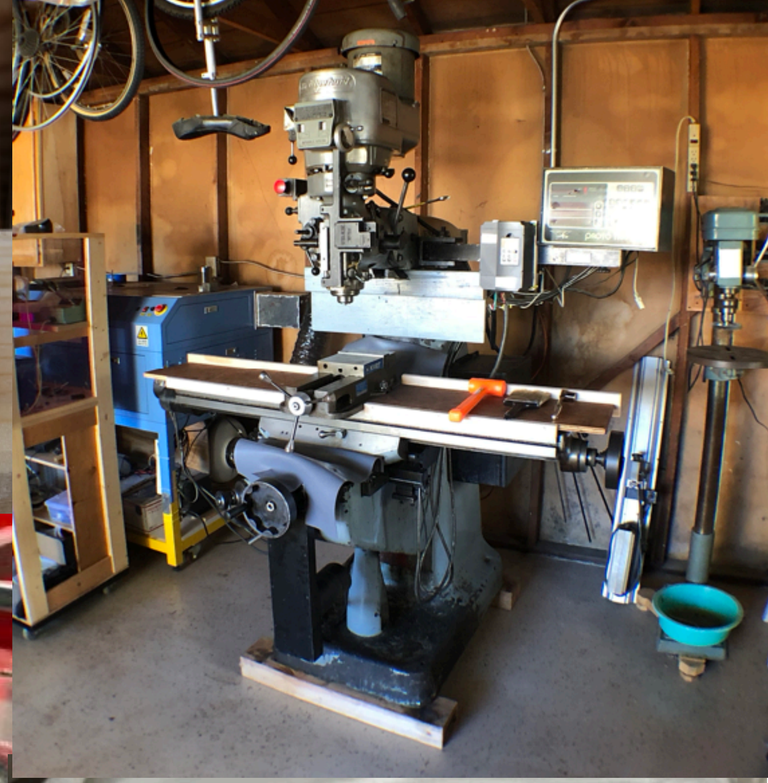
Flexure Lecture

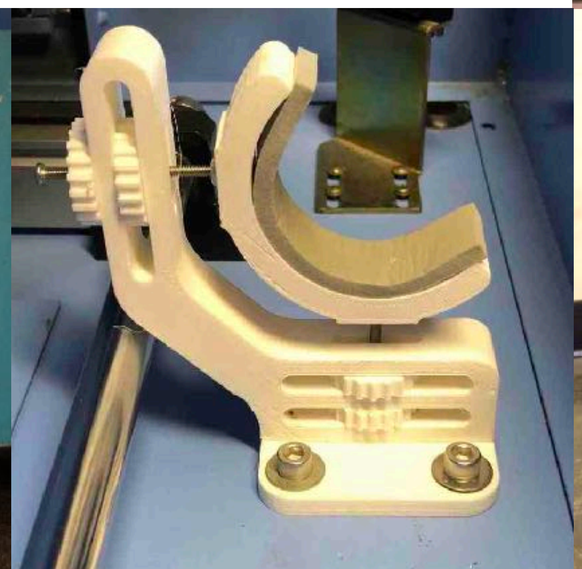
Hackaday Superconference 2019

Intro

- Studied mechanical engineering at MIT
- Apple, Kitty Hawk, startup
- Personal projects (woodworking, bikes, machining, welding, laser cutting, sewing, etc)






Why flexures are awesome:

Flexures all around us

Design tradeoffs

Ease of manufacturing

Examples in projects

Hands-on: Flexure gripper

Why flexures are awesome:

What is a flexure?

Flexures all around us

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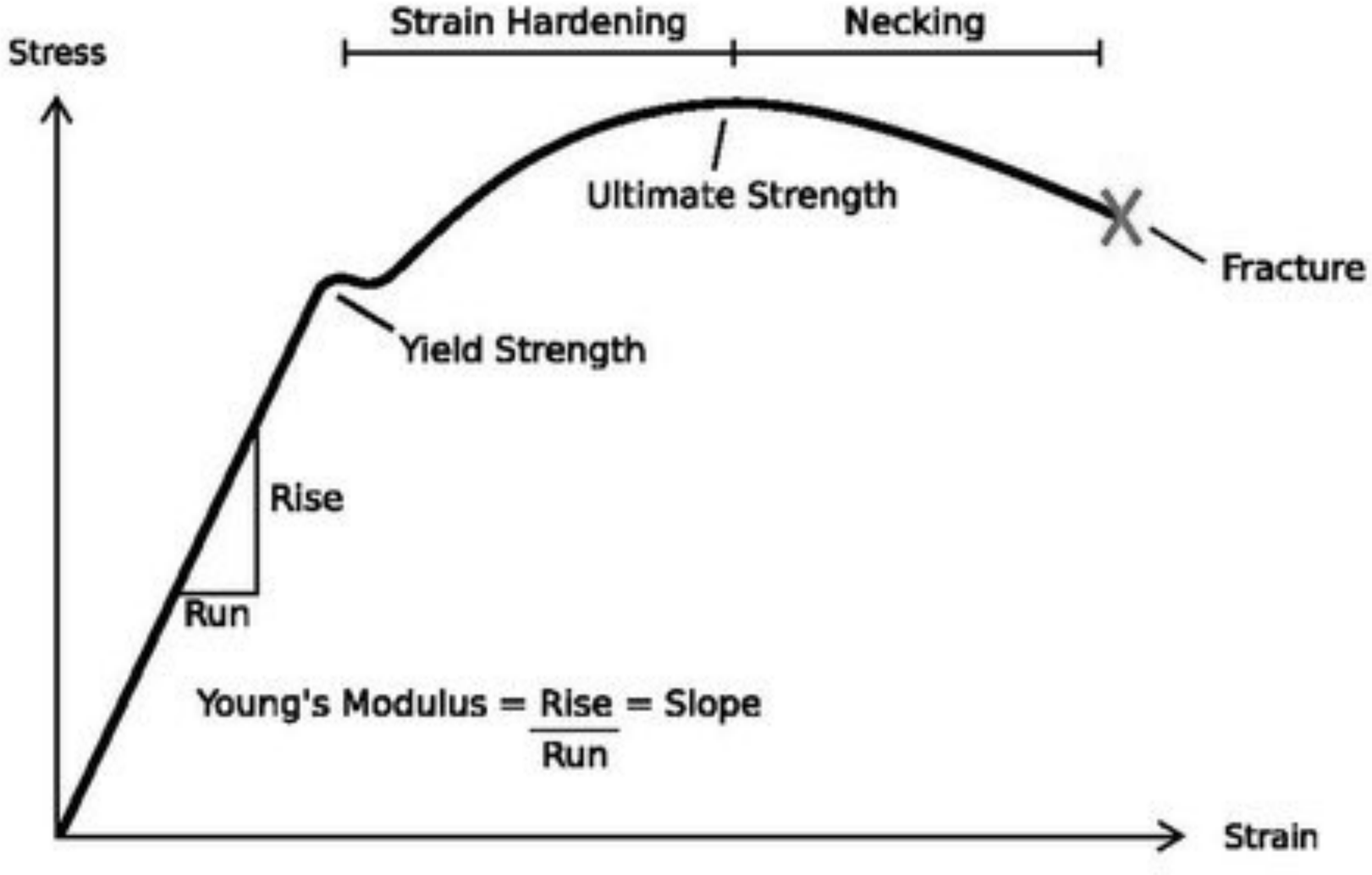
Flexure:
a flexible element (or combination of elements) engineered to be compliant in specific degrees of freedom

https://en.wikipedia.org/wiki/Flexure

What is a spring?

