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Finite Elements Analysis of Glassy metal flex-joints for interferometer mirror suspensions

LIGO Intern, July-December 2002

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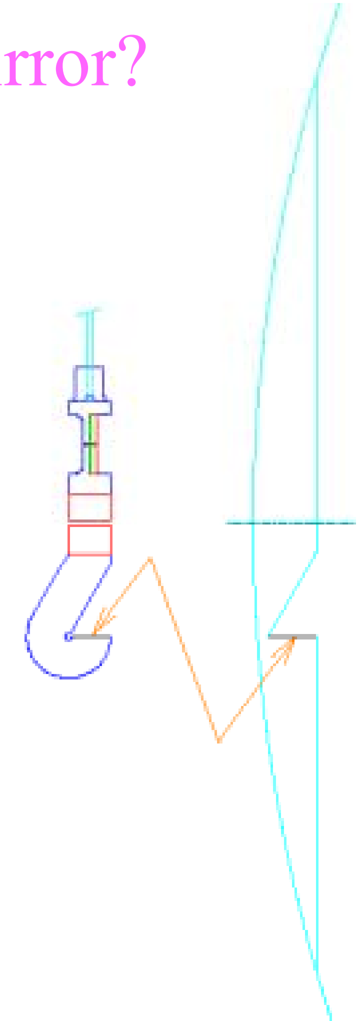
Glassy Metals Mirror Suspension

How can we support the mirror?

Working Hypothesis

- 4 Indium coated ledges in the mirror to attach the hooks with amorphous MoRuB membrane
- Suspended by Glassy metal (Vitreloy) wires



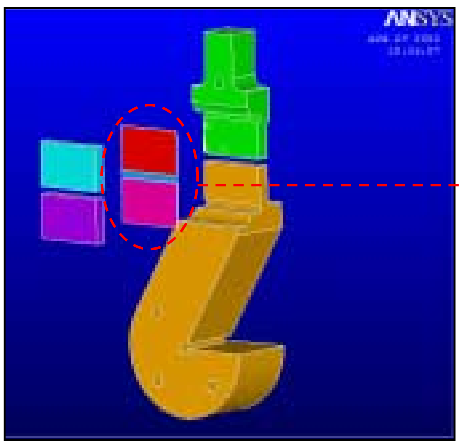
Glassy Metals Mirror Suspension. Flex-joint Dimensions.

- Assembly(“sandwich” brazed):

  “Cavaliers”

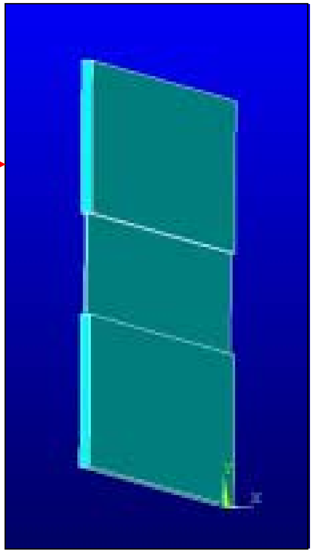
  + MoRuB Membrane

  + Hook



- Total Height 16.7mm

- Initial Membrane Geometry
  - Length: 2mm
  - Width: 3mm
  - Thickness: 50μm
    10μm
    50μm



- No transition fillet radius

Effect of geometry on Q-factor

- Glassy metals have lower intrinsic Q-factor than Fused Silica, but much more advantageous possible geometries.

- Pendulum Q Factor

$$Q_p \approx Q_{material} * (mgL/k)$$

for k<<mgL/2

Membrane stiffness $k=EI$

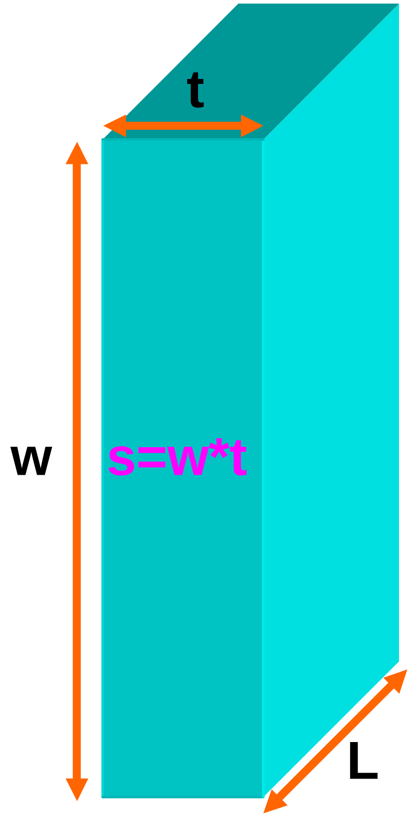
E - Young's modulus
I - Inertia of the section

$$I=wt^3/12=st^2/12$$

t can be decreased because of the high Yield point of MoRuB (~5GPa)

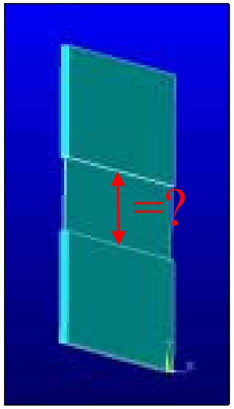
Small t means smaller k

⇒ *larger* Q_p



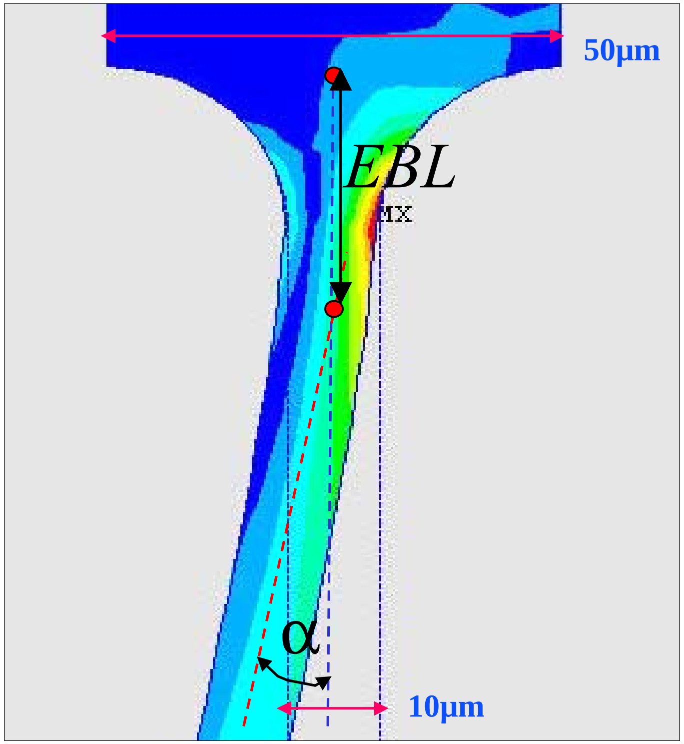
FEA – Effective Bending Length of the MoRuB Membrane

- Need to have an estimate of the initial length for the thin part of the membrane.



