ME 254, Lecture 2

The Spirit of Compliant Design

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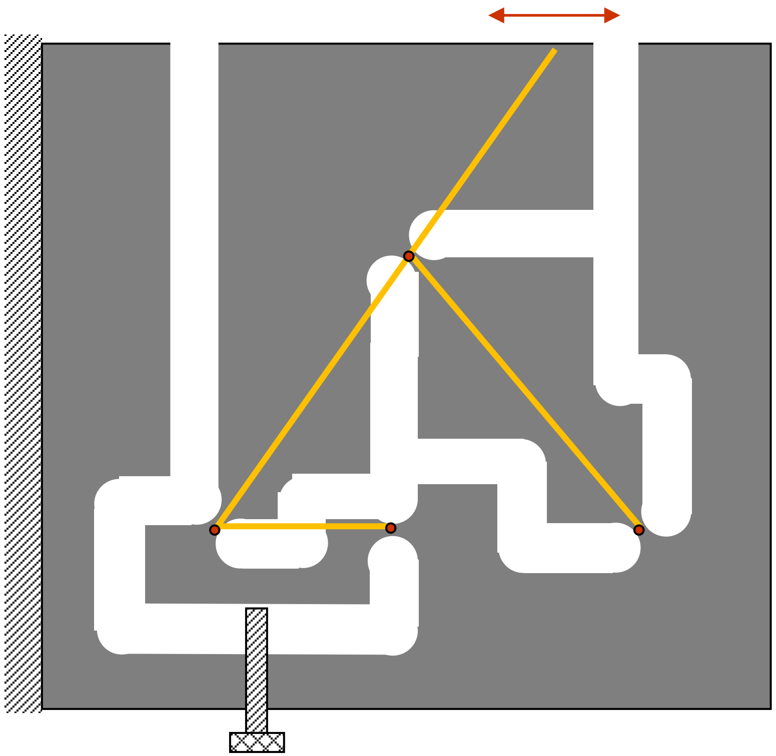
Prefer hinges to sliders;
flexures to either.

A design principle espoused by M. J. French.

Discrete compliance



Distributed compliance

And then there is semantics!

The term “compliant mechanism” was coined by Prof. Ashok Midha.

Two connotations and one concept

सुनम्य

ನಮ್ಯ

Deformable
Elastic
Flexible
Lithe
Limber
Lissome
Pliable
Pliant
Supple
…

Compliant

Accommodating
Acquiescent
Agreeable
Amenable
Complaisant
Non-resistant
Obedient
Obliging
Yielding
…

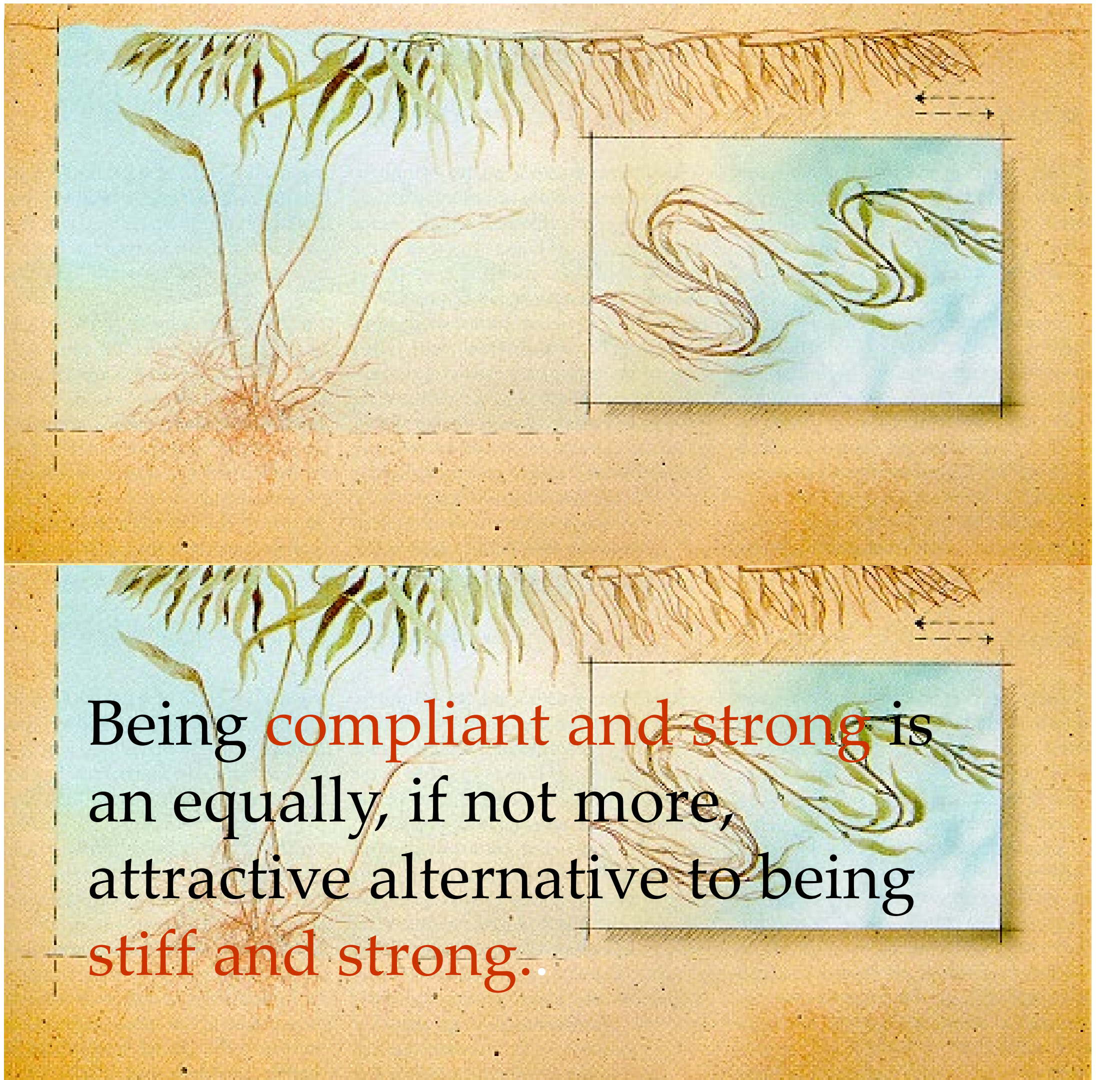
अनुवर्ती

ಅನುನೆಯ

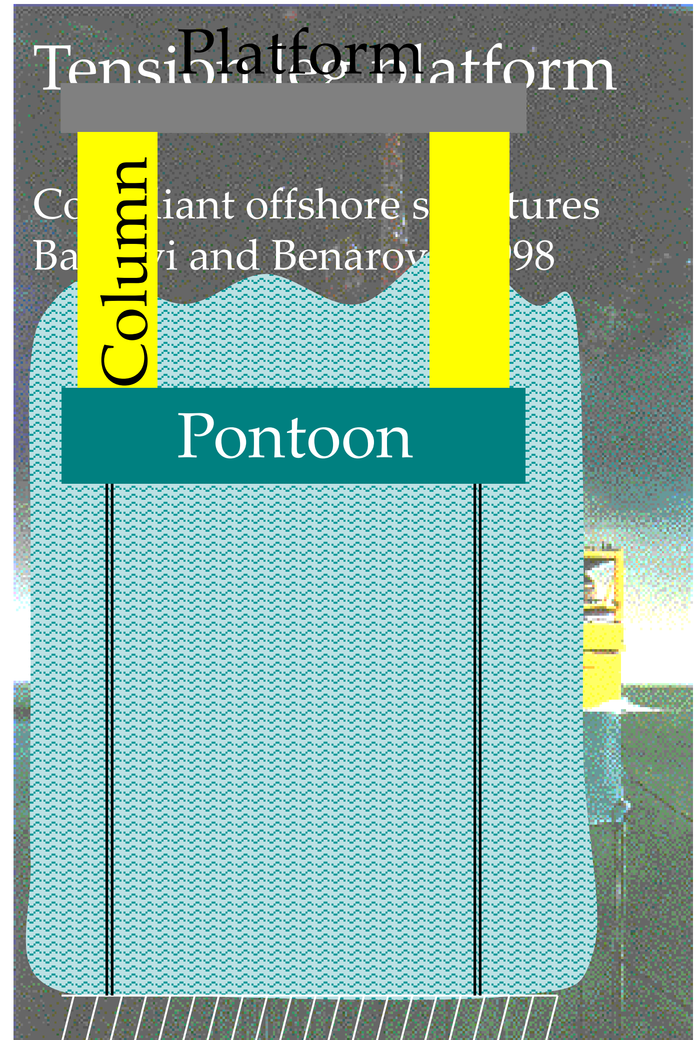
ಸುಲಭವಾಗಿ ಬಾಗುವ; ಹೊಂದಿಕೊಳ್ಳುವ; ನಮ್ಯ

ವಿಧೇಯ, ಅನುವರ್ತನಶೀಲ, ನಮ್ಯ, ಆಜ್ಞಾನುವ ರ್ತಿ

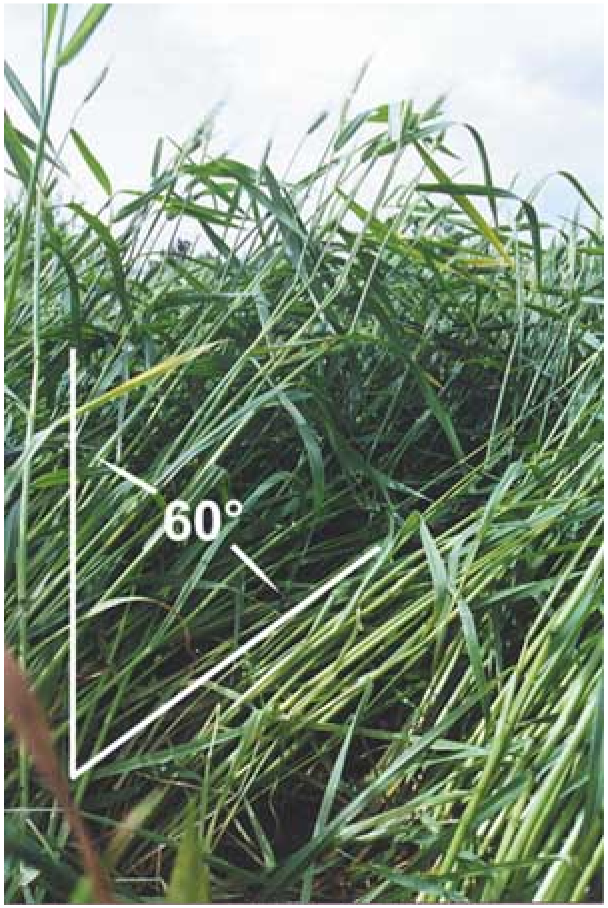
A picture is worth 1000 words!