An elastic object that stores energy

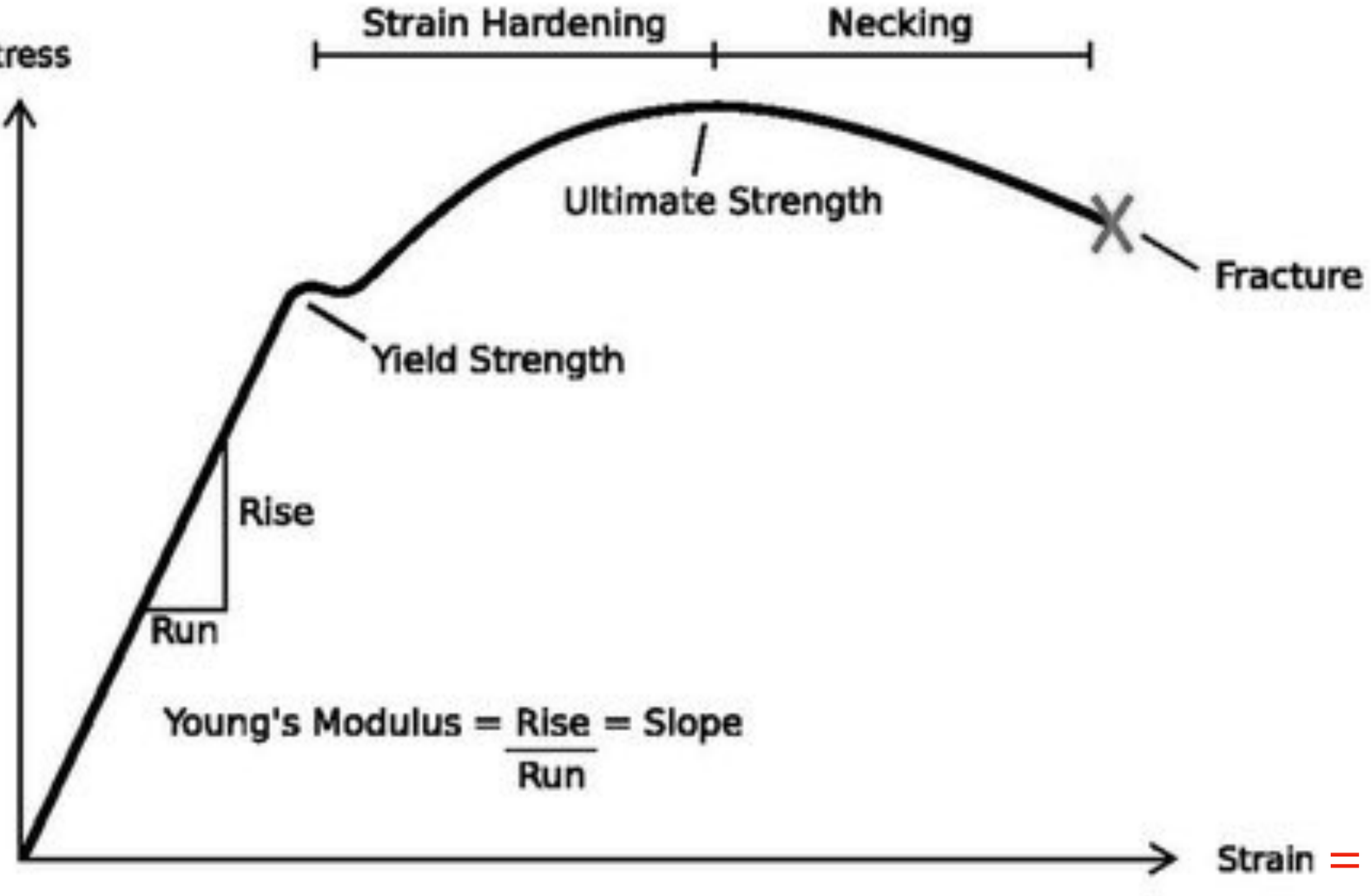


Breakeydown (https://en.wikipedia.org/wiki/File:Stress_Strain_Ductile_Material.pdf), “Stress Strain Ductile Material“, https://creativecommons.org/licenses/by-sa/3.0/legalcode

What is a spring?

an elastic object that stores energy *Wikipedia*

Force / Area = Stress
[Pa, lbf/in²]