- Definition:

The effective bending length is defined as the distance from the beginning of the thin part of the membrane to the intersection of its neutral fiber before bending and the linear extrapolation of the straight part of the flex-joint's neutral fiber after bending.



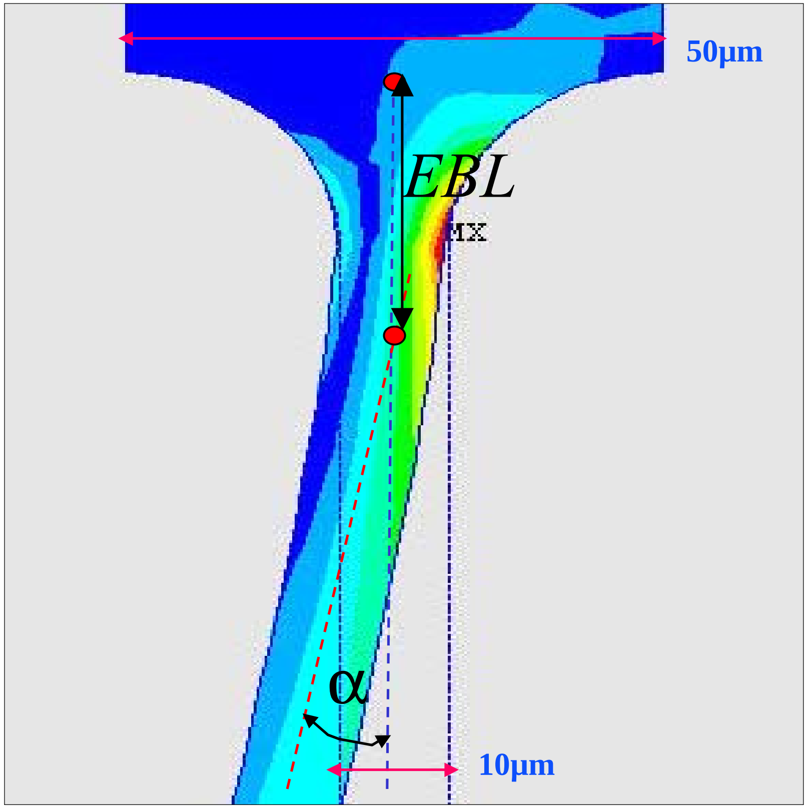
FEA – Effective Bending Length of the MoRuB Membrane

- Numerical Simulations made for

  Constant bending angles
  α = 0.7degrees, 5 degrees and the extreme case of 45degrees

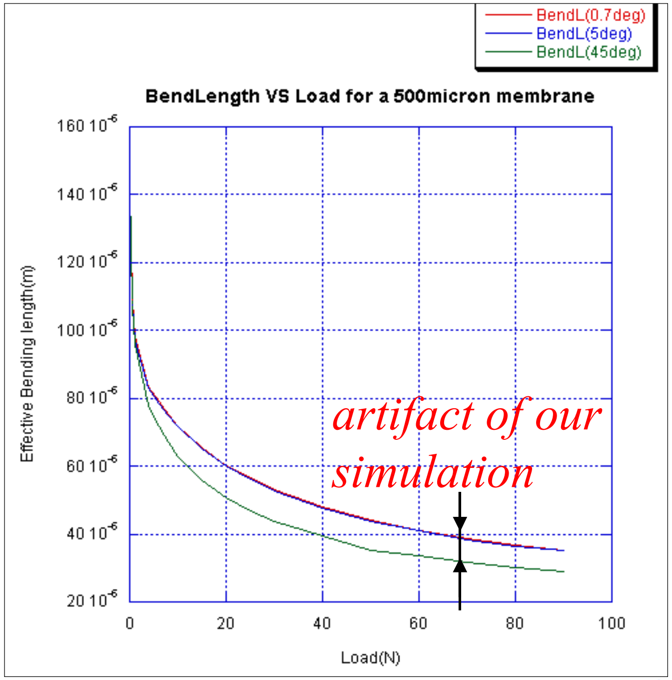
  with

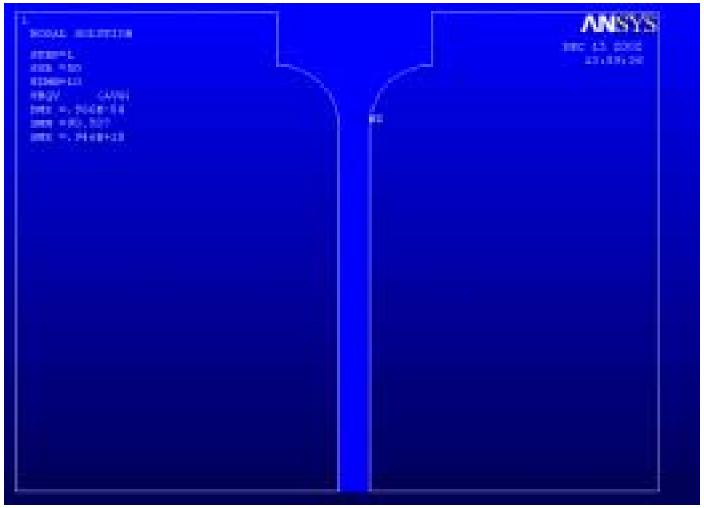
  traction loads varying from 0 to 90N.



FEA – Effective Bending Length of the MoRuB Membrane

- Results:
  - ✓ Similar curve shapes
  - ✓ Nearly identical values for small bending angles (0.7 and 5deg)