Being compliant and strong is an equally, if not more, attractive alternative to being stiff and strong..

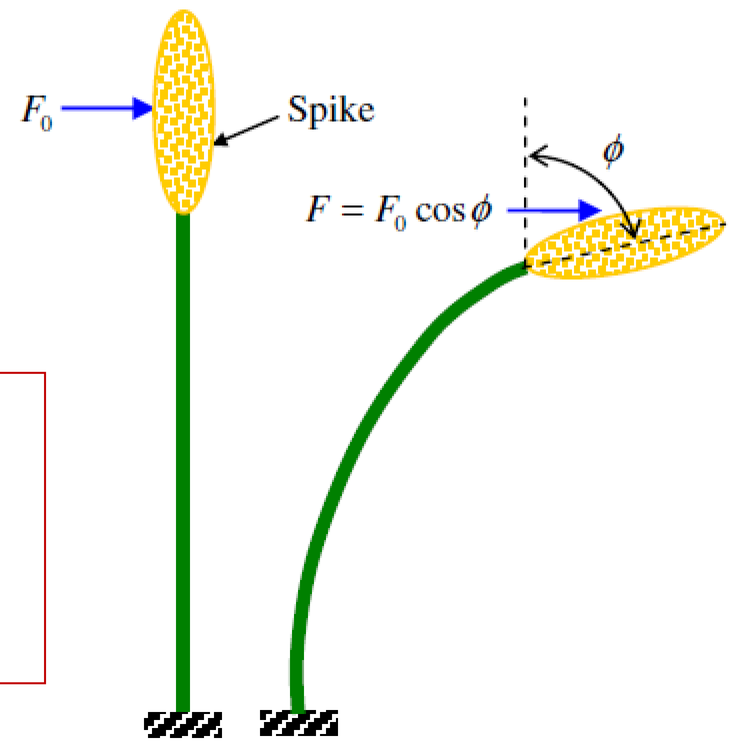


The importance of being compliant



How wheat plants avoid "lodging" by being compliant.

Struct Multidisc Optm'n (2009) 39:327–336
With
P. Sivanagenrda



http://www.fao.org/docrep/006/x8234e/x8234e08.htm

Don't they break?

Yes, they do…like all others that are not designed well.

- Ability to withstand overloads – "I bend but I break not."

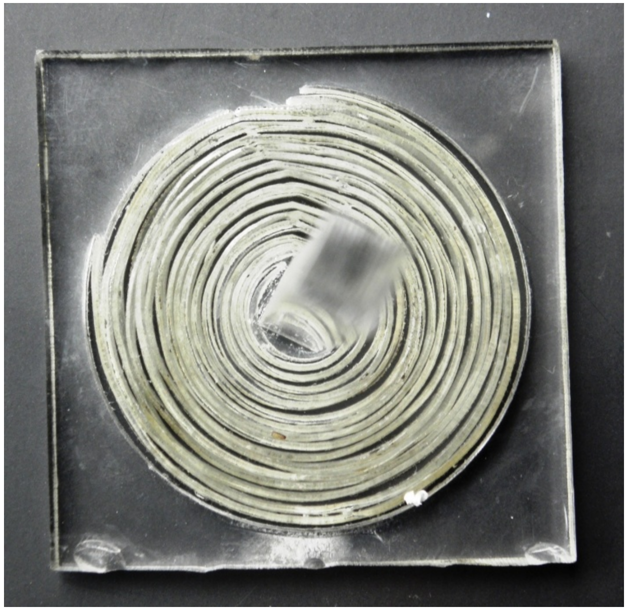
But flexibility does not imply the lack of strength.

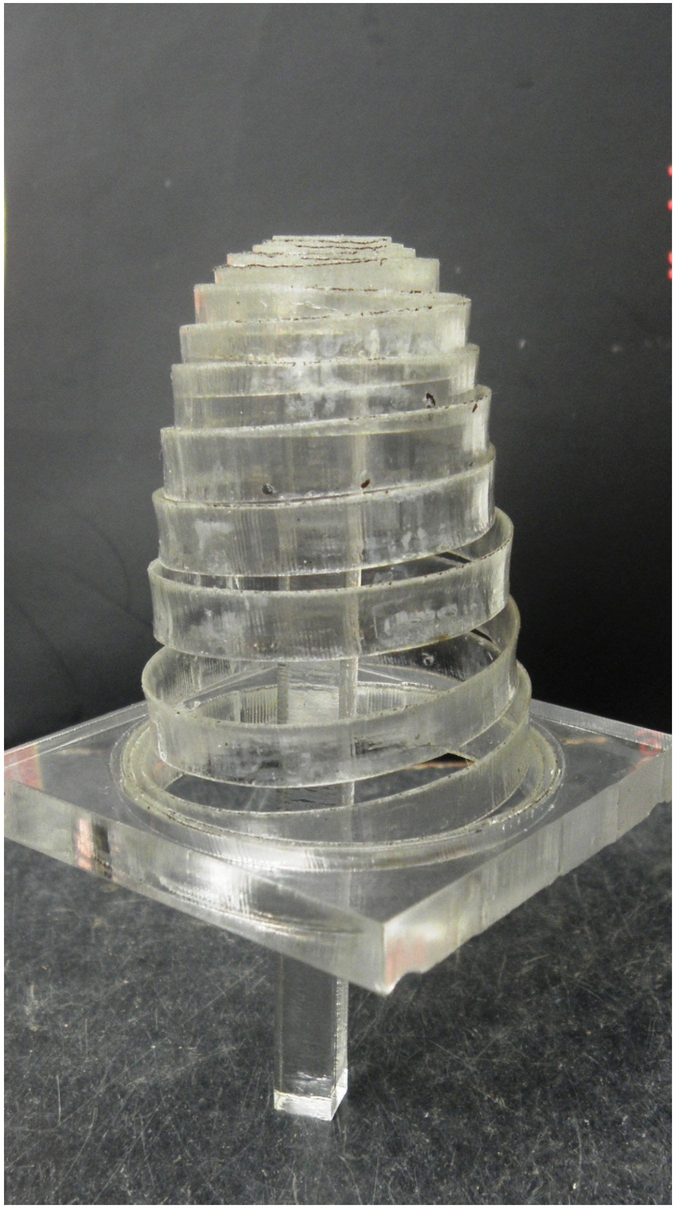
And, rigidity does not imply strength either!

It is a question of choosing the right material and having a suitable design.

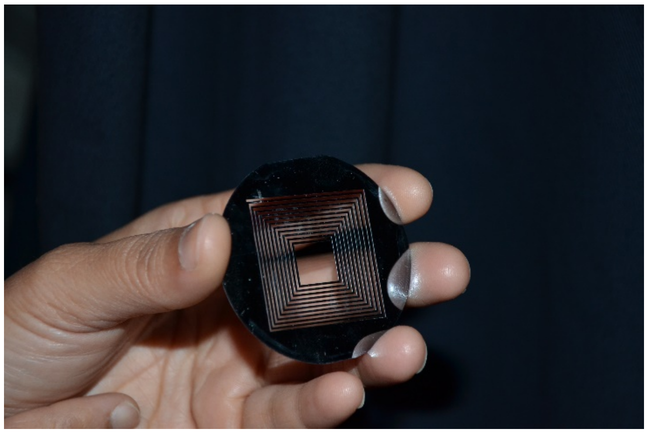
Flexibility and shape

Cut a spiral in an acrylic sheet and pull up the centre. This shows that flexibility is a matter of design.

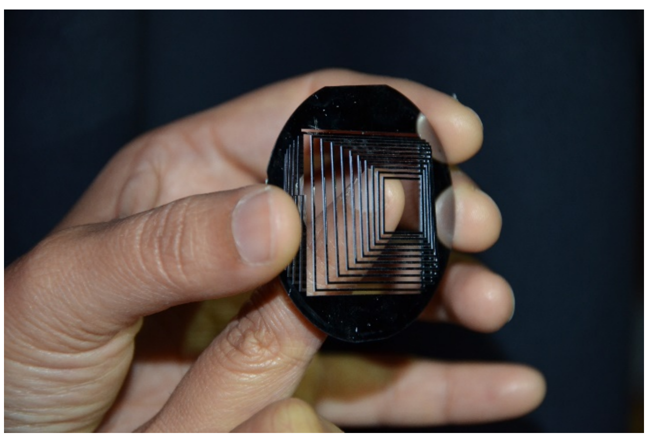


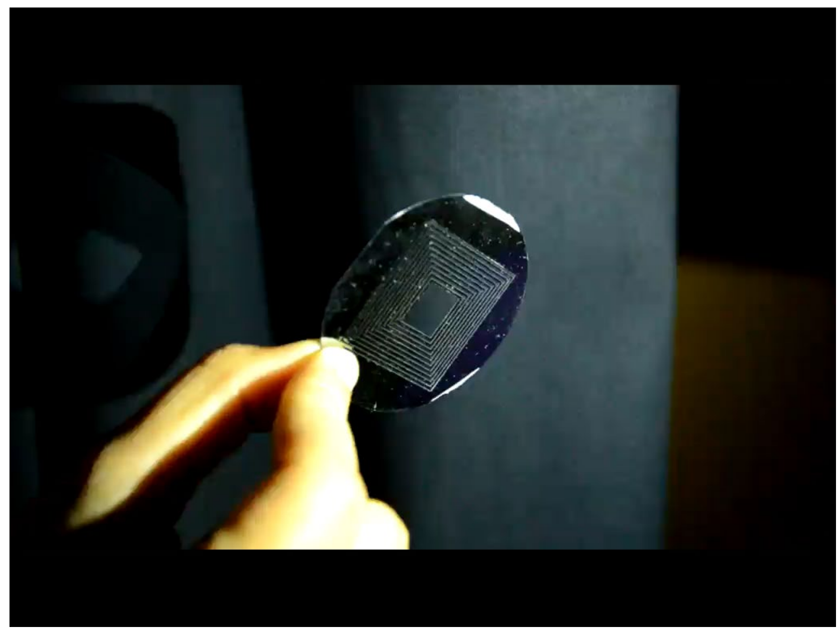


Brittle materials can be made to be very flexible.



A spiral etched into a silicon wafer makes it a flexible conical spring.



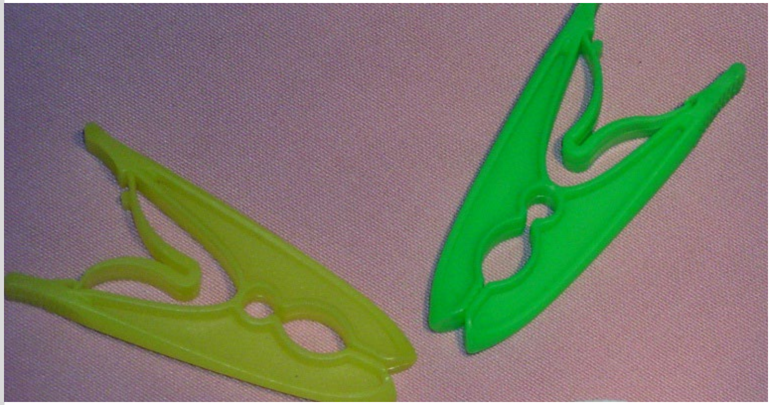


"One-piece clothes peg holds clothes in gales!"