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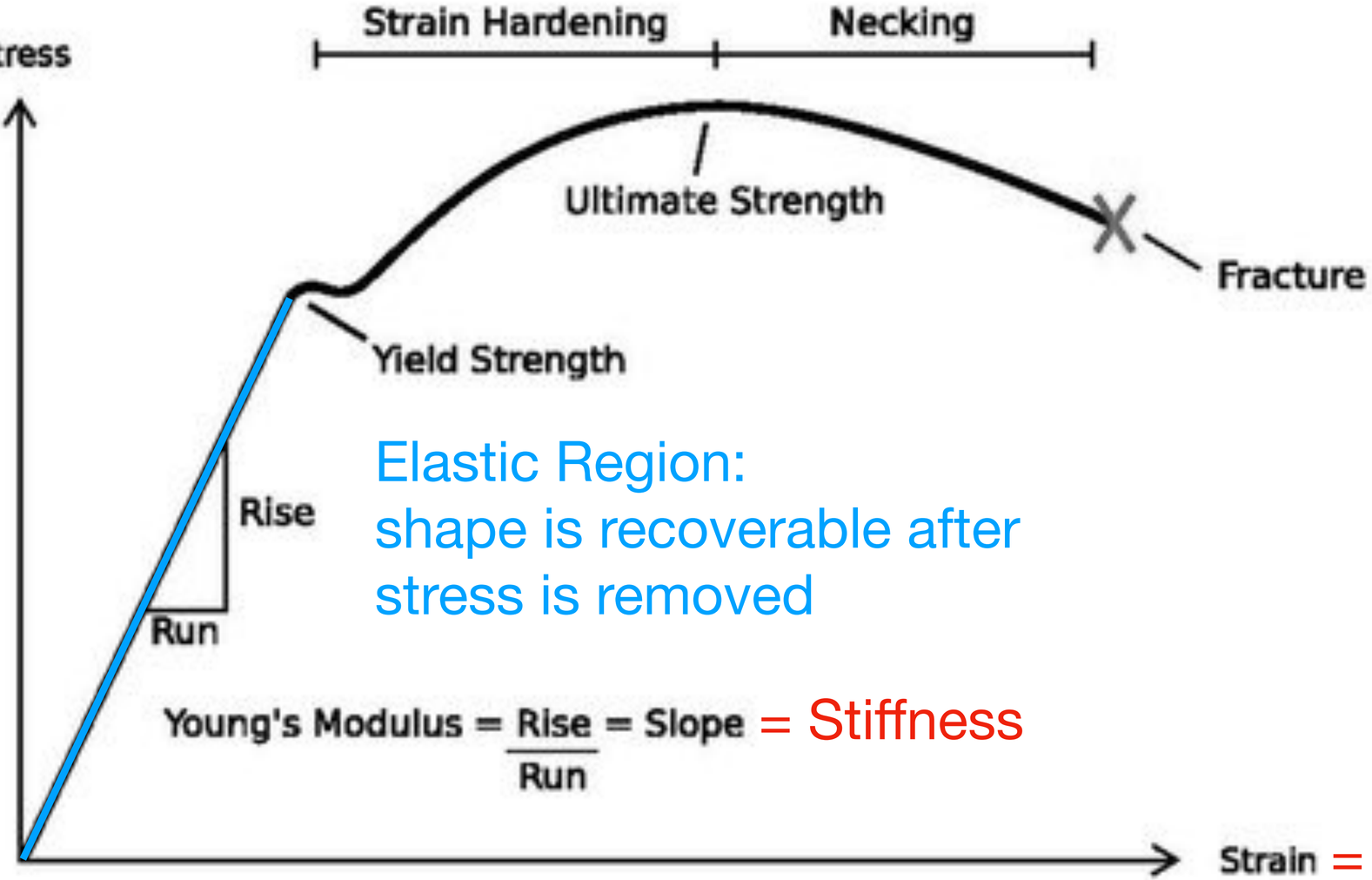
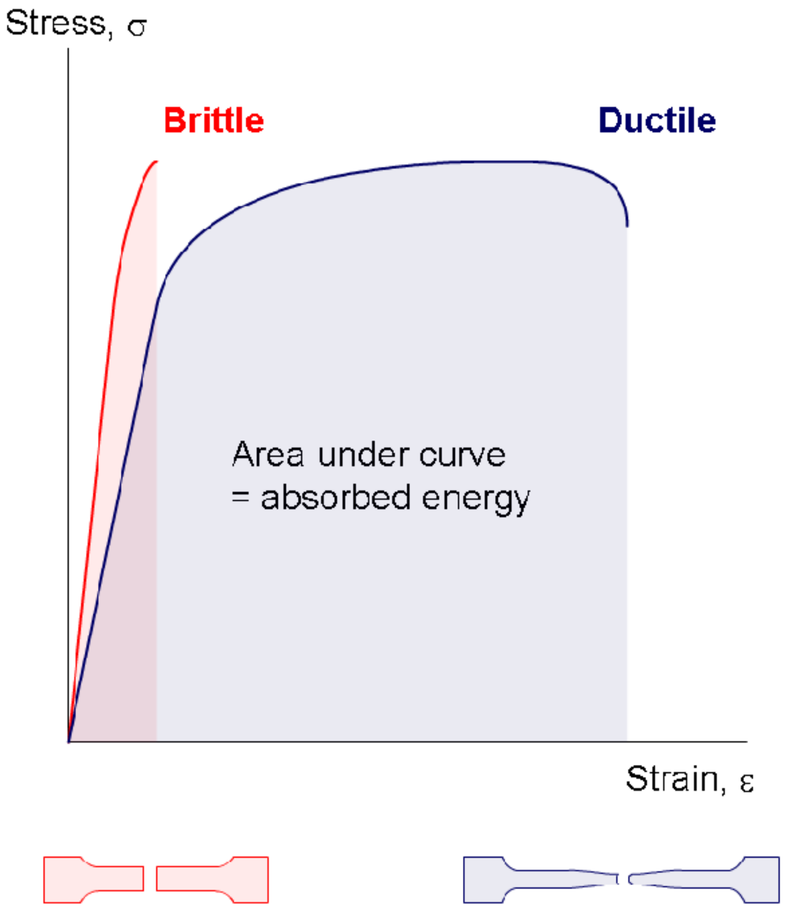


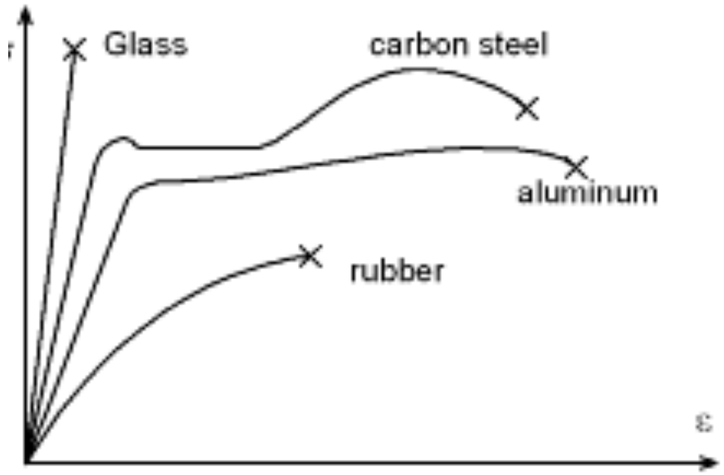
Elastic Region:
shape is recoverable after stress is removed

Breakeydown (https://en.wikipedia.org/wiki/File:Stress_Strain_Ductile_Material.pdf), "Stress Strain Ductile Material", https://creativecommons.org/licenses/by-sa/3.0/legalcode

Let’s build some intuition on materials

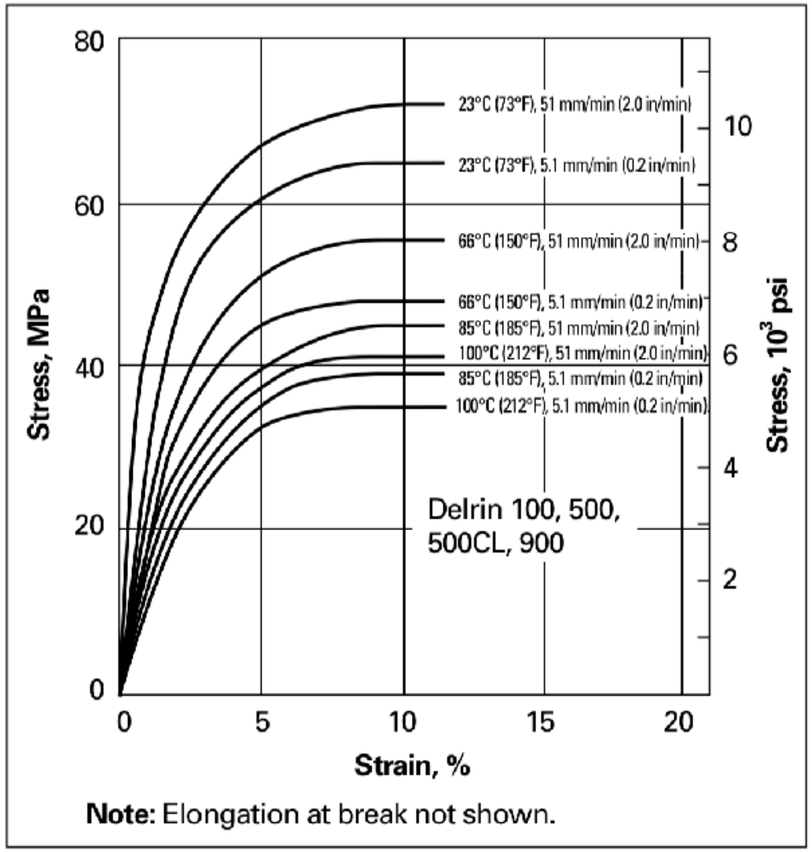


Amgreen (https://commons.wikimedia.org/wiki/File:Brittle_v_ductile_stress-strain_behaviour.png), “Brittle v ductile stress-strain behaviour“, https://creativecommons.org/licenses/by-sa/3.0/legalcode



https://www.ecourses.ou.edu/cgi-bin/eBook.cgi?doc=&topic=me&chap_sec=01.3&page=theory