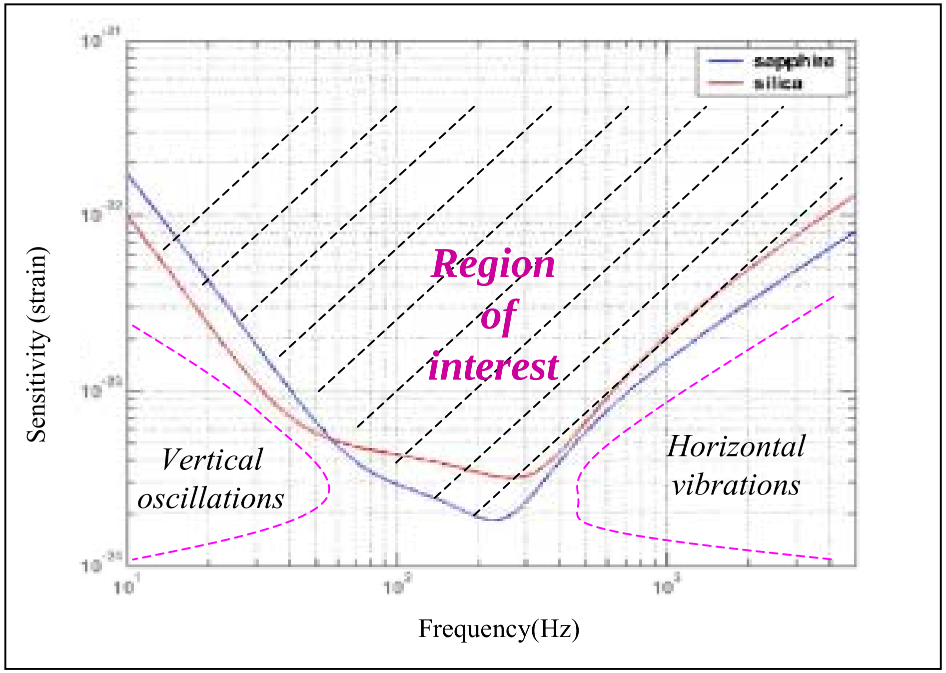




Conclusion ⇒ **The effective bending length for loads above 70N is less than 40µm on both ends of the membrane.**

FEA – Natural modes of the suspension system

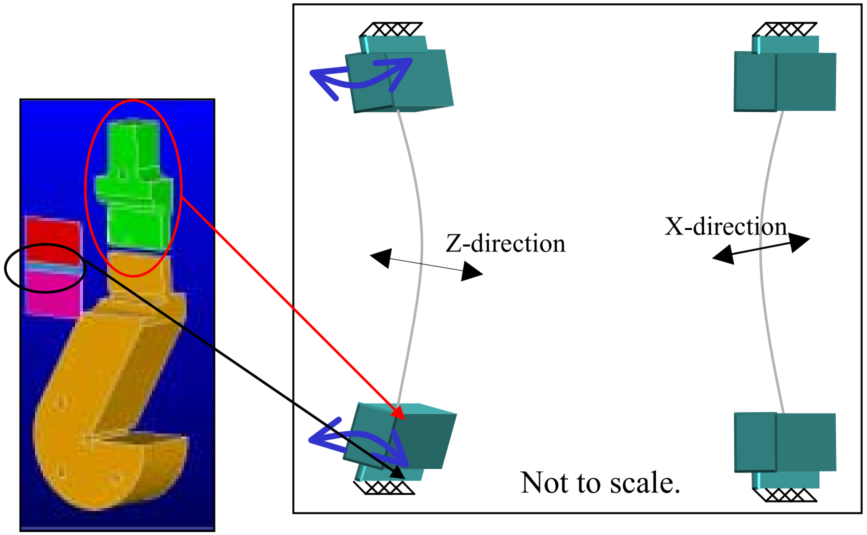
- Aims:
  - ✓ Extract Violin modes and Vertical bouncing modes of the glassy metal suspension system.
  - ✓ Compare them to those of fused silica wires.



Note: To stay out of the region of interest – Vertical preferable low frequencies and Horizontal preferable high frequencies.

FEA – Natural modes of the suspension system. Violin modes.

- System parameters for glassy metals and fused silica models:
  - ✓ Length = 1m
  - ✓ Fiber diameter = 0.3mm



- Results:

	Vitreloy fiber + MoRuB Flex-joint + Mass (M)				Fused Silica fiber
	Pre-strained to 1.5% (Ø 0.3mm)	Pre-strained to 1.75% (Ø 0.3mm)	Pre-strained to 1.8% (Ø 0.3mm)	Pre-strained to 1.75% (Ø 0.182mm)[1]	Loaded to 0.6GPa (Ø 0.3mm)
First frequency Z	237.26 Hz	256.27 Hz	259.88 Hz	256.47 Hz	258.58 Hz
First frequency X	239.02 Hz	258.16 Hz	261.79 Hz	258.43 Hz	258.58 Hz

FEA – Natural modes of the suspension system. Violin modes.

- Changes in the mass of the moving part of the hook.
- Insignificant changes in the natural modes

		1000mm Vitreloy + MoRuB Flex-joint + Mass (M)				
		0.25*Mass	0.5*Mass	Mass	2*Mass	4*Mass
1 Newton Pre-Stress Force	First frequency Z	24.381 Hz	24.381 Hz	24.380 Hz	24.380 Hz	24.378 Hz
	First frequency X	24.560 Hz	24.560 Hz	24.560 Hz	24.560 Hz	24.560 Hz
75 Newton Pre-Stress Force	First frequency Z	206.95 Hz	206.94 Hz	206.94 Hz	206.93 Hz	206.92 Hz
	First frequency X	208.49 Hz	208.49 Hz	208.49 Hz	208.49 Hz	208.49 Hz

FEA – Natural modes of the suspension system. Vertical bounce modes.

- Vertical oscillations depend on the elongation of the fiber under load.
- Vitreloy can be safely loaded up to 1.75%-1.8% (elasticity limit given at 2% deformation and large critical defect size).

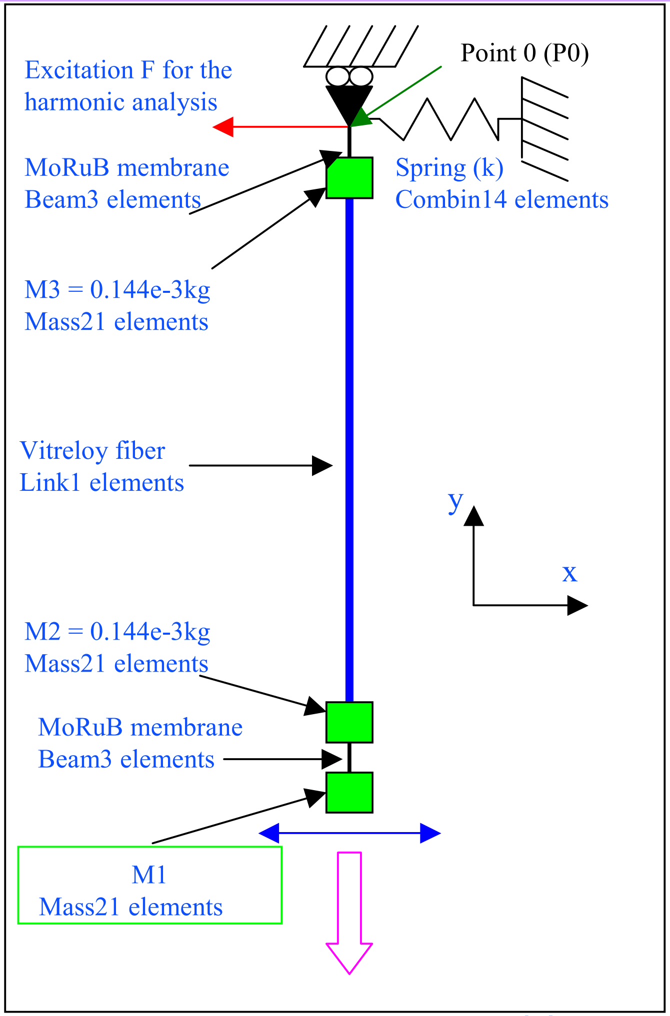
⇒ Low values for vertical bounce modes.

