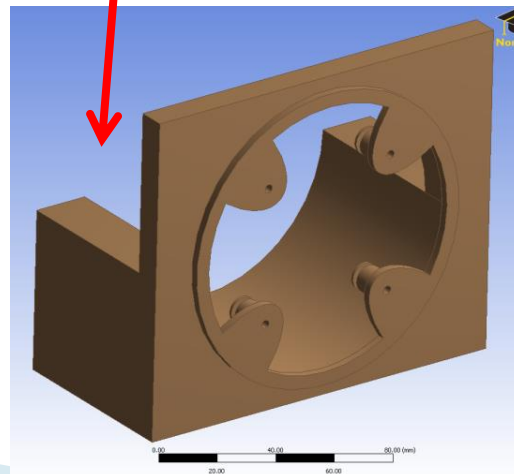
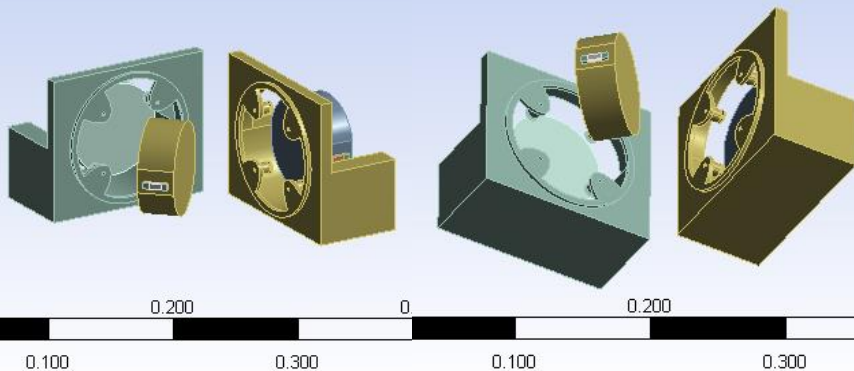


Marionette:
steel, 1.1 *kg*



C+CH: anticorodal, 5.3 *kg*

BCH: anticorodal, 1 *kg*



Input Payload

Low Frequency Vibration Modes

Total Deformation

Y: Modal (ANSYS)

Total Deformation

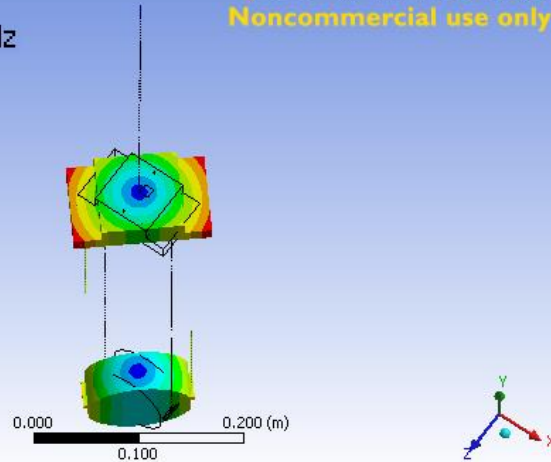
Type: Total Deformation

Frequency: 5.6519e-002 Hz

Unit: m

Time: 5.6519e-002

6/30/2014 3:19 PM



Total Deformation 2

Y: Modal (ANSYS)

Total Deformation 2

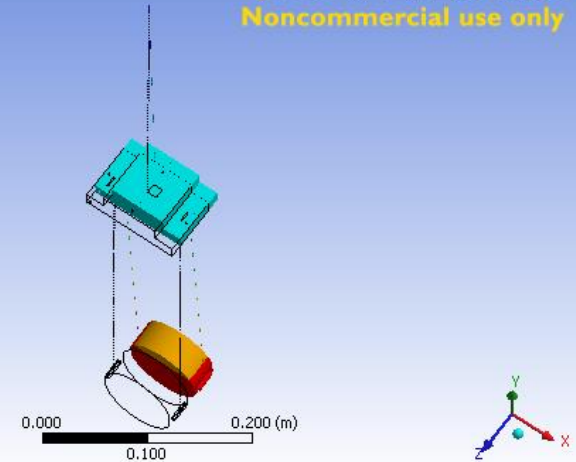
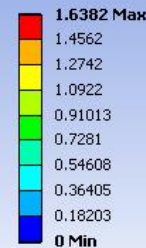
Type: Total Deformation