From the product description…

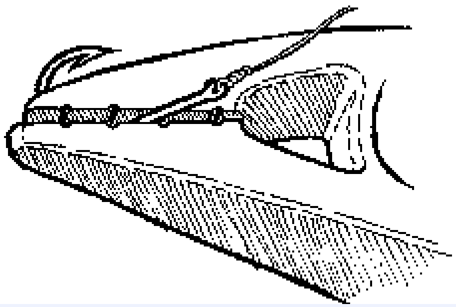
Up to 3 times stronger than metal sprung pegs.

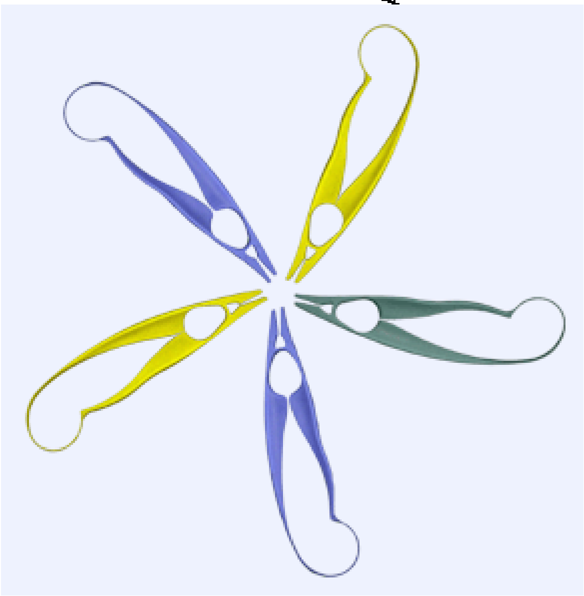
Imagine a clothes peg which:
. Is a single moulded item
. Has no metal parts to rust
. No wood to stain clothes
. Will not break, made of polypropylene
. Grips your clothes even in gales

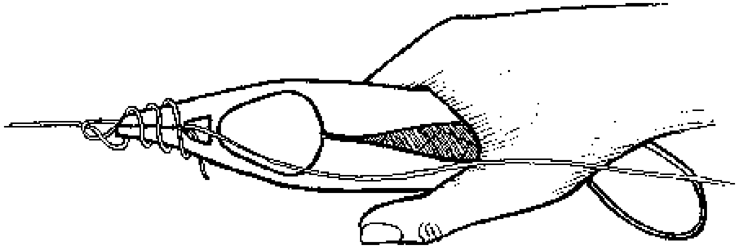


This BRITISH product which is UNIQUE in design has a POWERFUL integral spring action. Being made in 100% PLASTIC they are totally RUST FREE

Aesthetics made easier.







- Aesthetics made easier

Compliers, a fish-hook remover

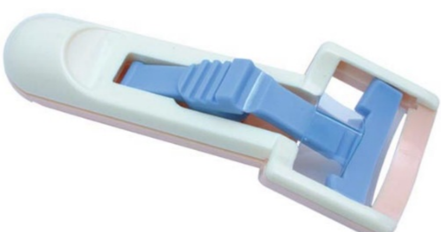
From www.compliersinc.com

Prof. Ashok Midha
Missouri University of Science and Technology

Which one will you buy?

Tweezerman

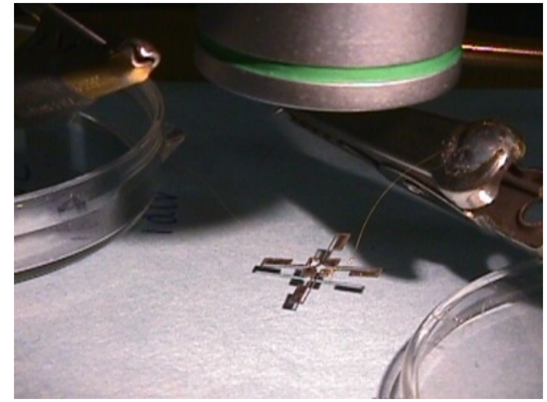
Preo



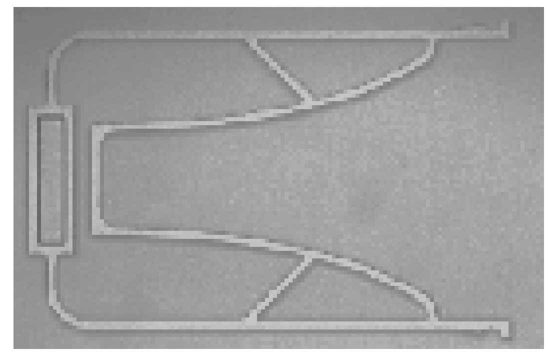
Beautyimpex

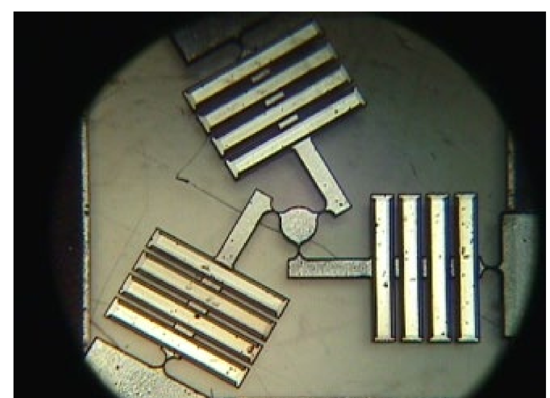
Audrey

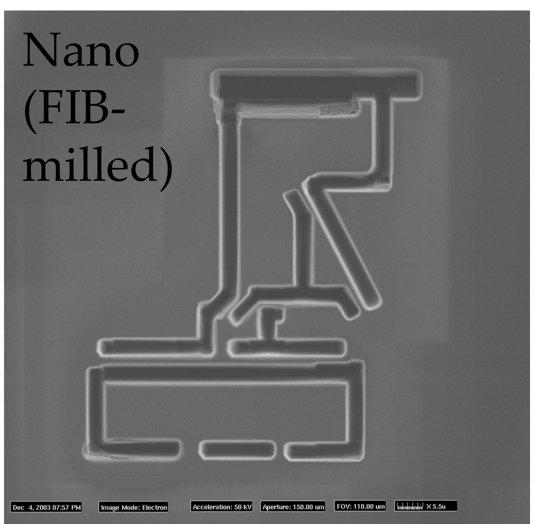
Size no bar!



Macro

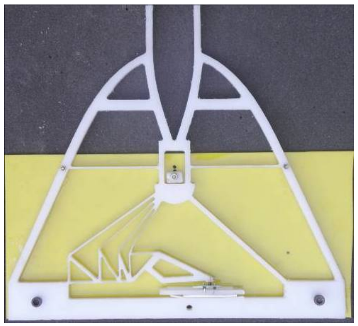


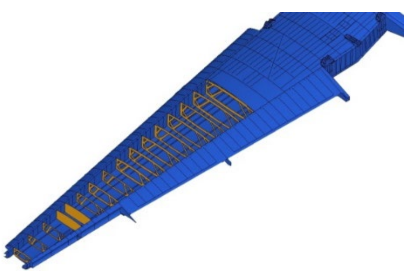




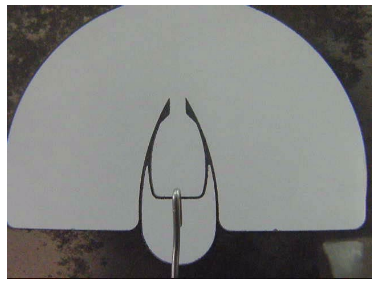
Different sizes, materials, and prototyping techniques