	Glassy Metals Suspensions (1 meter)			Fused Silica fiber (1 meter)
	Pre-strained to 1.5% (Ø 0.3mm)	Pre-strained to 1.75% (Ø 0.3mm)	Pre-strained to 1.8% (Ø 0.3mm)	Loaded to 0.6 GPa (Ø 0.3mm)
Vertical oscillations	4.069 Hz	3.770 Hz	3.716 Hz	5.499 Hz

Thanks to Phil Willems for his help.

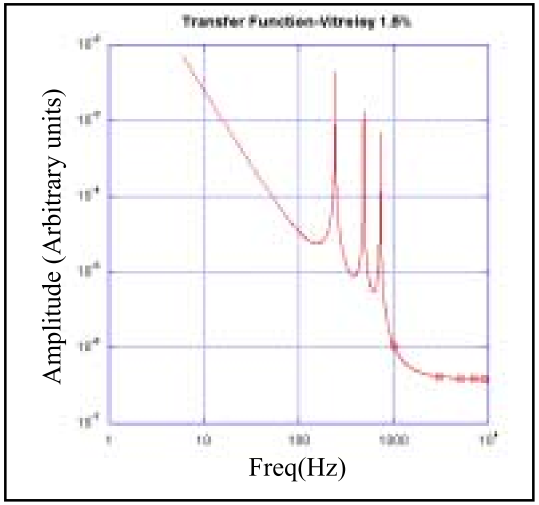
FEA – Harmonic response of the suspension system.

- Are glassy metals suspensions a good mechanical attenuator?
- Plot the transfer functions for the response to a harmonic excitation.
- Finite Elements model

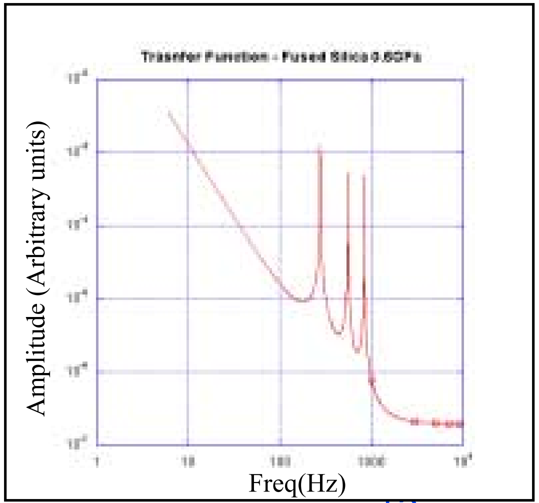


FEA – Harmonic response of the suspension system.

- Conditions of analysis - Fused Silica and Glassy Metals:
  - 1 meter length
  - Vitreloy – 1.5% strain
  - Fused Silica – 0.6GPa

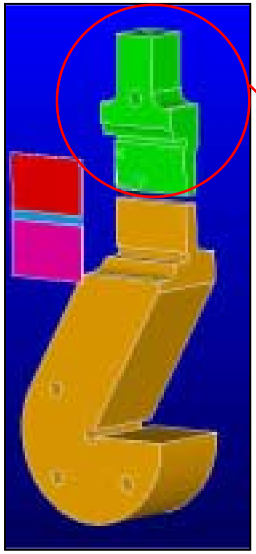


- Results:
- Good mechanical attenuation
- Fused silica fibers slightly better



FEA – Harmonic response of the suspension system.

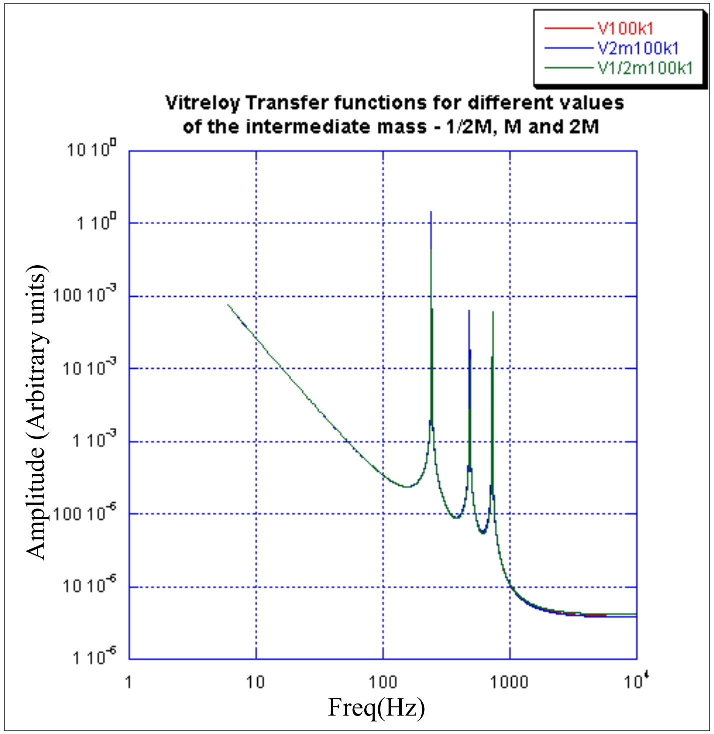
- Changes in the mass of the upper part of the hook.
- No changes in the transfer function



M=0.144e-3kg

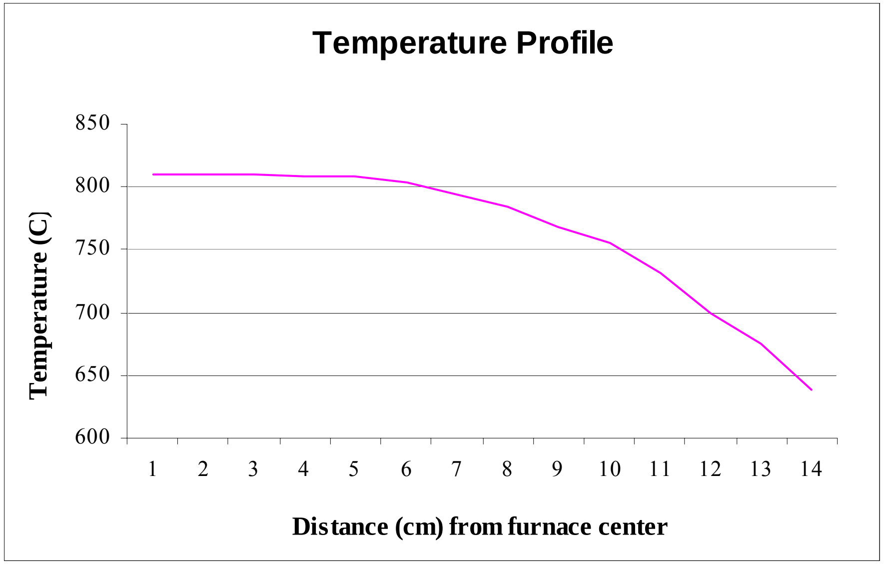
M'=2M

M"=M/2



What else?