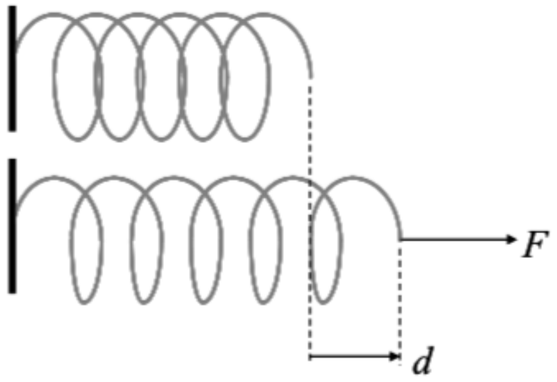
Figure 1. Stress Strain Curves for Delrin Acetal Resins at Various Temperatures and Rates of Loading (ASTM D638)



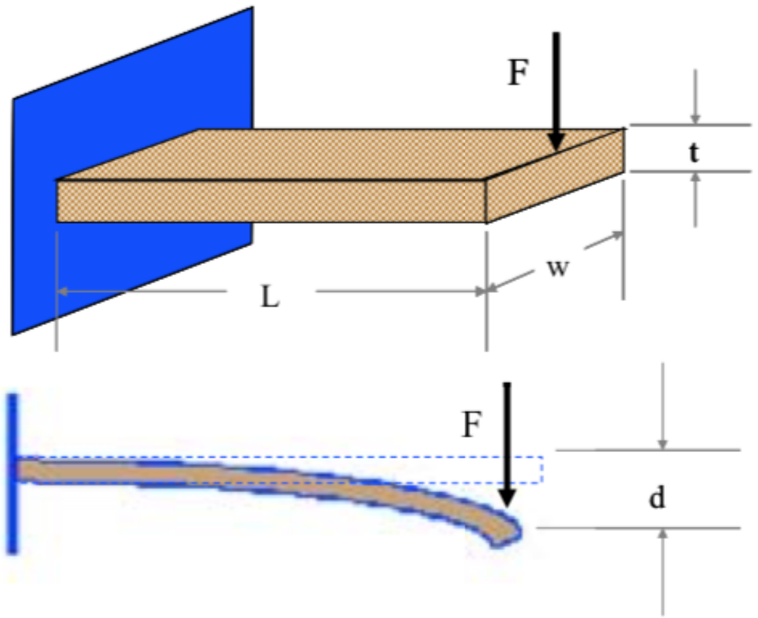
https://www.dupont.com/content/dam/dupont/products-and-services/plastics-polymers-and-resins/thermoplastics/documents/Delrin/Delrin%20Design%20Guide%20Mod%203.pdf

Beam Bending

For a spring: $F = k * d$

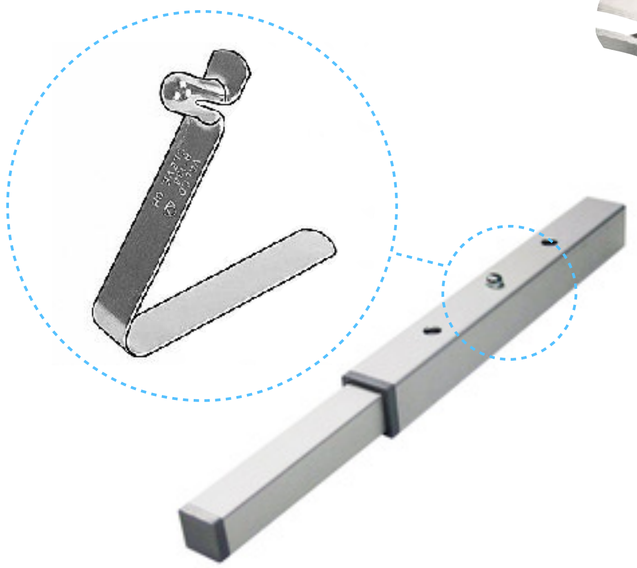


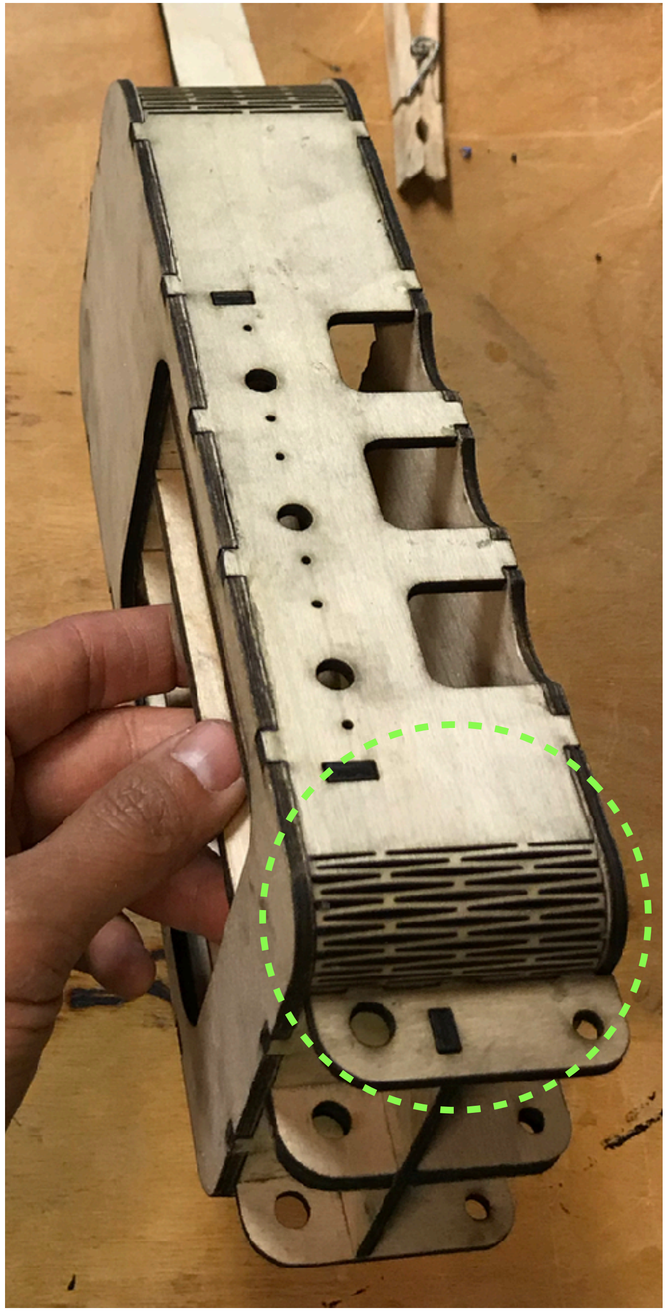
For a cantilevered beam: $F = \frac{E * w * t^3}{4 * L^3} * d$



https://materion.com/-/media/files/alloy/newsletters/technical-tidbits/issue-no-20--cantilever-beams---part-1-beam-stiffness.pdf