Frequency: 0.64528 Hz

Unit: m

Time: 0.64528

6/30/2014 3:19 PM



Total Deformation 3

Y: Modal (ANSYS)

Total Deformation 3

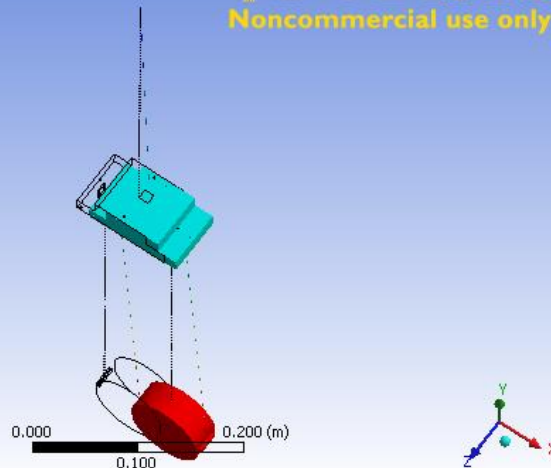
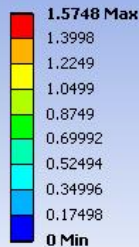
Type: Total Deformation

Frequency: 0.64545 Hz

Unit: m

Time: 0.64545

6/30/2014 3:19 PM



Total Deformation 4

Y: Modal (ANSYS)

Total Deformation 4

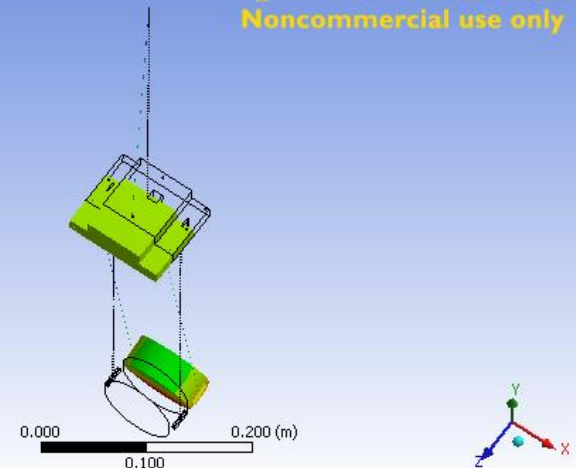
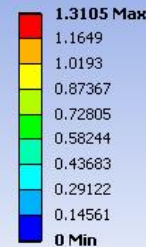
Type: Total Deformation

Frequency: 1.0803 Hz

Unit: m

Time: 1.0803

6/30/2014 3:19 PM



Input Payload

Low Frequency Vibration Modes

Total Deformation 5

Y: Modal (ANSYS)

Total Deformation 5

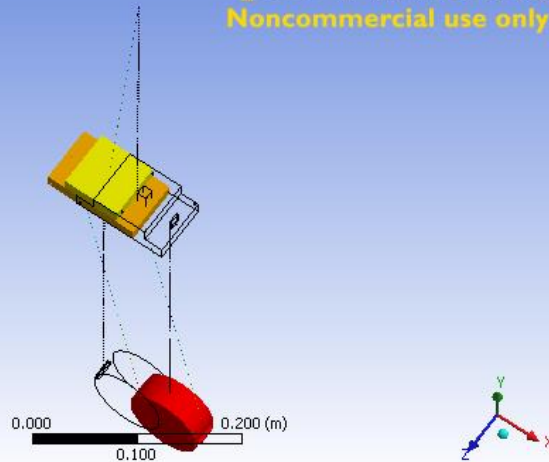
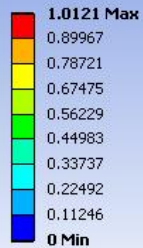
Type: Total Deformation

Frequency: 1.0877 Hz

Unit: m

Time: 1.0877

6/30/2014 3:22 PM



Total Deformation 6

Y: Modal (ANSYS)