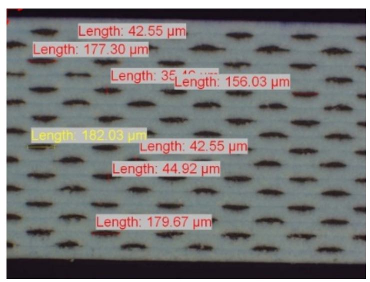
Macro

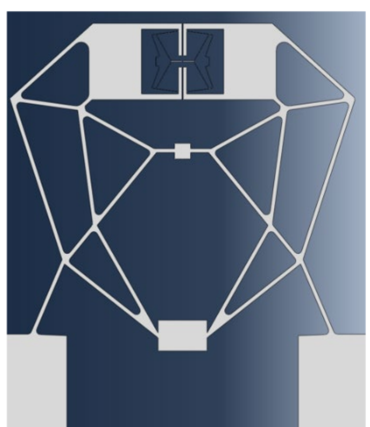




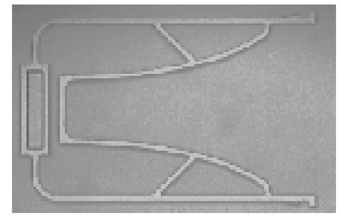
Meso

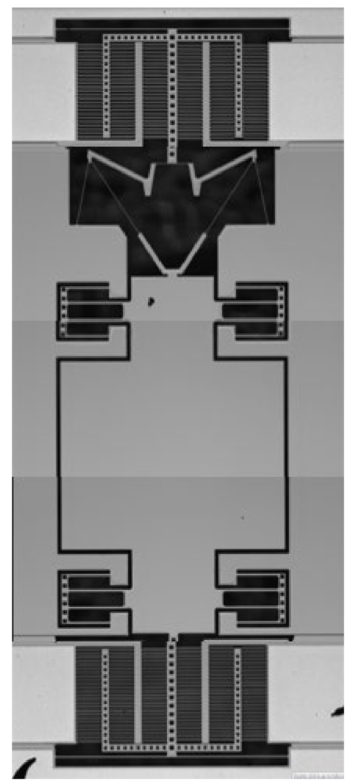




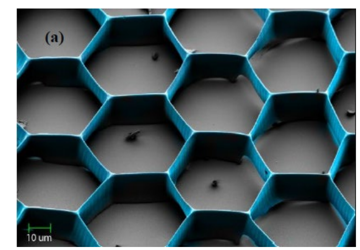


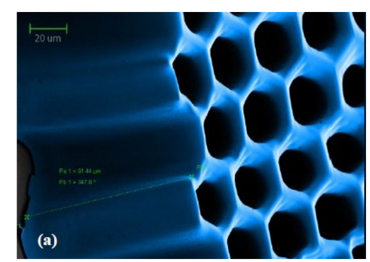
Micro





Nano

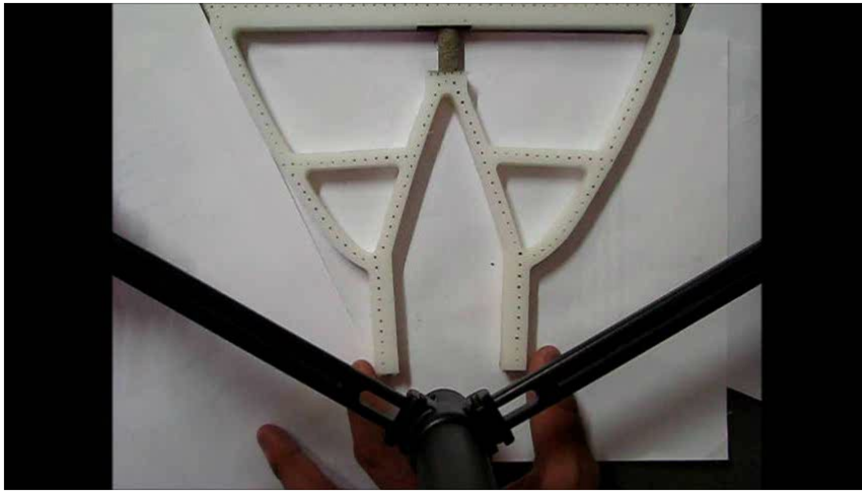


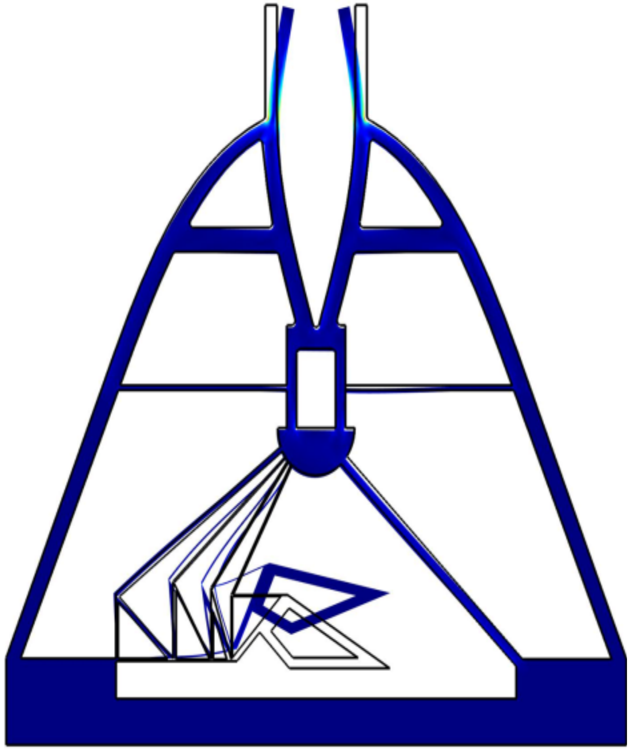


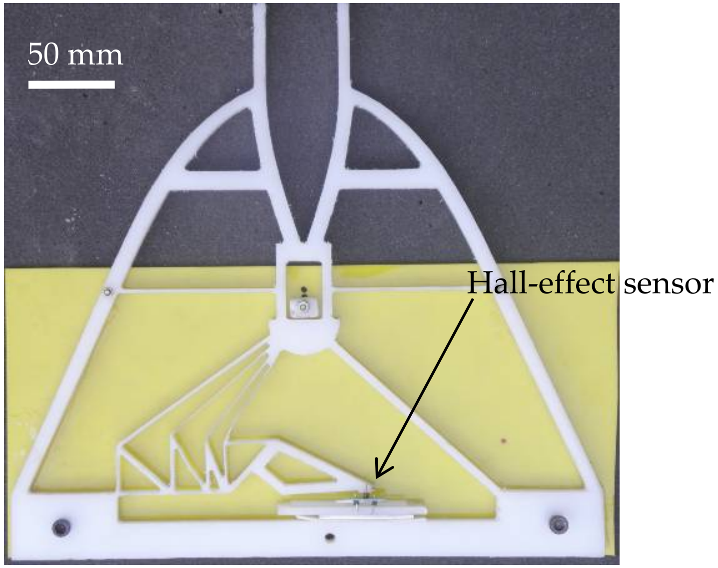
Macro

Compliant Mechanisms

Testing cemented sand-specimens

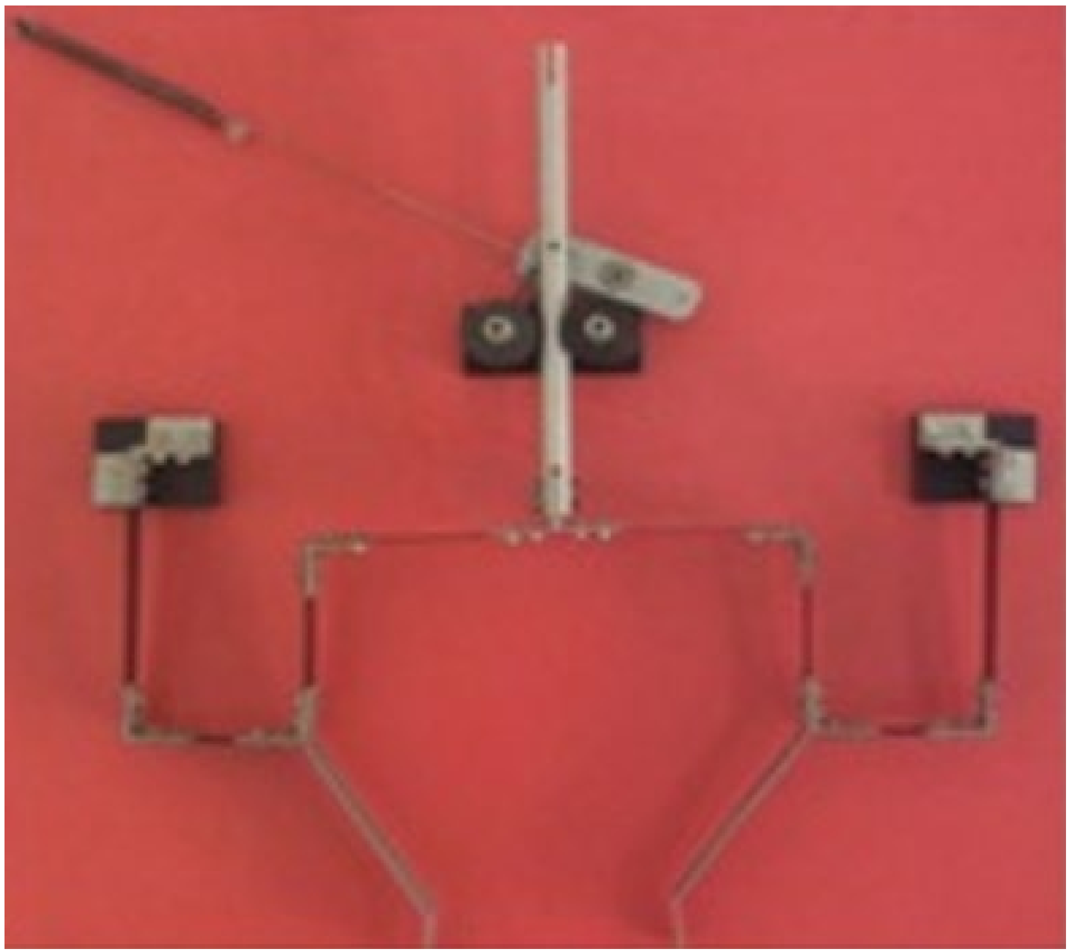






Work with Dr. Santosh Bharagav, Prof. Tejas Murthy and Mr. Ramesh

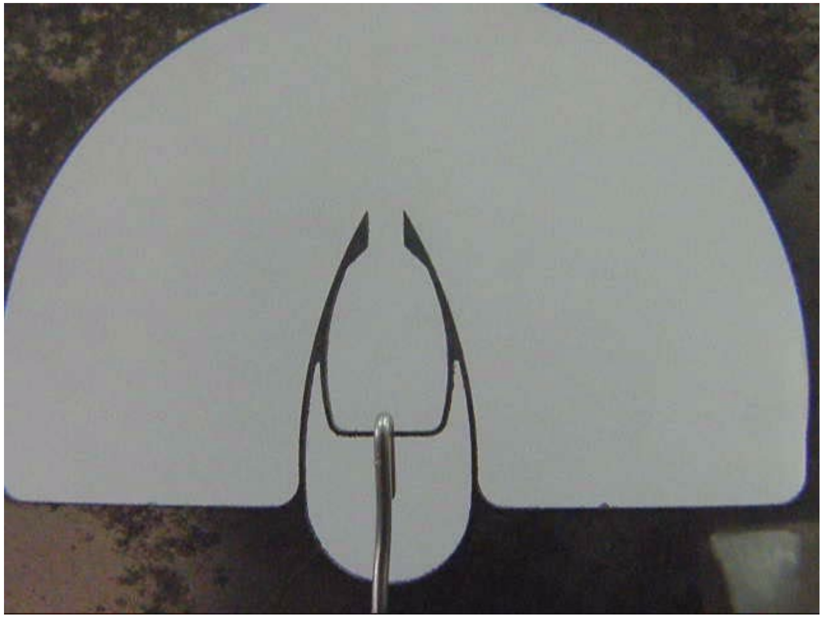
Spring-steel strips fastened to aluminium brackets.