- Ansys is fine, but "it's not always the first girl who make the best wife" (R&D).
- Continued SURF students' work
  - » X-ray diffraction and phase transition in MoRuB (Brian Emmerson and Barbara Simoni).
  - » "New" furnace – much better temperature control



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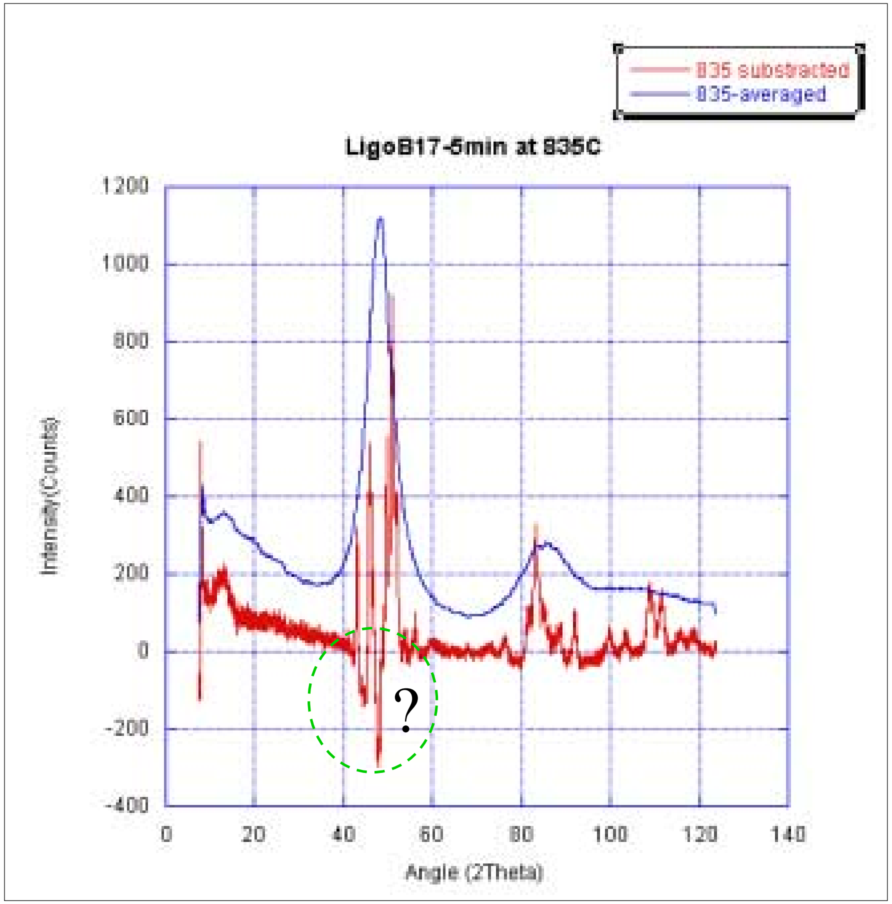
What else?

- Found problems. ☹
- Figured out a possible solution. ☺
- Work continues.



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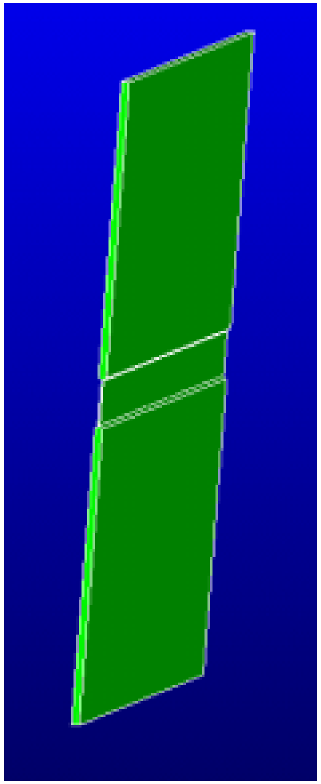
Study of the MoRuB blade

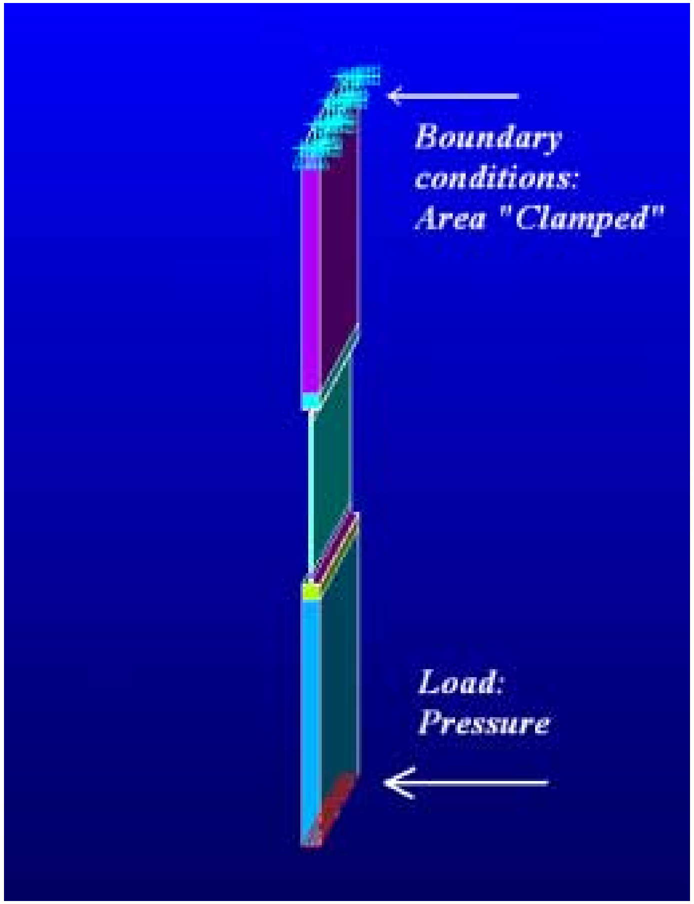
- Best geometry: transition between 10 & 50 microns
- Distribution of Strain Energy in the Flex in one Oscillation
- Maximum Angle of the Flex loaded at 80%
- Thermal Properties: results, accuracy & improvements