Total Deformation 6

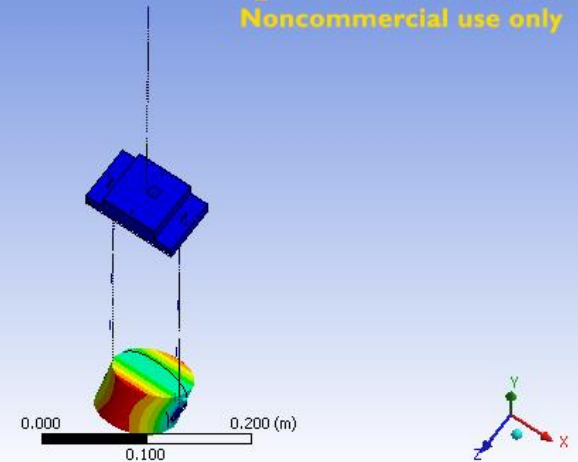
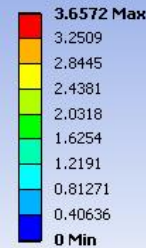
Type: Total Deformation

Frequency: 1.5642 Hz

Unit: m

Time: 1.5642

6/30/2014 3:22 PM



Total Deformation 7

Y: Modal (ANSYS)

Total Deformation 7

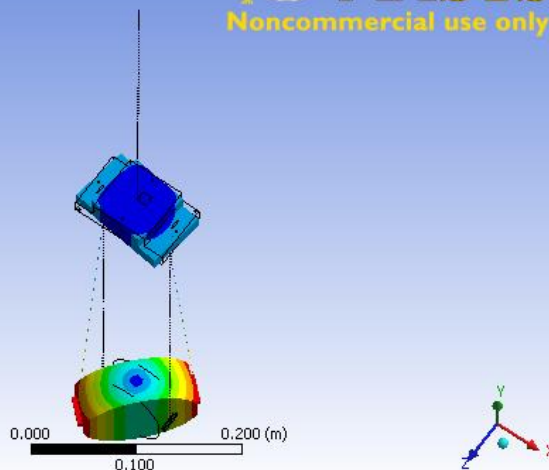
Type: Total Deformation

Frequency: 1.5834 Hz

Unit: m

Time: 1.5834

6/30/2014 3:22 PM



Total Deformation 8

Y: Modal (ANSYS)

Total Deformation 8

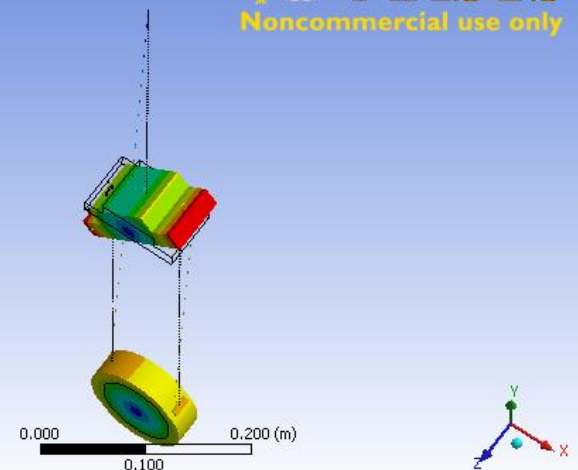
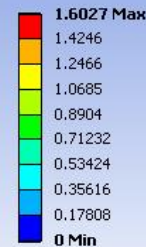
Type: Total Deformation

Frequency: 2.9571 Hz

Unit: m

Time: 2.9571

6/30/2014 3:22 PM



Input Payload

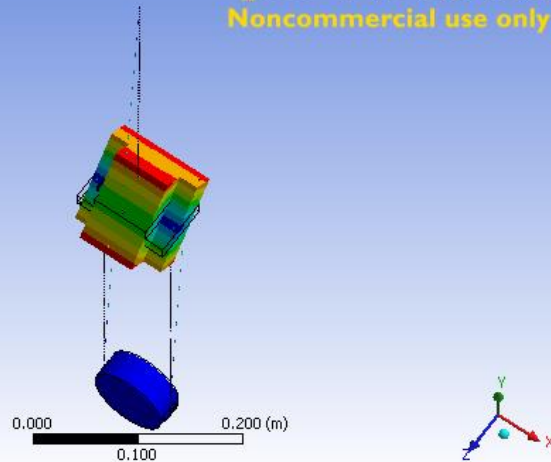
Low Frequency Vibration Modes

Total Deformation 9

Y: Modal (ANSYS)
 Total Deformation 9
 Type: Total Deformation
 Frequency: 4.5185 Hz
 Unit: m
 Time: 4.5185
 6/30/2014 3:23 PM