Meso

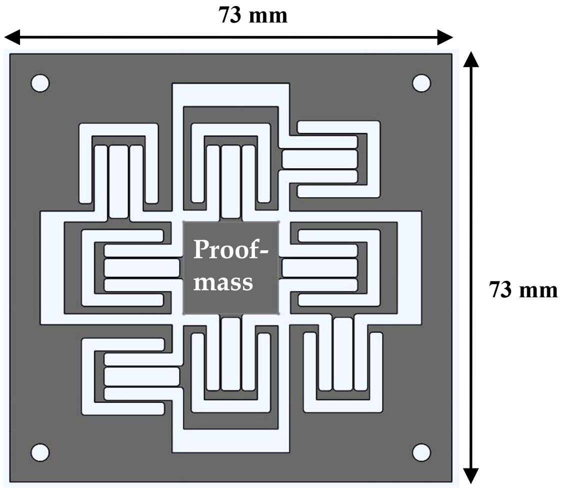
Compliant Mechanisms

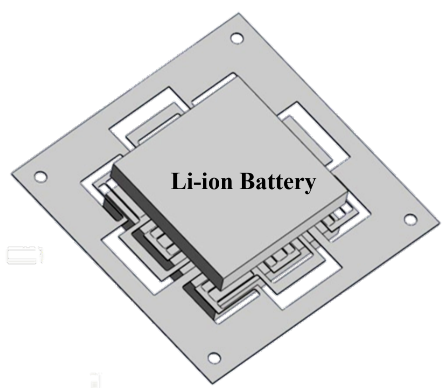
Spring-steel gripper



Miniature gripper made using spring steel

Design of a Meso-scale Dual-axis Meso-Accelerometer

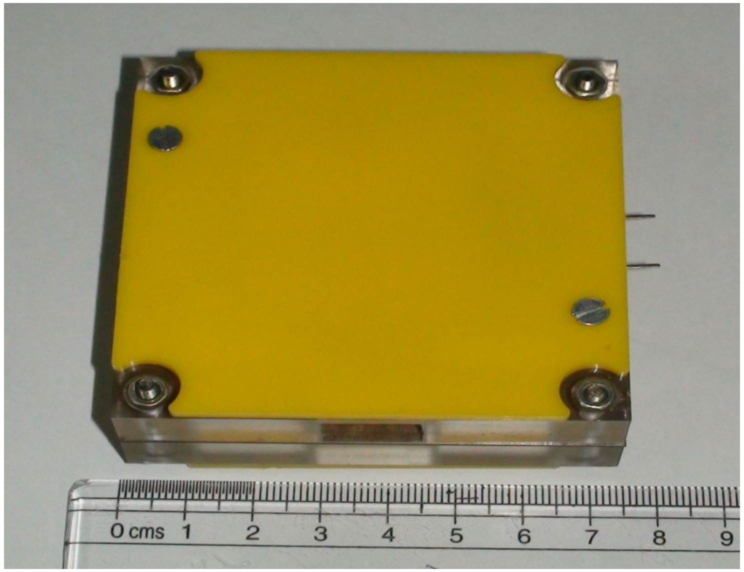


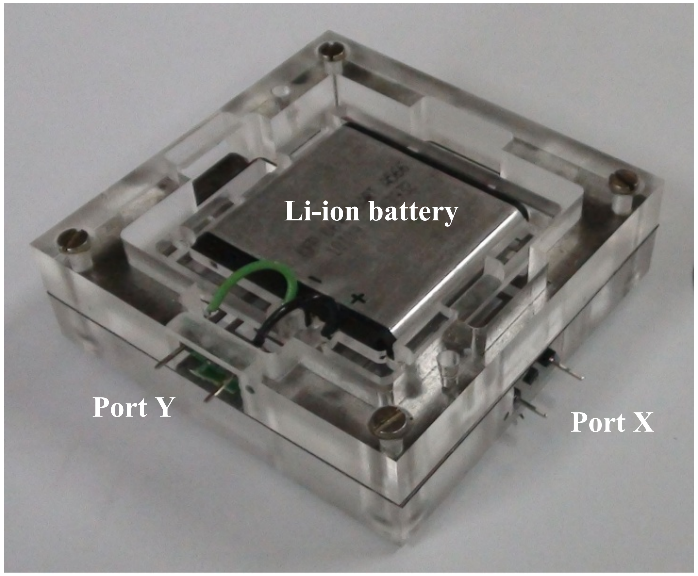


- We started with 0.5 mm thick spring steel foil.
- Wire-cut EDM on spring steel foil to curve the modified de-coupling mechanism.
- Overall dimension of 73 mm × 73 mm × 0.5 mm.
- Displacement at Port X measures the acceleration along X direction.
- Similarly Port Y for Y direction
- Enhanced sensitivity of the accelerometer by attaching:
  Spring steel metal pieces and
  Li-ion batteries as extra mass.
- Inbuilt power supply.
- Meso-scale accelerometer design with dual-axis sensing.

Packaging

❑ The device is placed inside the acrylic housing and the final manual assembly, shown in the figures below, is performed using screws.



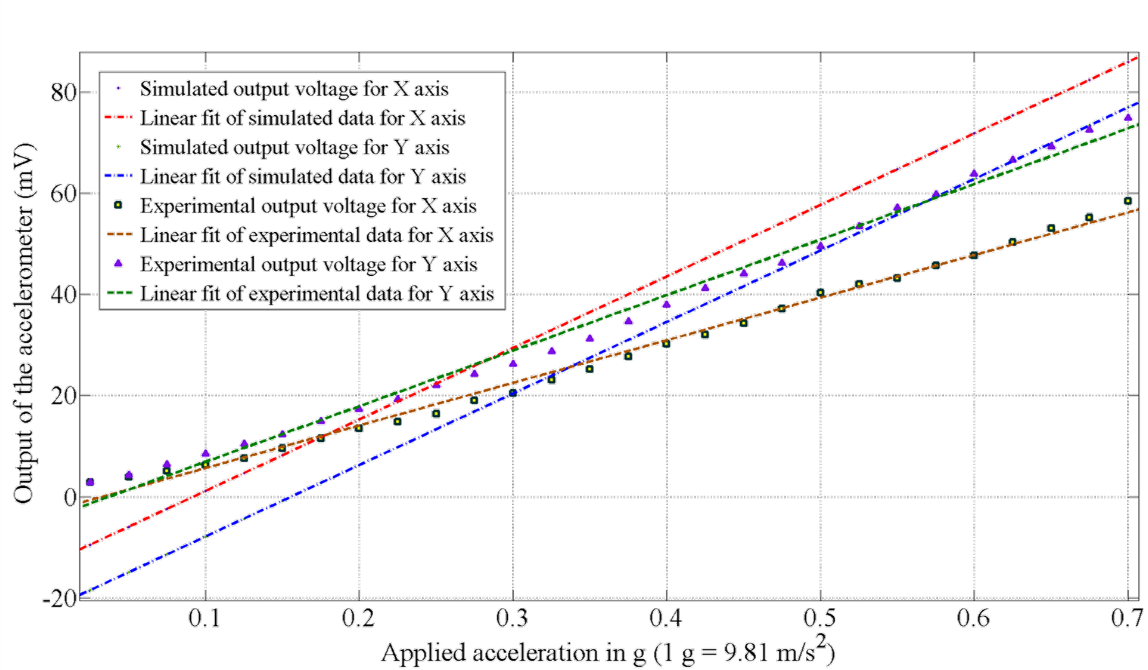


❑ The overall dimension of the packaged meso-scale spring steel dual-axis accelerometer is 73 mm × 73 mm × 28.5 mm.

Calibration and testing…

Experimental calibration

The DUT was again vibrated at different acceleration values varying from 25 milli-g to 0.7 g at a fixed frequency of 10 Hz.



- Simulated sensitivity:
  140 mV/g
- Experimentally obtained sensitivity:
  78 mV/g (X axis)
  102 mV/g (Y axis)
- Minimum detectable acceleration:
  25 milli-g for both the axes
- Measured cross-axis sensitivity:
  13.09 % and 12.08 %
  (X and Y axis respectively)

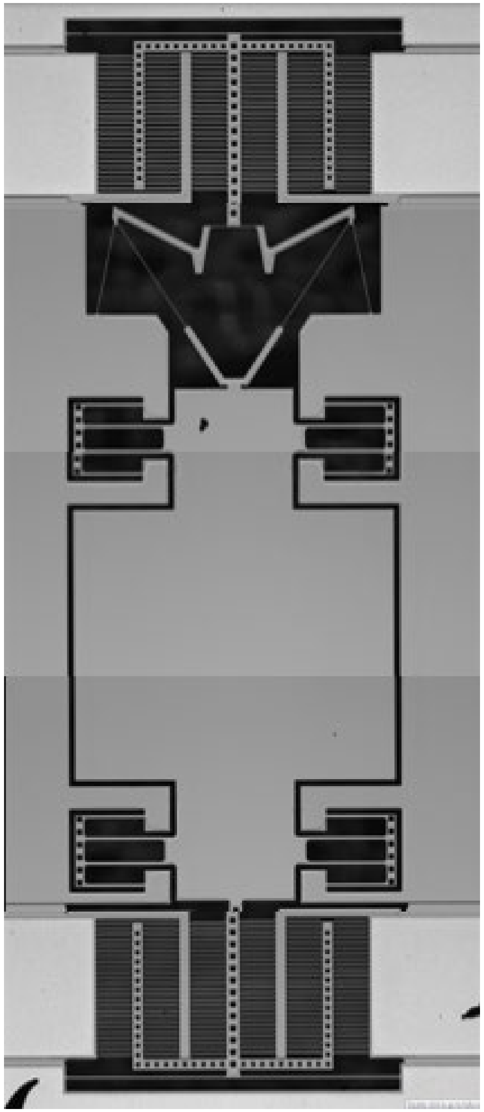
Reason for high cross-axis sensitivity:

I. Asymmetric manual assembly of the parts
II. Asymmetric battery shape

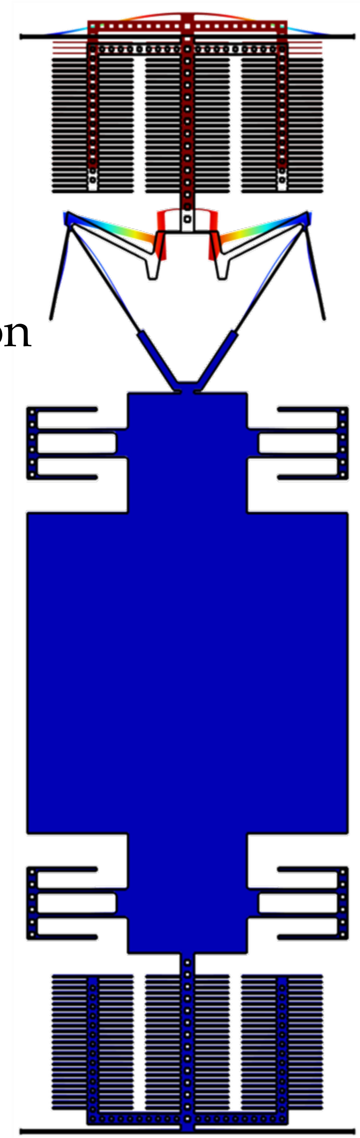
Micro

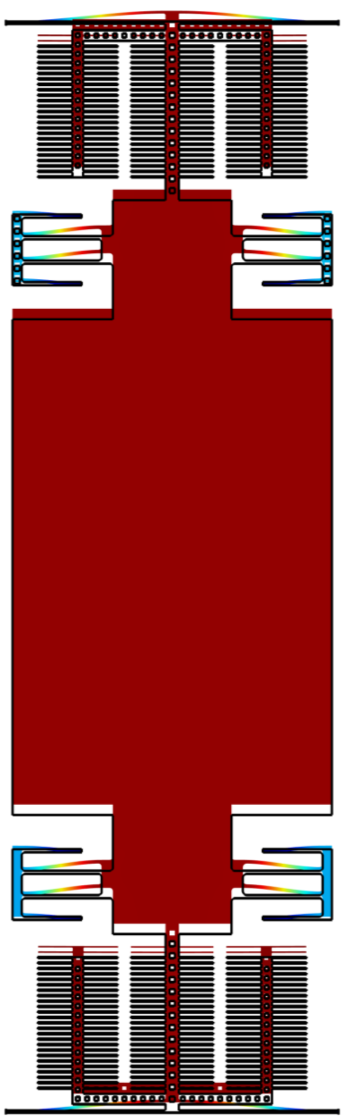
Compliant Mechanisms

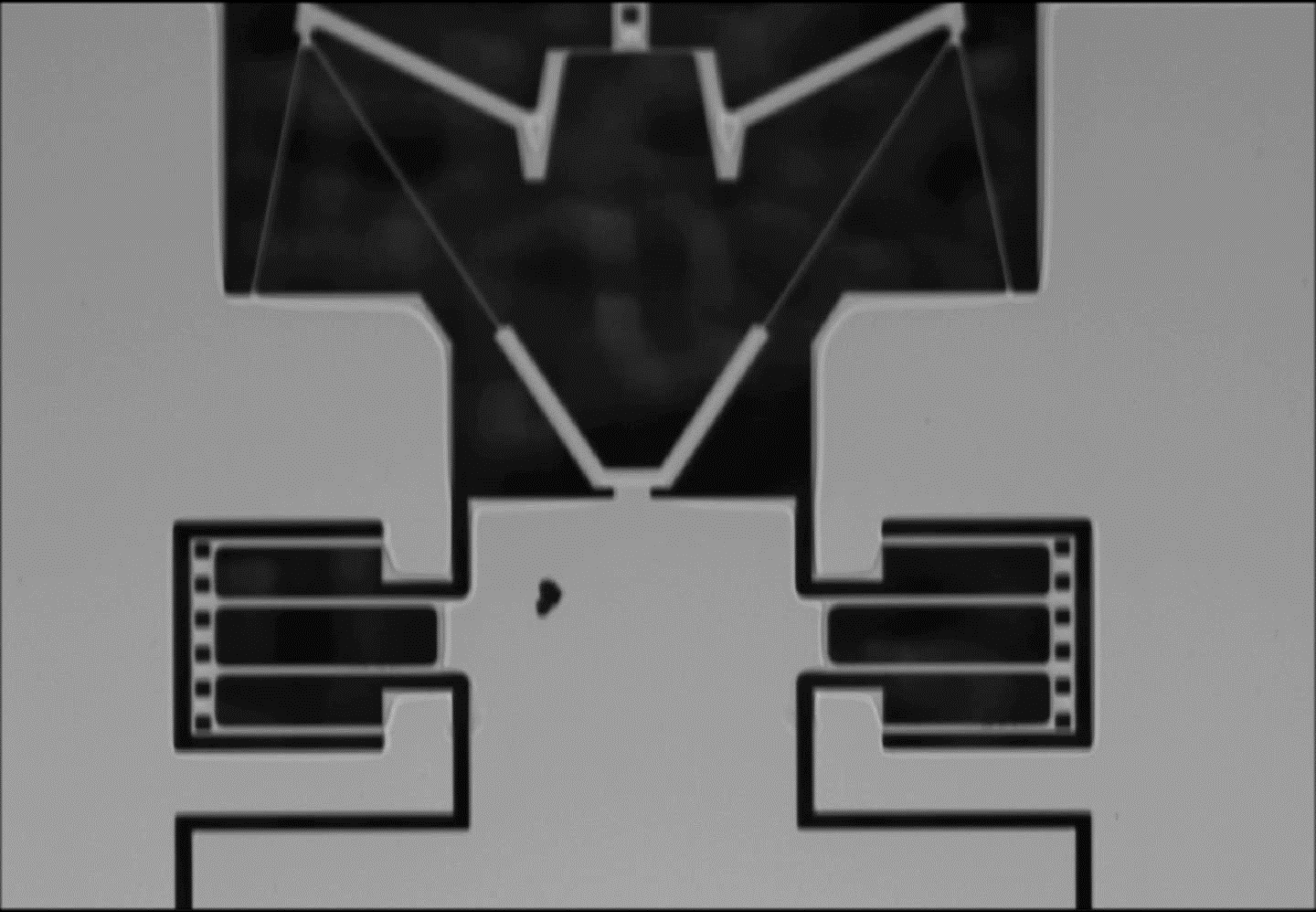
Micromachined accelerometer



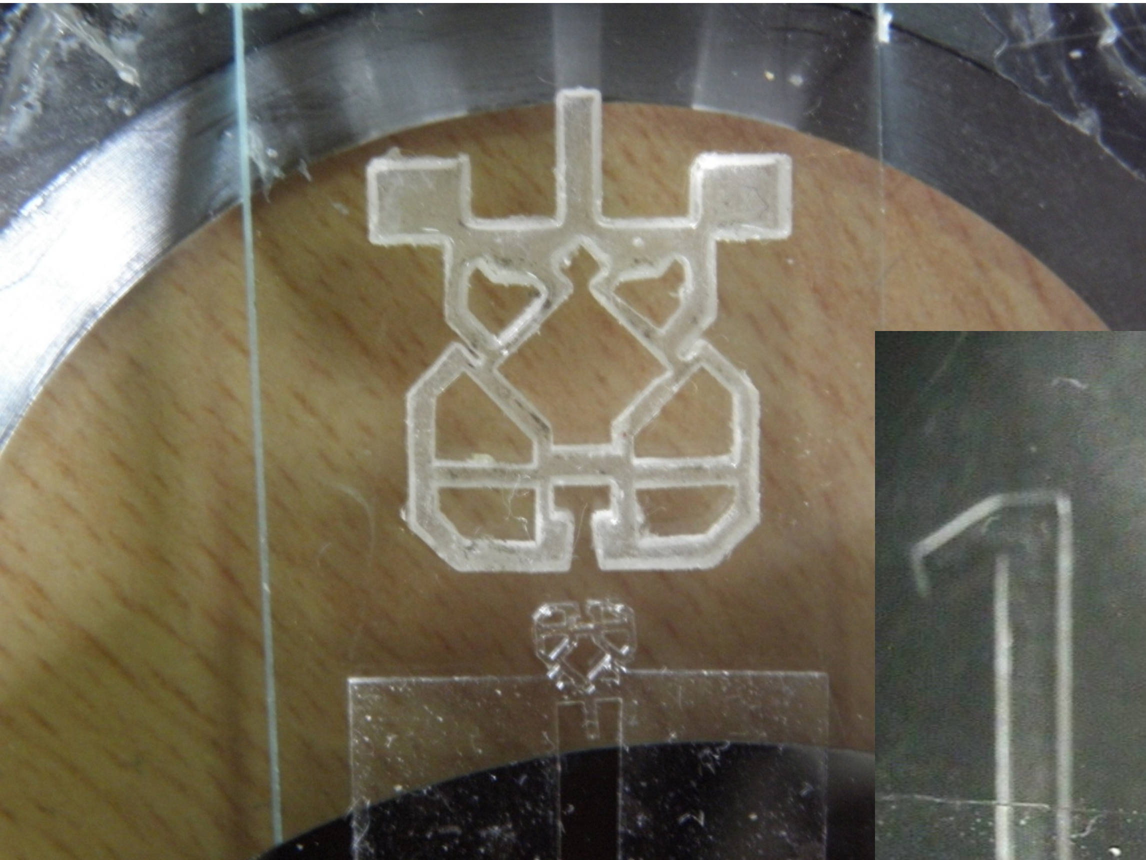
Mechanical amplification of 6.4

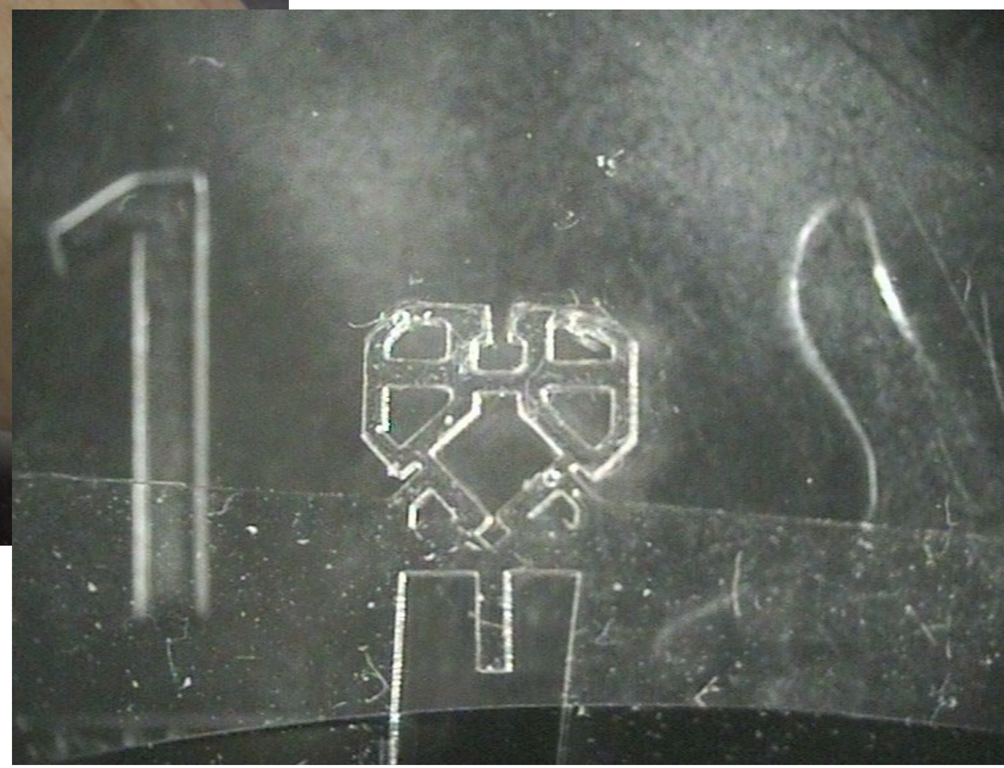






Miniature grippers





Nano

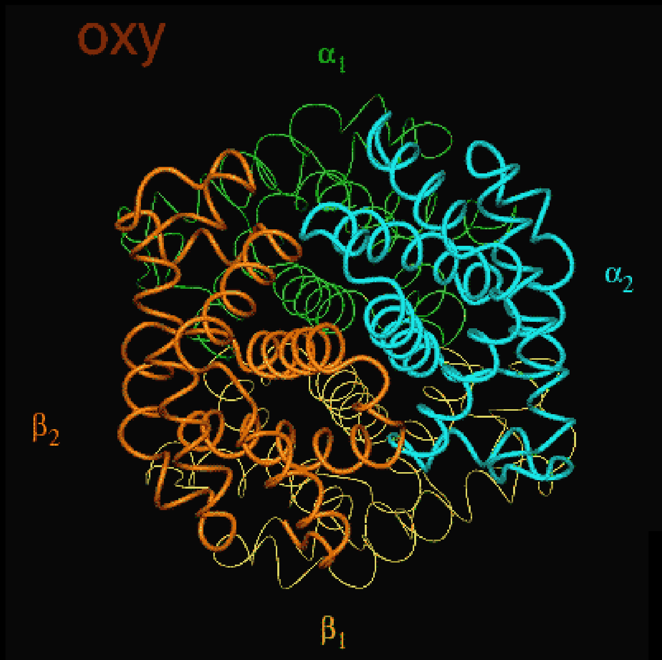
Compliant Mechanisms

http://www.andrew.cmu.edu/user/jl2p/Hb_html/dimers.html

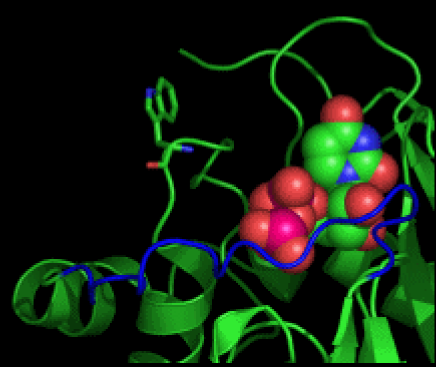
Proteins are deformable structures.