GEOMETRY OF THE MEMBRANE OF MORUB

Transition between 50 Microns thick to 10 Microns for Minimum Stress Concentration

GEOMETRY OF THE MEMBRANE OF MORUB

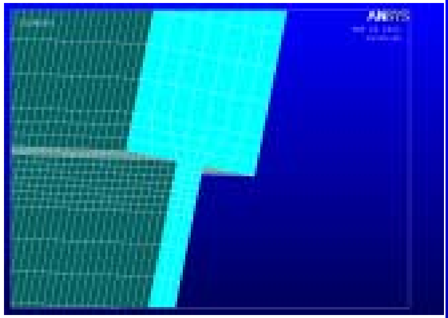


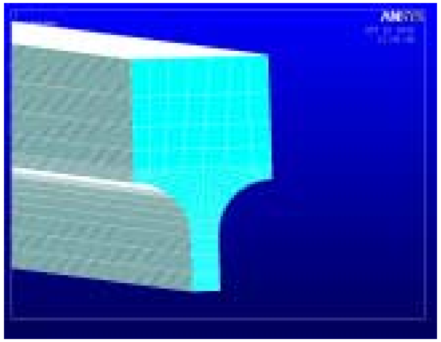
Conditions of the Analysis:

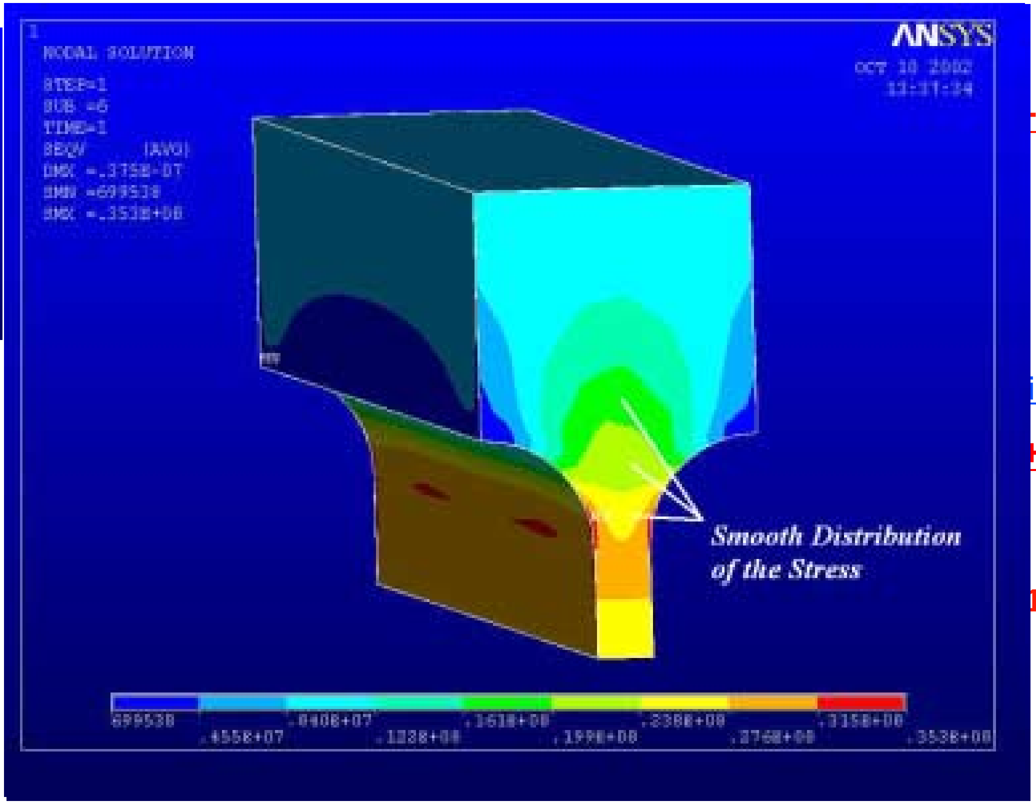
- Pure traction on the Bottom: 75N Load turned into a pressure
- Area Clamped on the Top

We vary the transition shape under the same conditions.

GEOMETRY OF THE MEMBRANE OF MORUB







-10 Pa

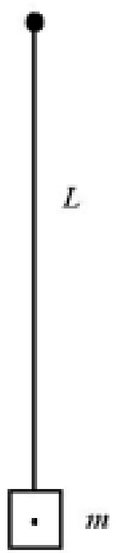
ion

+8 Pa

100
radius

Location of Strain Energy

Let’s take a simple pendulum…



FOR ONE OSCILLATION

For every Material: $Loss = \dfrac{E_S}{Q_{MATERIAL}}$

E_S = Strain Energy,

$Q_{MATERIAL}$ = Quality Factor of the Material

For the entire system, (as an approximation):

$$Losses = \alpha_{MoRuB}\frac{E_S}{Q_{MoRuB}} + \alpha_{Braze}\frac{E_S}{Q_{Braze}} + \alpha_{Hook}\frac{E_S}{Q_{Hook}} + \ldots$$

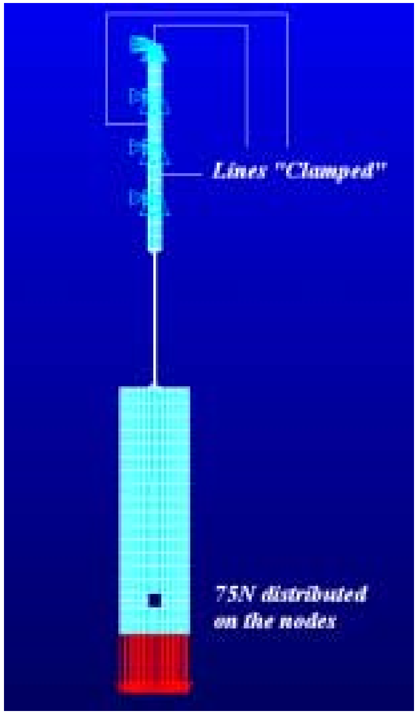
α_i = fraction of Energy stored by the Component i

e Q factor of Braze is expected to be very low.