1.6941 Max
 1.5059
 1.3177
 1.1294
 0.94118
 0.75295
 0.56471
 0.37647
 0.18824
 0 Min

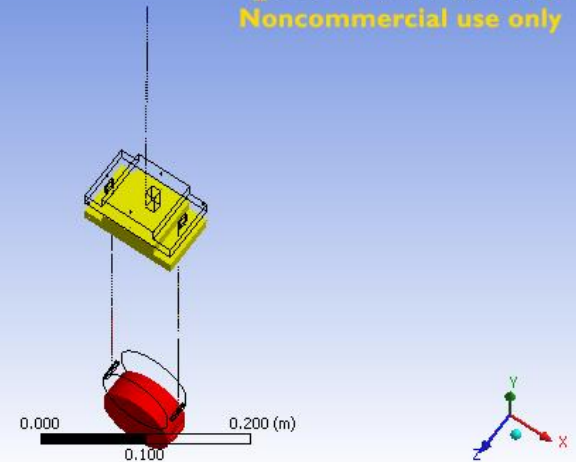


Total Deformation 10

Y: Modal (ANSYS)
 Total Deformation 10
 Type: Total Deformation
 Frequency: 24.014 Hz
 Unit: m
 Time: 24.014
 6/30/2014 3:23 PM



1.0456 Max
 0.92943
 0.81325
 0.69707
 0.58089
 0.46471
 0.34854
 0.23236
 0.11618
 0 Min

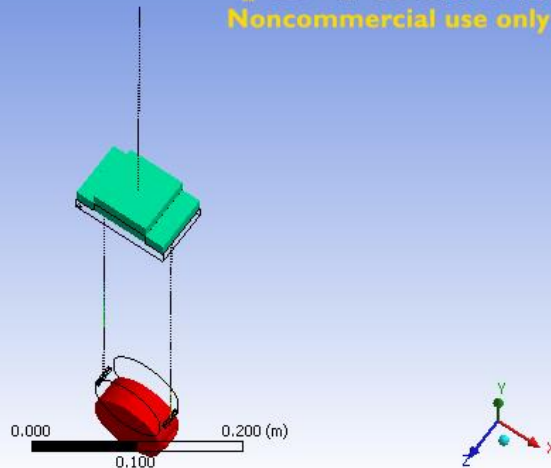


Total Deformation 11

Y: Modal (ANSYS)
 Total Deformation 11
 Type: Total Deformation
 Frequency: 54.458 Hz
 Unit: m
 Time: 54.458
 6/30/2014 3:23 PM



1.4735 Max
 1.3098
 1.146
 0.98232
 0.8186
 0.65488
 0.49116
 0.32744
 0.16372
 0 Min

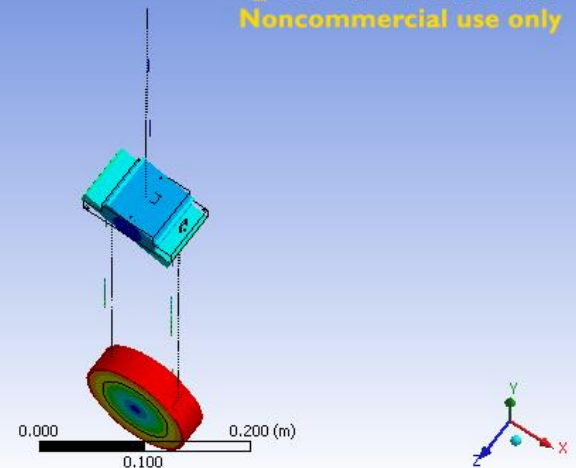


Total Deformation 12

Y: Modal (ANSYS)
 Total Deformation 12
 Type: Total Deformation
 Frequency: 75.053 Hz
 Unit: m
 Time: 75.053
 6/30/2014 3:23 PM