Examples All Around Us





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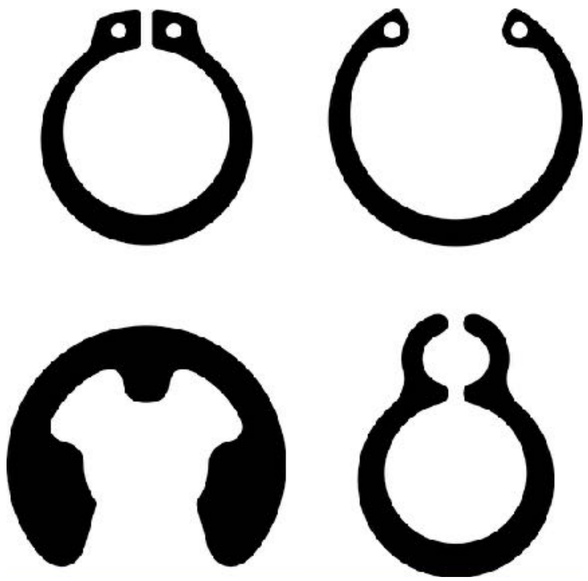
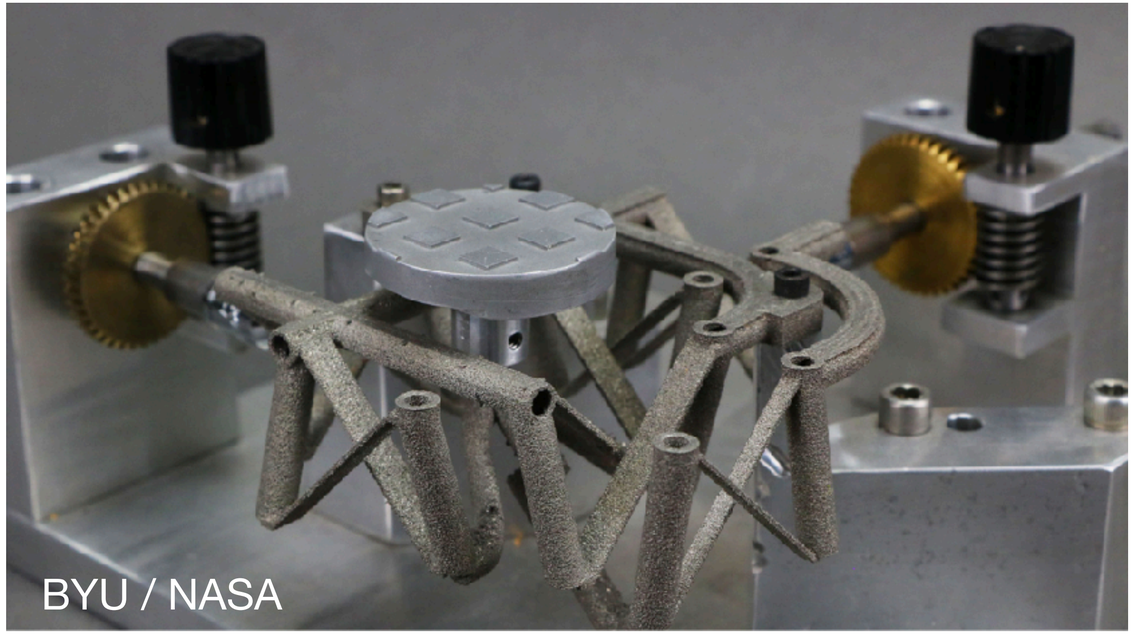
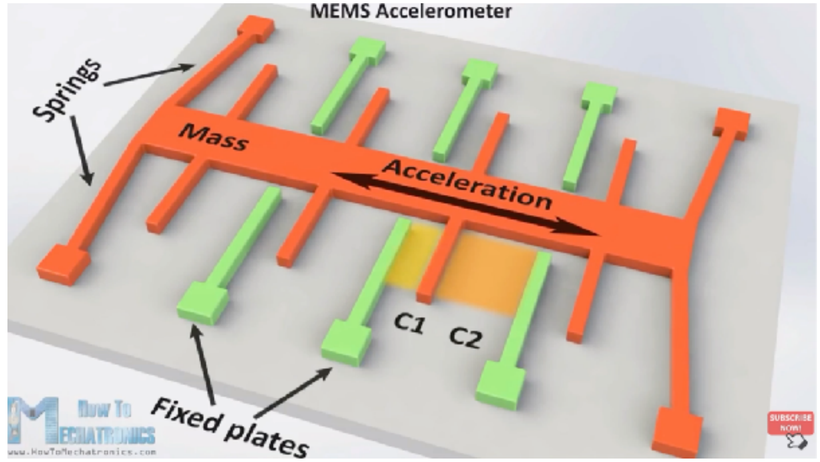
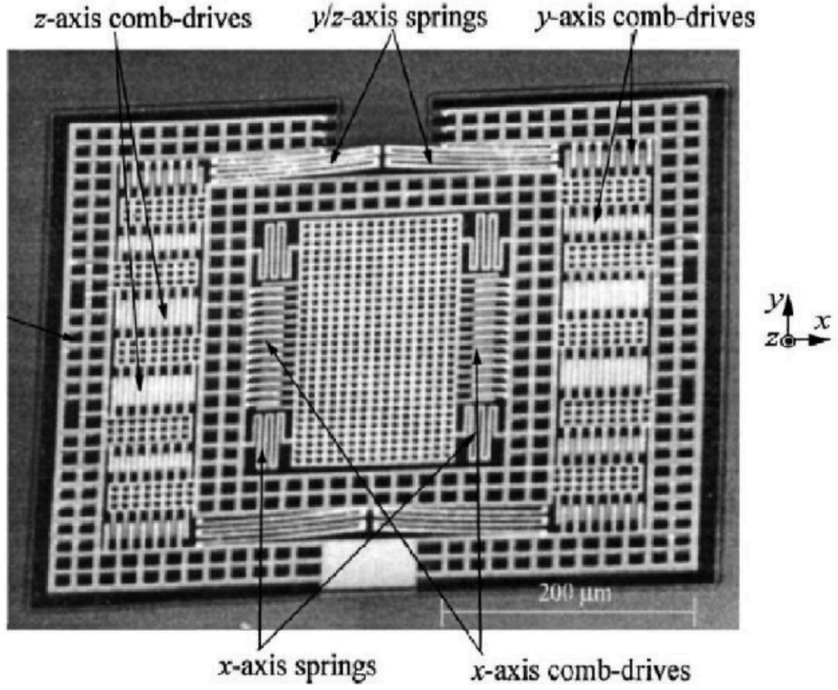