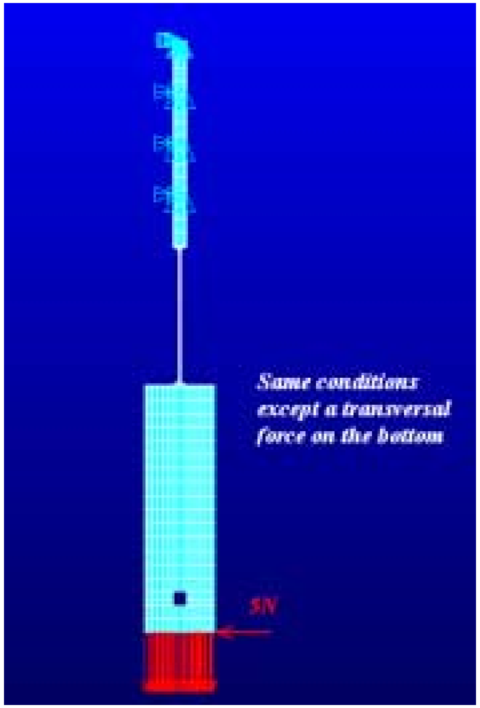
…..l Braze affect the efficiency of the MoRuB Flex-joint?

Location of Strain Energy

CONDITIONS OF THE ANALYSIS: **Comparison between two positions of the Flex-Joint in a 2-Dimensional model**



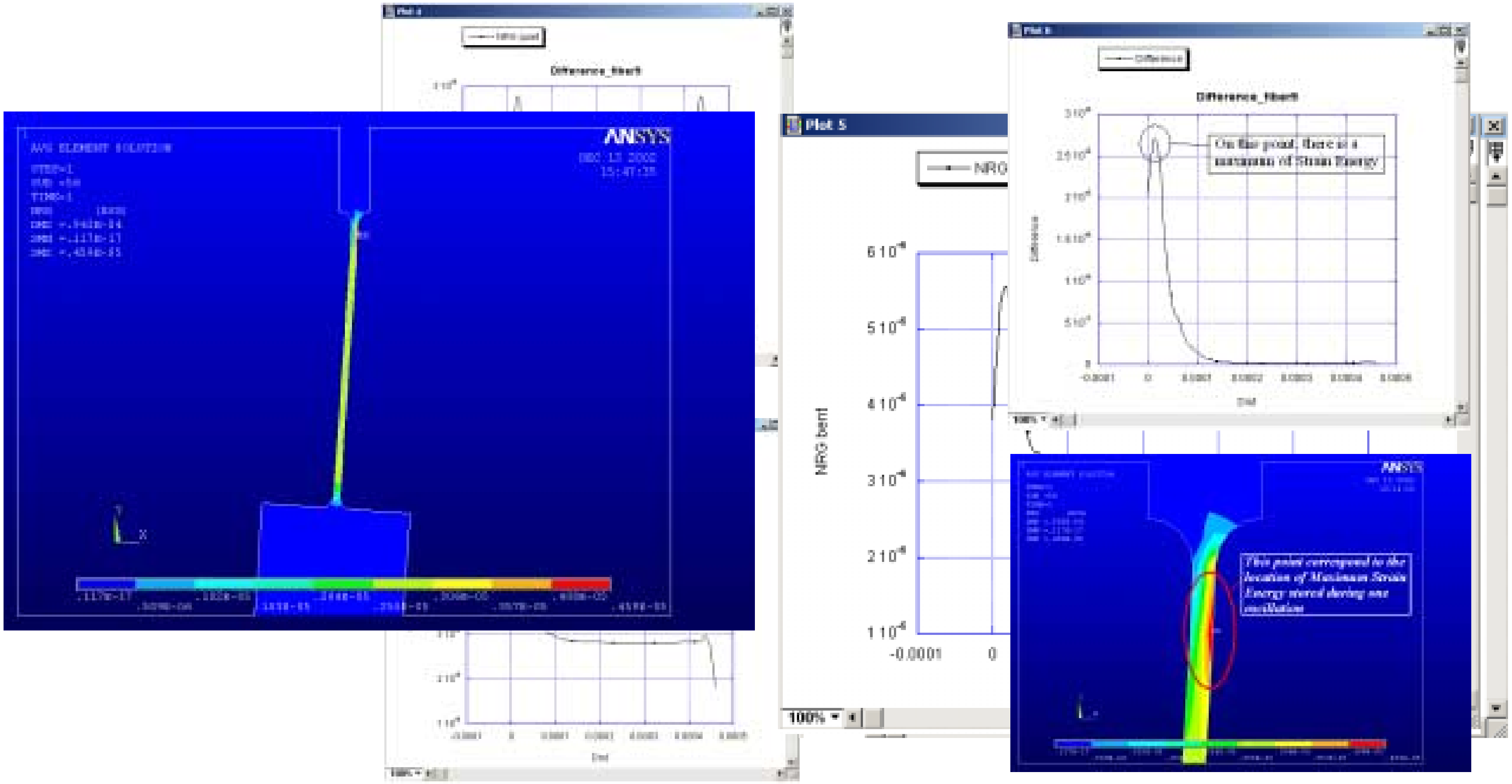
"Quiet" position



"Bent" position

Location of Strain Energy

The principle



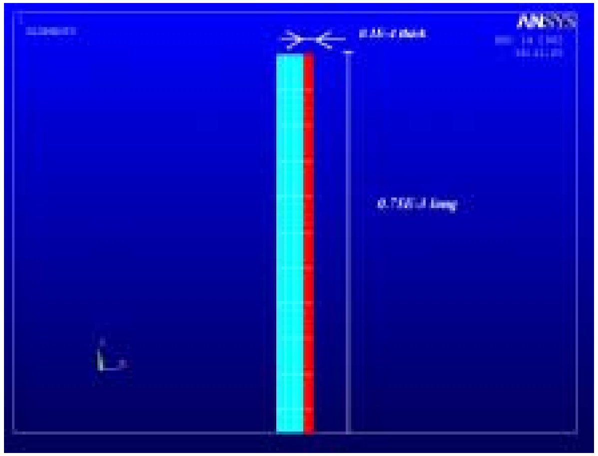
"Bent" position

Location of Strain Energy

We do the same in all layers and Integrate the Curves.

We found a Amount of Strain Energy of: **2.05E-5 Joules** in the MoRuB membrane

BRAZE



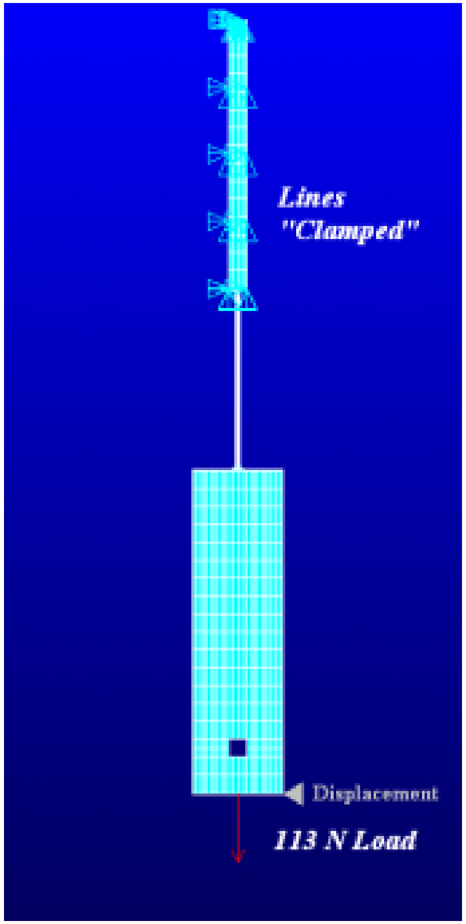
Basically the same principle.