2.373 Max
 2.1094
 1.8457
 1.582
 1.3183
 1.0547
 0.79101
 0.52734
 0.26367
 0 Min



Input Payload

Violin Vibration Modes

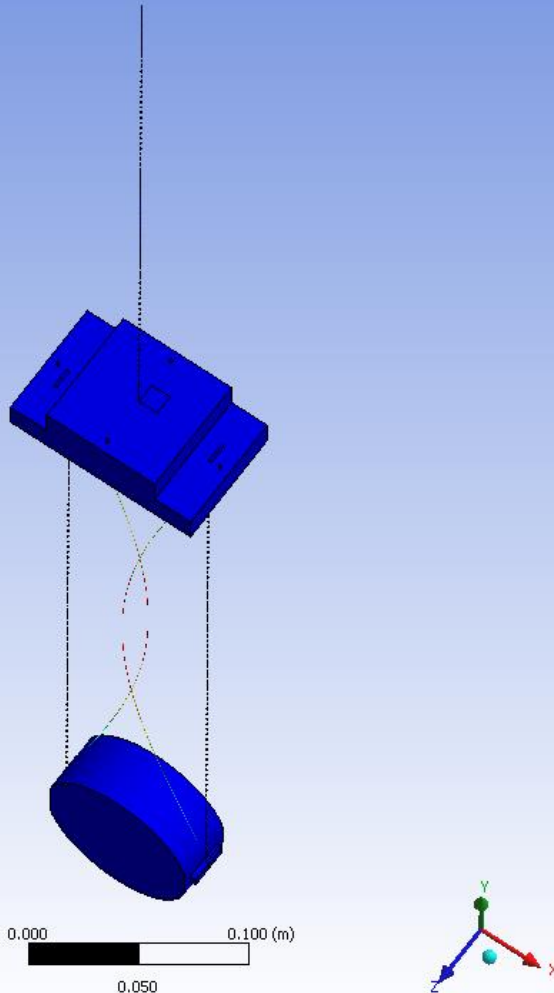
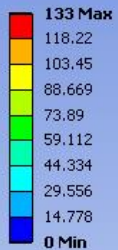
Total Deformation 13

Y: Modal (ANSYS)

Total Deformation 13
Type: Total Deformation

Frequency: 128.69 Hz
Unit: m

Time: 128.69
6/30/2014 3:29 PM



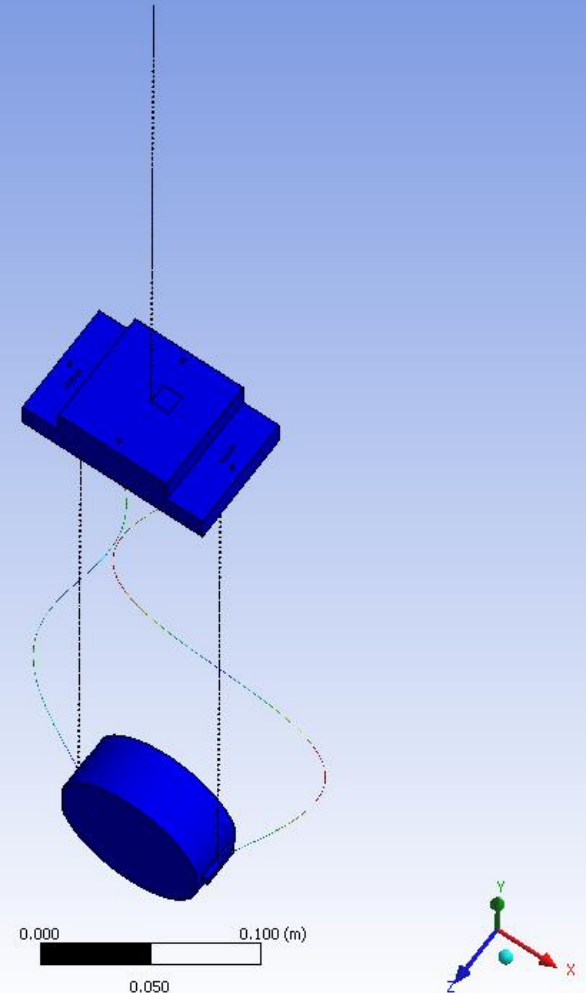
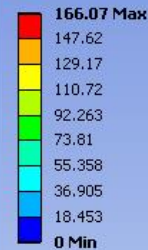
Total Deformation 19

Y: Modal (ANSYS)