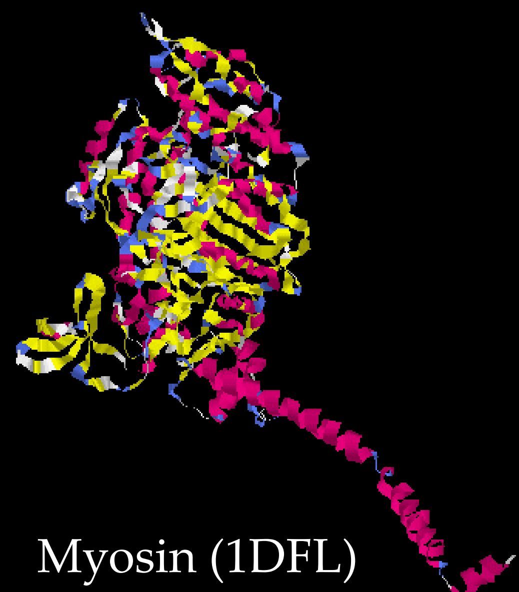
They are nano-compliant mechanisms found in biological matter.

Flexible motions—conformational changes—endow functionality to most proteins.



Hemoglobin





Myosin (1DFL)

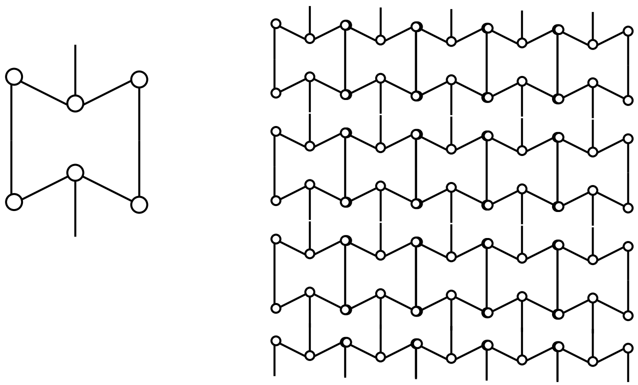
Lactoferrin (1LFG)

G. Chirikjian, Johns Hopkins University

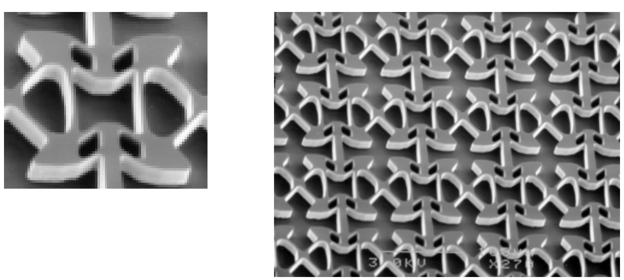
3D too…

Meta-materials

- Material microstructure design



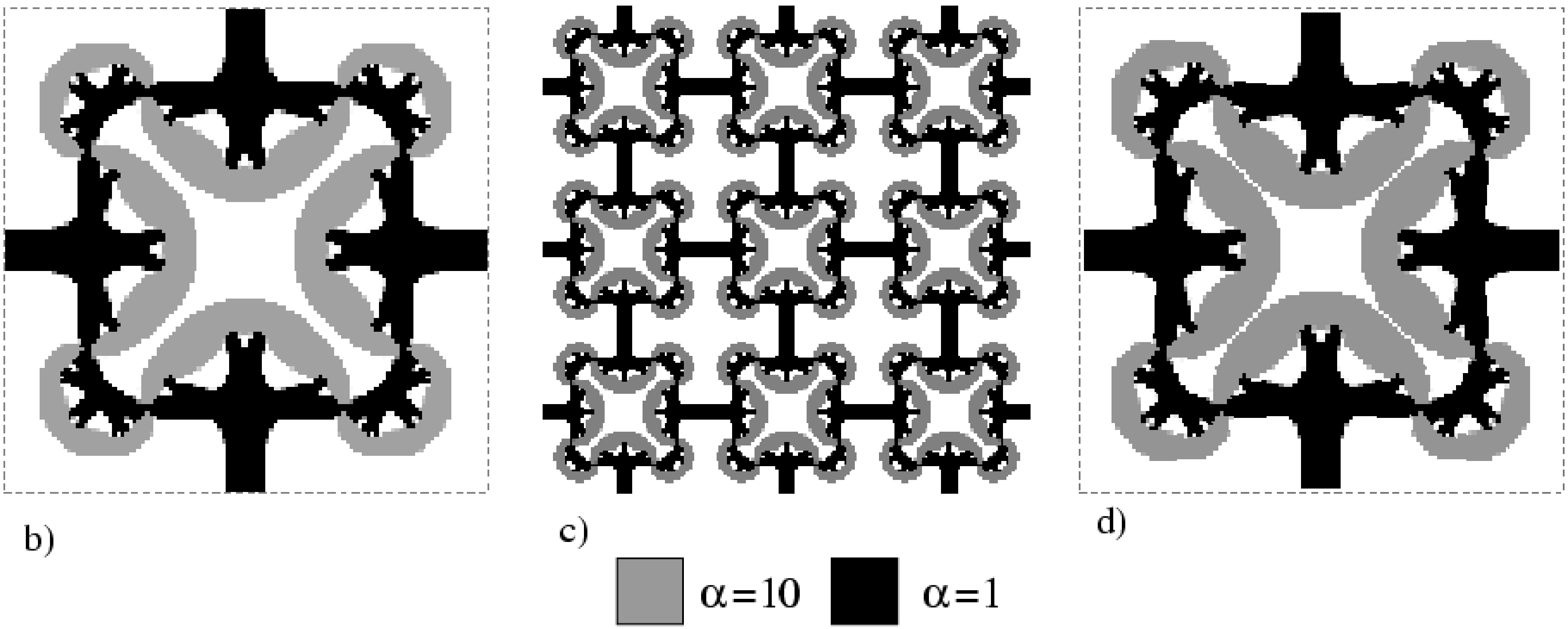
(Almgren, 1982)



(Made by Hsu using MIT’s wafer bonding, 1996)

Negative thermal expansion coefficient

(Sigmund, Denmark Technical University)



Are there any disadvantages to compliant mechanisms?

Efficiency and mechanical advantage compromised!

$$\Delta W = \left(F_{in} + \frac{\Delta F_{in}}{2} \right) \Delta_{in} - \left(F_{out} + \frac{\Delta F_{out}}{2} \right) \Delta_{out}$$

$$\approx F_{in} \Delta_{in} - F_{out} \Delta_{out}$$

$$= \Delta SE$$

$$\Rightarrow F_{out} \Delta_{out} = F_{in} \Delta_{in} - \Delta SE$$

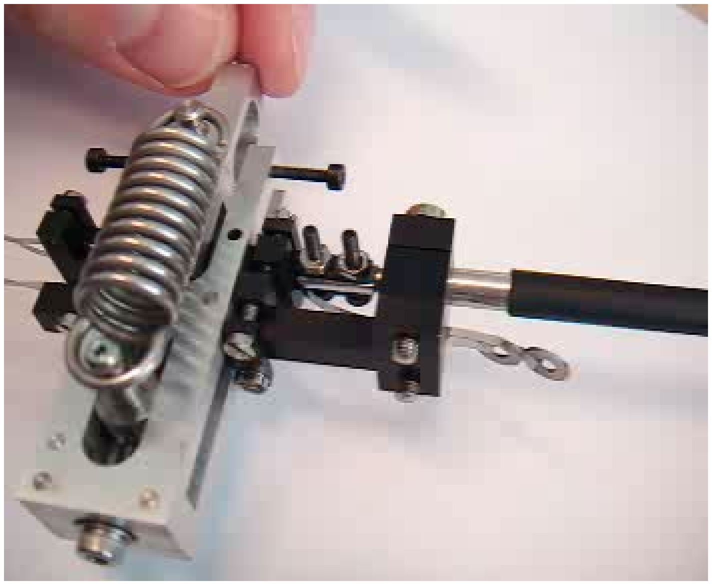
$$\Rightarrow \frac{F_{out}}{F_{in}} = \frac{\Delta_{in}}{\Delta_{out}} - \frac{\Delta SE}{F_{in} \Delta_{out}}$$

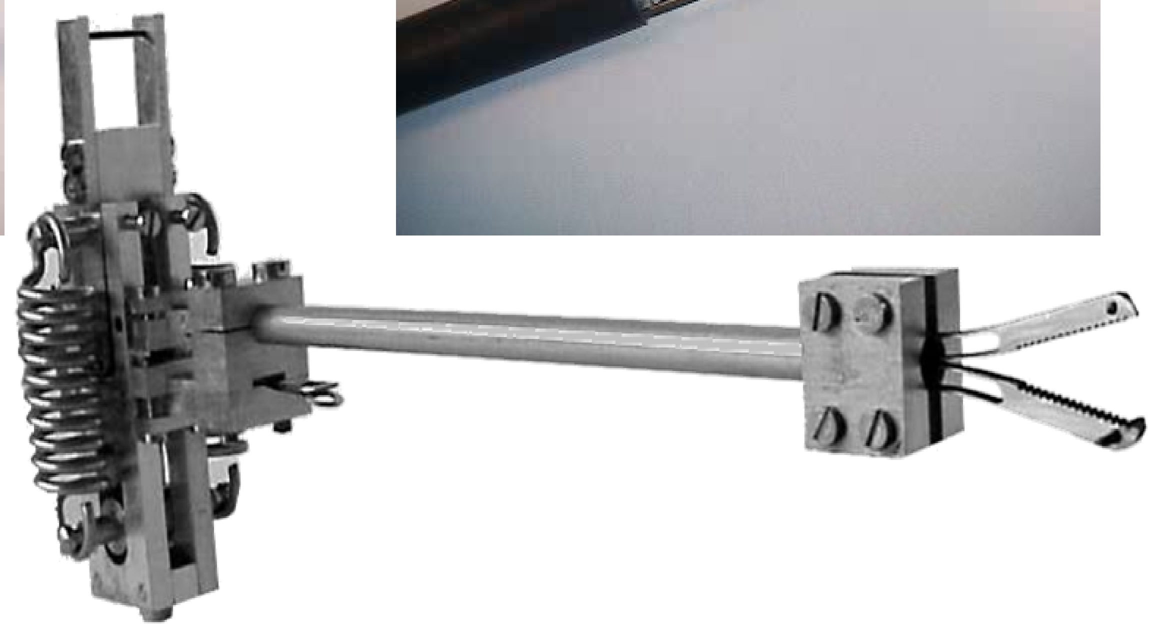
$$\Rightarrow MA = MA_r + MA_c$$

More about in a later lecture.