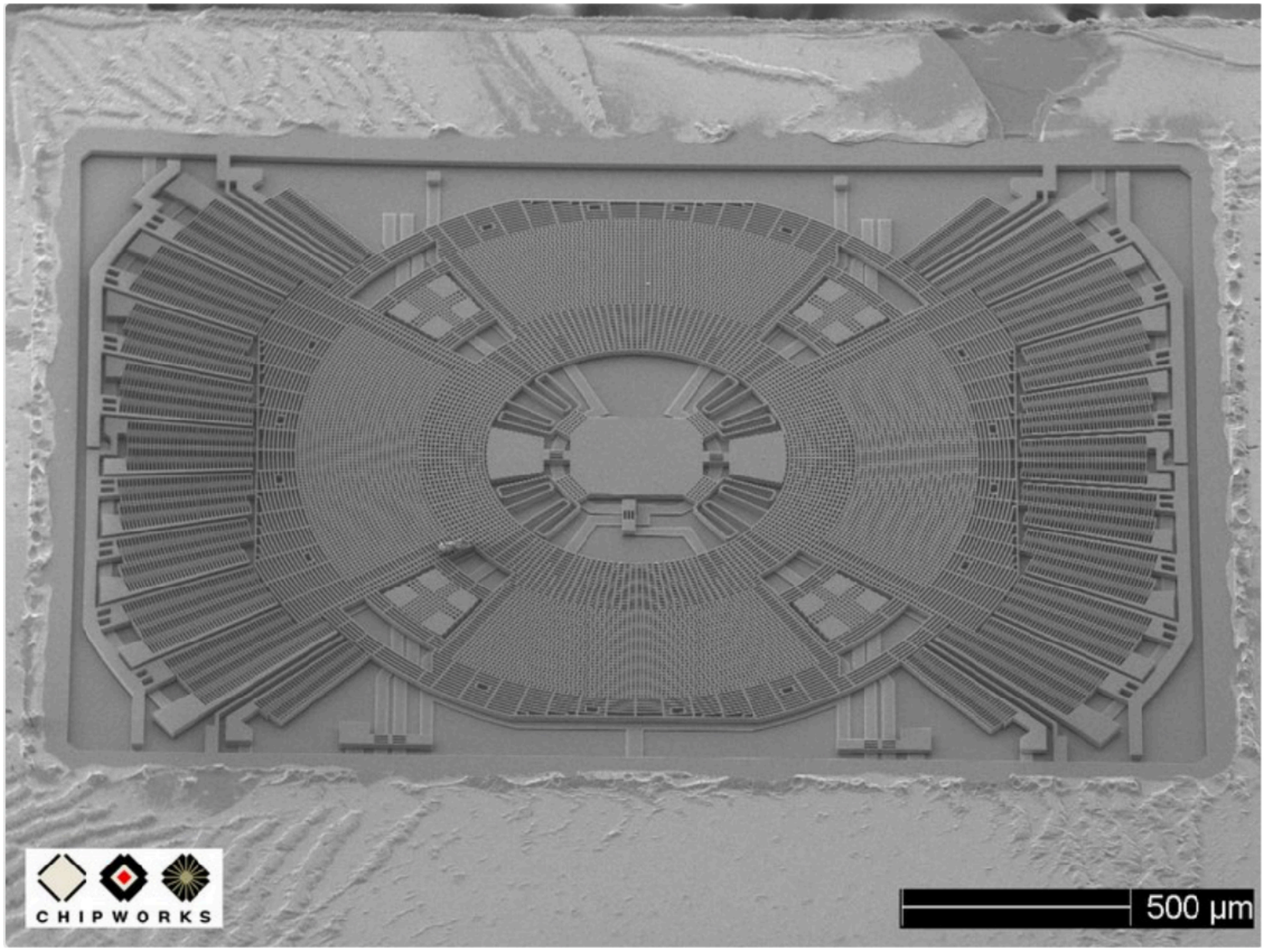
Examples All Around Us

MEMS Microelectromechanical Systems





"MEMs Accelerometers" M. Andrejasic, 2008



ST LYPR540AH 3-axis gyroscope

Design tradeoffs

Great resource:
BYU Compliant Mechanisms Research Group
https://www.compliantmechanisms.byu.edu/about-compliant-mechanisms

- Simple
  - Low part count
  - Reliable
- Compact
- Precise motion (no backlash)
- Energy storage in springs
- Potentially complex analysis
- Fatigue
- Limited range of motion

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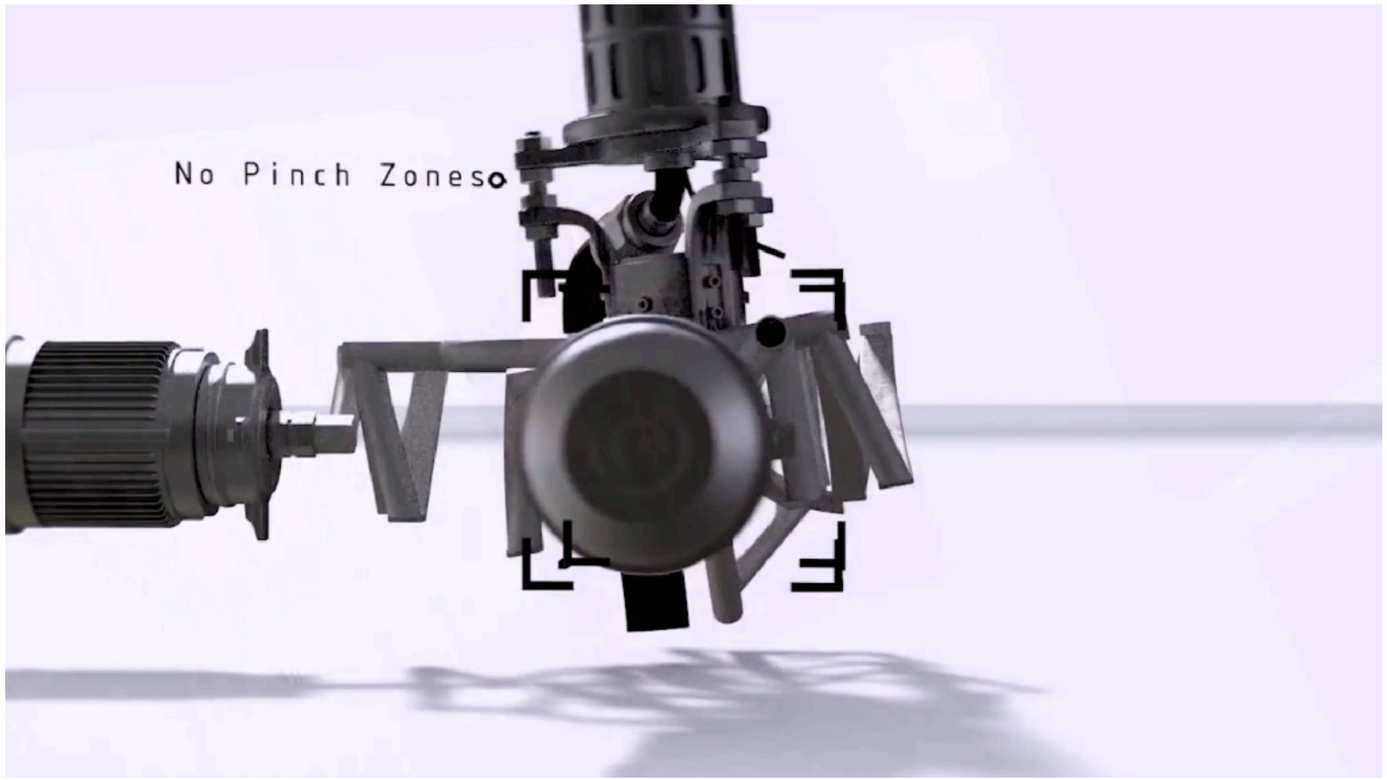