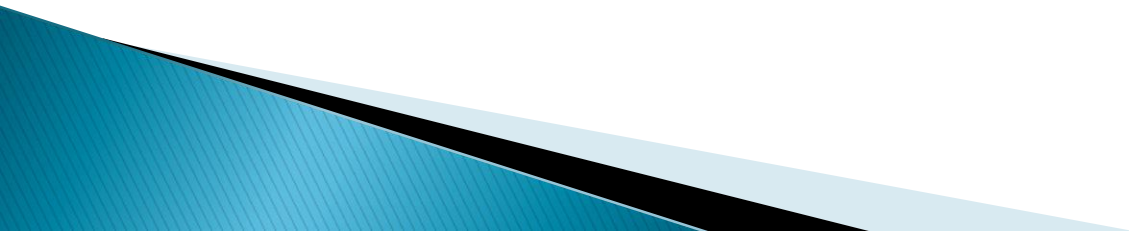
Total Deformation 19
Type: Total Deformation

Frequency: 257.86 Hz
Unit: m

Time: 257.86
6/30/2014 3:29 PM



Thermal Noise estimation



Thermal Noise estimation

$$S_z^{FDT}(\omega) = \frac{4k_B T}{m\omega} \frac{\omega_0^2 \Phi(\omega)}{(\omega^2 - \omega_0^2)^2 + (\omega_0^2 \Phi(\omega))^2}$$

$$\Phi(\omega) = (\varphi_{steel} + \varphi_{te,steel}) \frac{E_{wire0}}{E_{tot}} + \left(N\varphi_{FS} + N\varphi_{FS} \cdot 8 \frac{d_{s,FS}}{d} + N\varphi_{te,FS} \right) \frac{E_{wire}}{E_{tot}}$$

INPUT pendulum mode

$f_0 = 0.65 \text{ Hz}$

$$\varphi_{te}(\omega) = \Delta \frac{\omega\tau}{1 + (\omega\tau)^2} \quad \tau = \frac{c\rho d^2}{2.16 \cdot 2\pi k} \quad \Delta = \frac{Y\alpha^2 T}{c\rho}$$

Component	$E_s / E_{tot} z$
WIRE0	1.5e-3
WIRE1	2.8e-4

$$\sqrt{S_z^{FDT}(10 \text{ Hz})} = 1.7e-17 \frac{m}{\sqrt{\text{Hz}}}$$

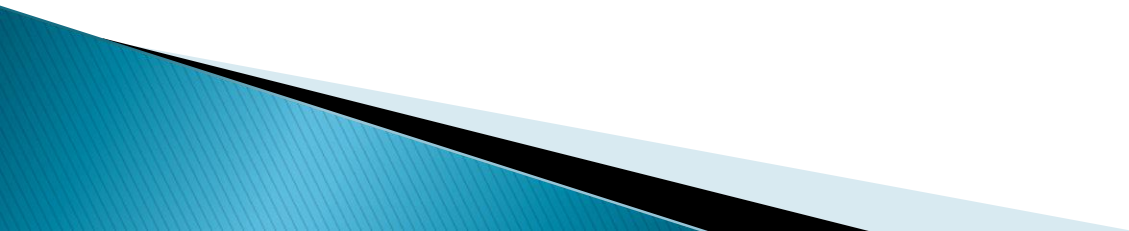
END pendulum mode

$f_0 = 0.78 \text{ Hz}$

Component	$E_s / E_{tot} z$
WIRE0	4.5e-4
WIRE1	3.5e-4

$$\sqrt{S_z^{FDT}(10 \text{ Hz})} = 6.0e-17 \frac{m}{\sqrt{\text{Hz}}}$$

Summary of updates



Summary of updates

- ITF Bench total mass $\sim 100 \text{ kg}$
- Single cage (L-shaped) for the BS payload and both the INPUT payloads
- END Marionette mass $\sim 1 \text{ kg}$ (steel)
- END Mirror mass $1 \text{e-}2 \text{ kg}$ (suprasil)
- END Mirror suspended by 2 fused silica wires with diameter: $5 \text{e-}5 \text{ m}$
- INPUT Marionette mass $\sim 1 \text{ kg}$ (steel)
- INPUT Mirror mass $\sim 0.3 \text{ kg}$ (suprasil)
- INPUT Mirror suspended by 2 fused silica wires with diameter: $2.8 \text{e-}4 \text{ m}$
- 20 Marionette coils (4 for each INPUT and END + 4 for the BS) and 8 Mirror coils (4 for each INPUT mirror)