(Salamon and Midha, 1998)

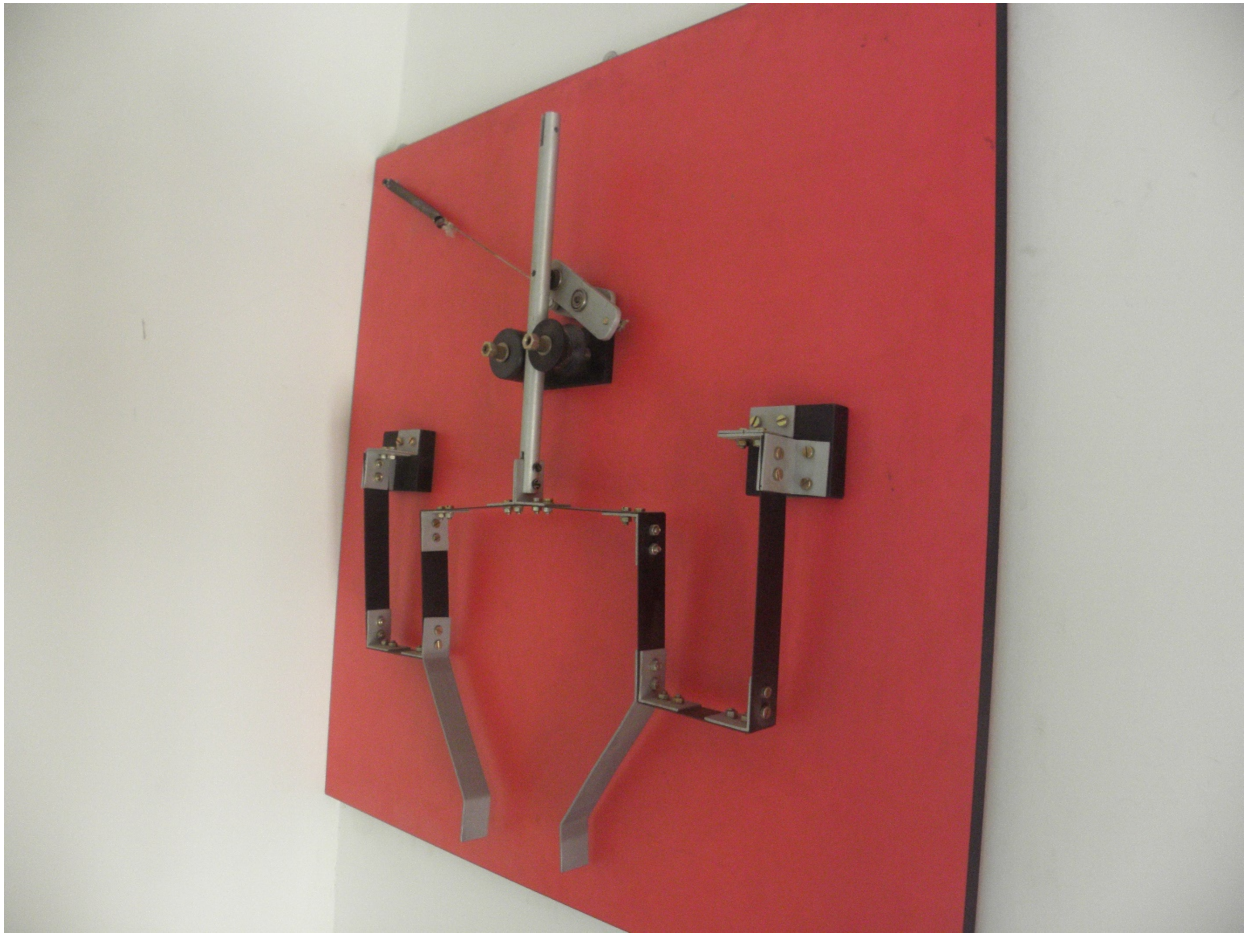
Static balancing: why?





Professor Just Herder, Delft University, The Netherlands

Static balancing of a compliant mechanism



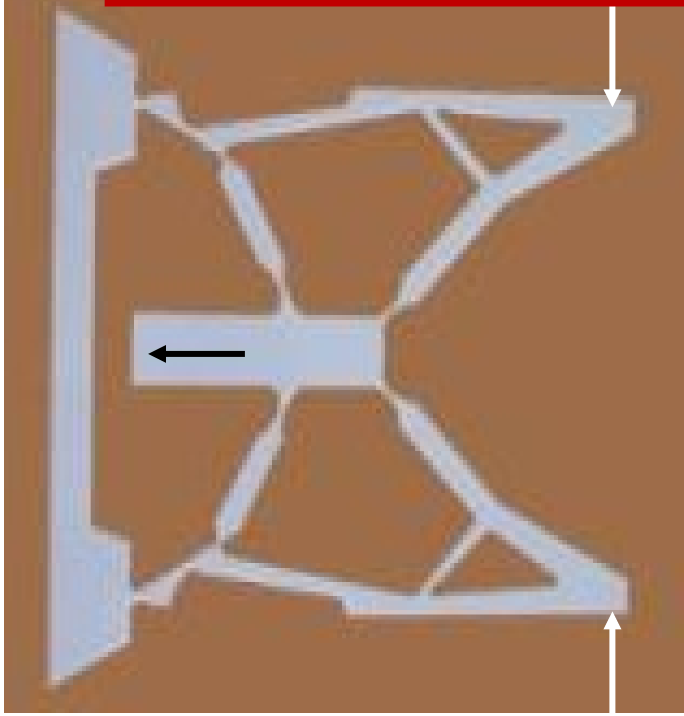
With Amrit Hansogi and Sanagemsh Deepak

High speed motion

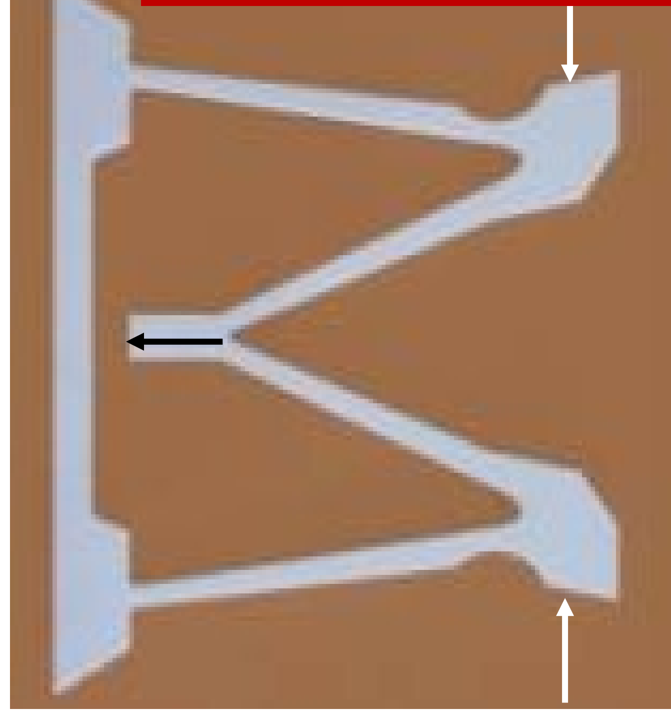
- Too many cycles
- Too low a frequency
- Nonlinear inertial effects
- Parametric resonance
- Viscoelastic effects

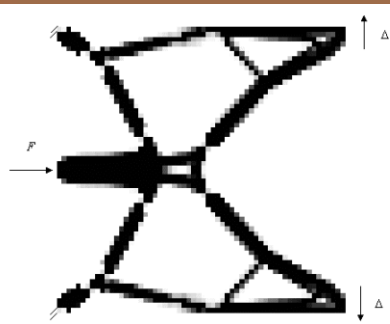
Optimum design for distributed compliance is still elusive… somewhat

Discrete compliance

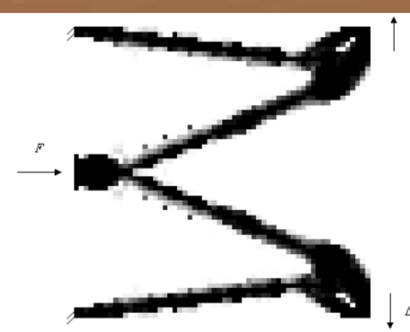


Distributed compliance





Synthesized topologies



With Luzhong Yin

Prefer hinges to sliders,
flexures to either.

M. J. French

Prefer hinges to sliders,
flexures to either,
distributed compliance to all.

Compliant utopia

- Distributed compliance
  - Geometry — Uniform geometry.
  - Kinematics — Equal deformation.
  - Stress — Evenly stressed.
- Helical spring is a good candidate.

Multi-disciplinary and Multi-scale Device and Design Lab

Multi-disciplinary and Multi-scale Device and Design Lab

Thank you!

Sponsors

DST, BRNS, NPOL, ADA, NPSM, DRDO, ISRO, SBMT, NPMASS, and industries.

PhD students

A Narayana Reddy
Sourav Rakshit
Sudarshan Hegde
Sangamesh Deepak R
Sambuddha Khan
Santosh Bhargav
Sudhanshu Sekhar
Kiran Akella
Biplab Sarkar
T. J. Ramnath Babu
Nandhini Nehru
Shantanu Chakravarthy
Sreenath Balakrishnan
Rinu A.
Avinash Kumar
Safvan P
Rahul Singh
Prasenjit Sen
Akshay Desai
A. T. Nireekshit

Masters students

Girish Krishnan
V. S. S. Srinivas
M. Dinesh
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Look, Sci-Walker with compliant legs!

Pulkit Kapur, summer intern in IISc.