No backlash or friction

Video clip: “NSF helps launch origami into space - Science Nation” by National Science Foundation
Research by NASA and BYU CMR

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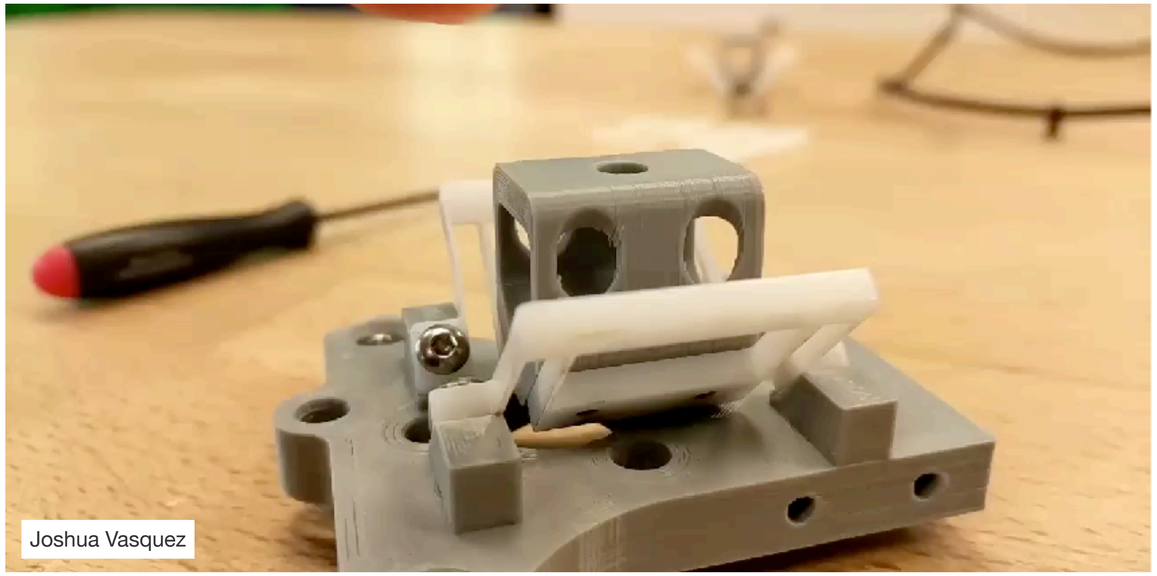