We find an amount of Energy of: **< 2.14E-8 J**

Ratio between the two amounts of Strain Energy

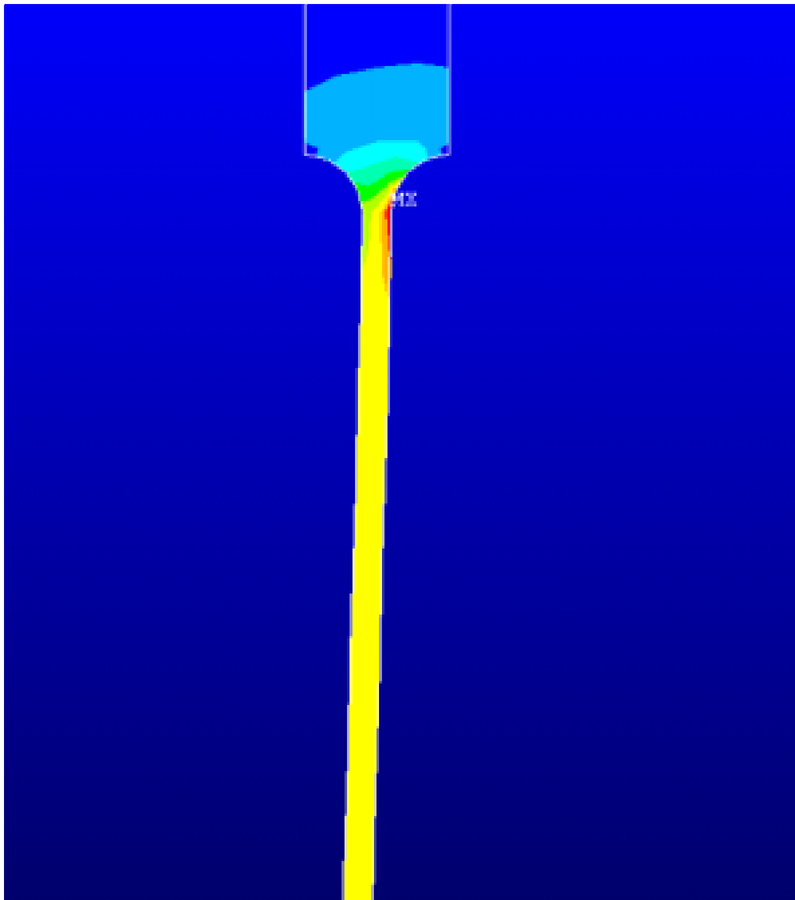
$$\frac{\alpha_{MoRuB}}{\alpha_{Braze}} \cong 1000$$

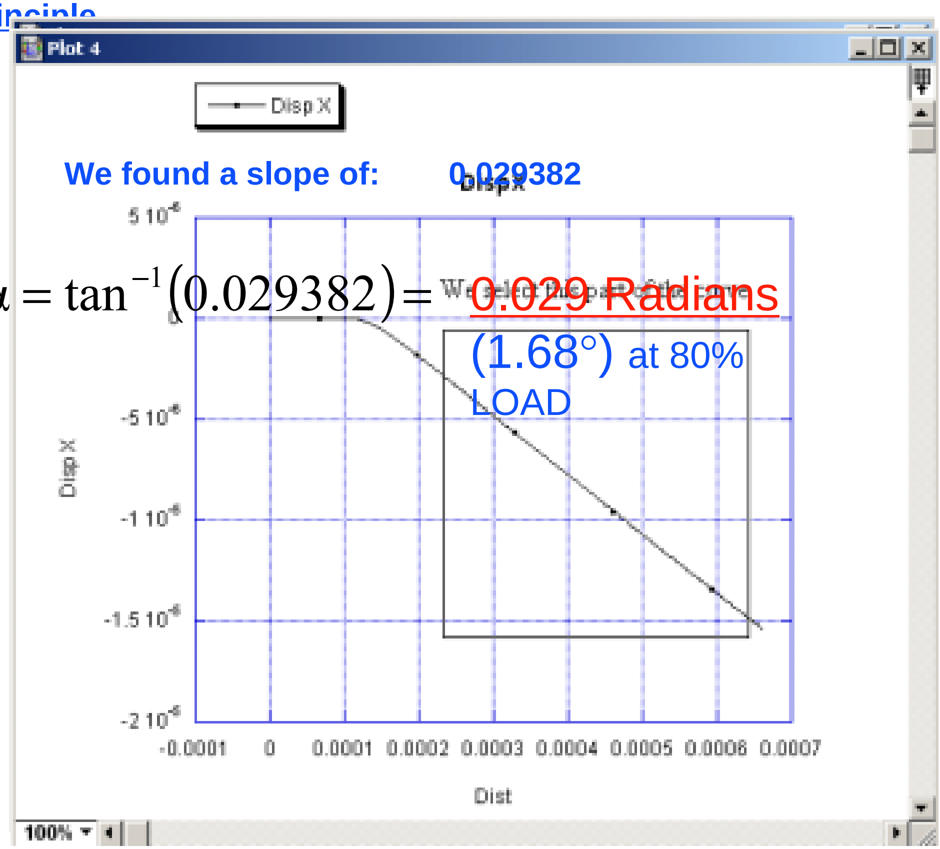
Maximum angle of the Pendulum



- Pendulum loaded at 80% of the Yield Point
- Moved aside until the Yield Point
- Measure the Angle

Maximum angle of the Pendulum





We found a slope of: 0.029382

$$\alpha = \tan^{-1}(0.029382) =$$ 0.029 Radians (1.68°) at 80% LOAD

Work on Thermal Properties: Still goes on…

Heat Capacity Measurement: we already have an accuracy of **30%**, and figured out how to improve to **10%.**

C= 132 J/K/g at 380K

Thermal Conductivity: we have completed Measurement of MoRuB, and the technique is improving.

K = 42.19 W/K/m at 350K

K = 27.77 W/K/m at 300K

Acknowledgments

- Thanks to

  - all the Glassy Metal team members and especially Hareem Tariq

  - All LIGO scientists and staff

  - Prof. Bill Johnson, Dr. Jan Schroers et al. from Caltech's material science laboratory

  - our mentor at INSA de Lyon – Prof. Régis Dufour

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