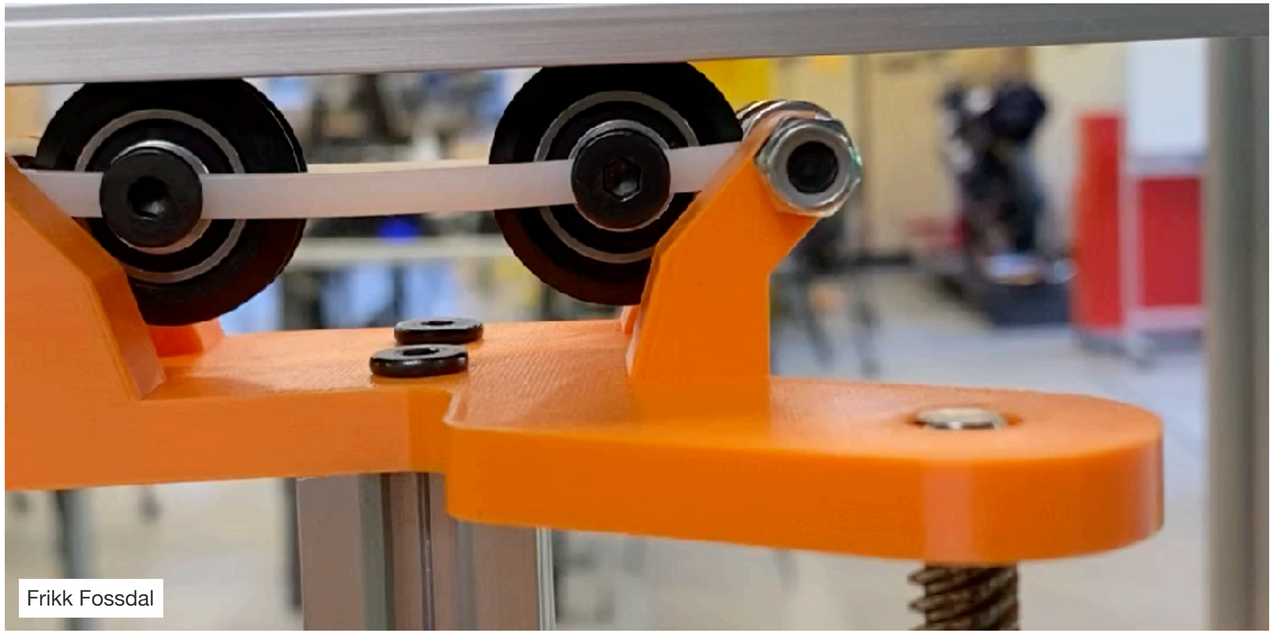

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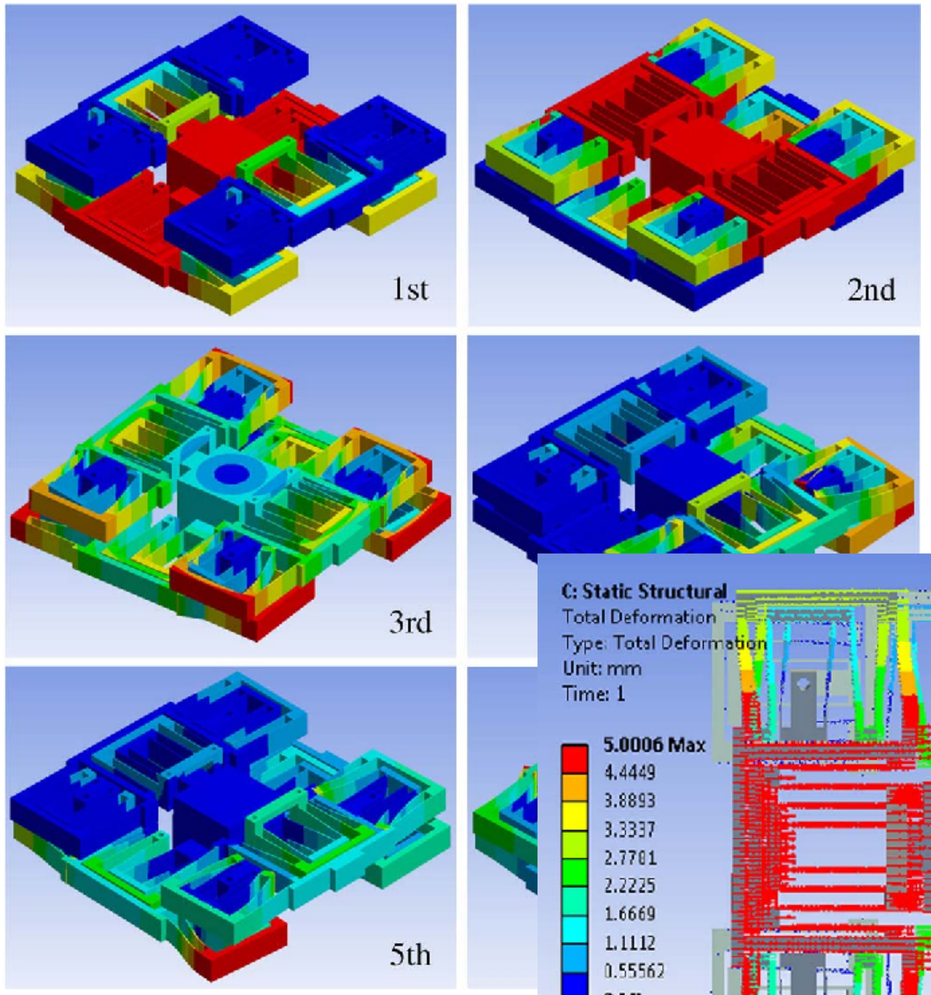
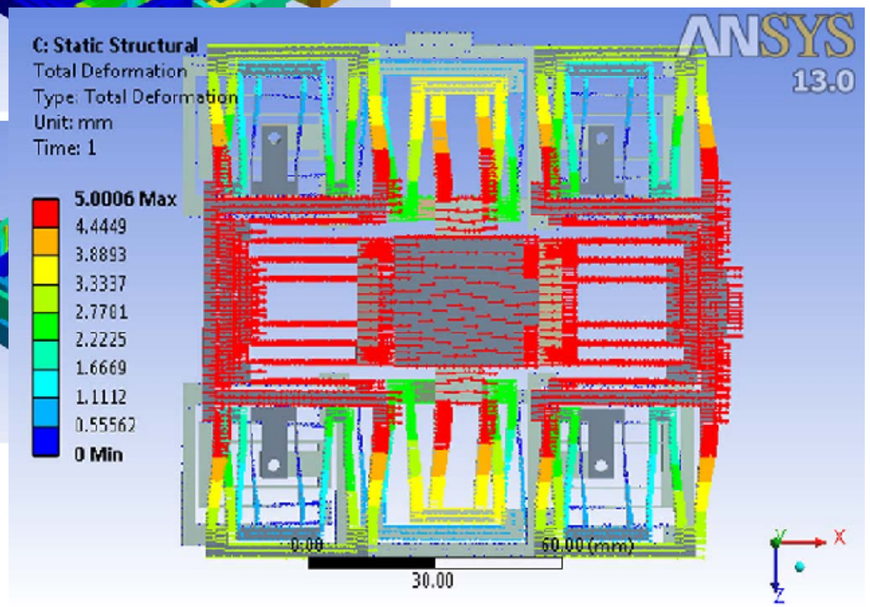
TABLE II
FIRST-SIX RESONANT FREQUENCIES OF THE XY STAGE (IN HERTZ)

Mode no.	1	2	3	4	5	6
Analytical	54.6	54.6	–	–	–	–
FEA	59.9	60.5	128.5	215.6	217.7	219.2





Xu, Qingsong. “Design and Development of a Compact Flexure-Based XY Precision Positioning System With Centimeter Range” IEEE Transactions on Industrial Electronics, vol, 61, Issue 2, Feb 2014

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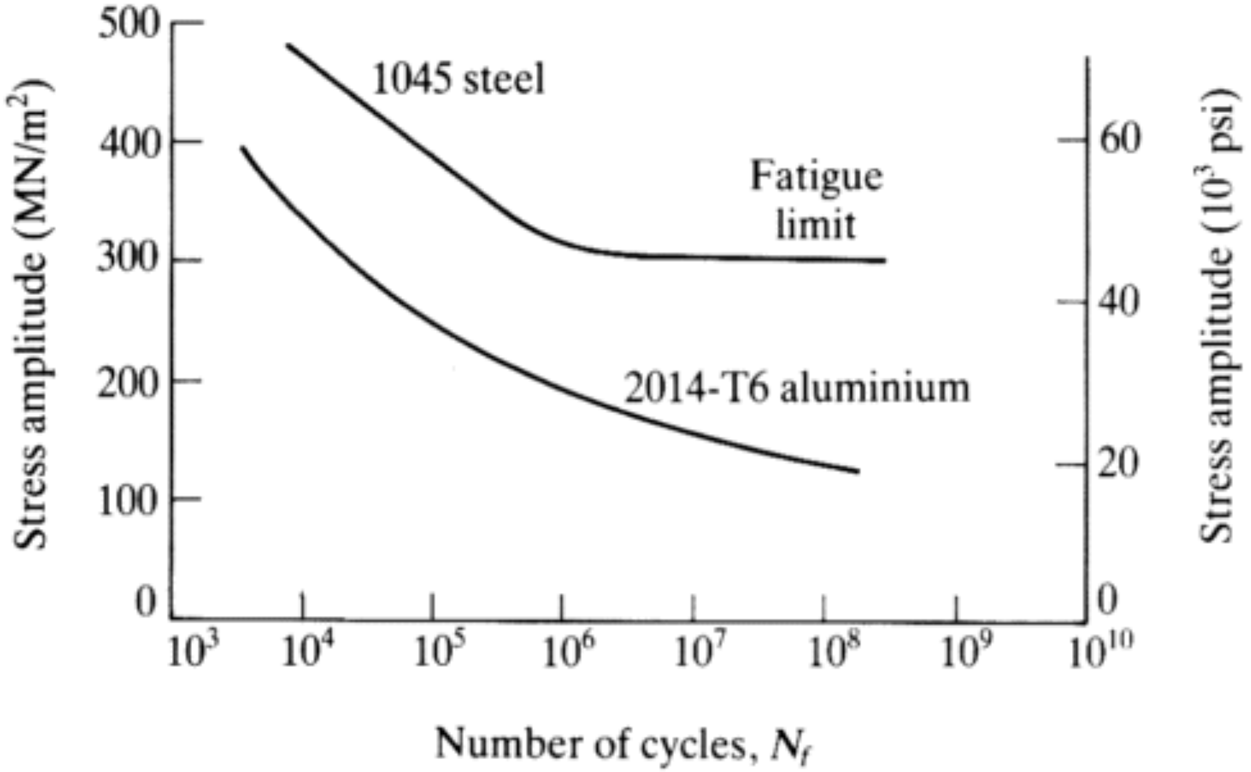
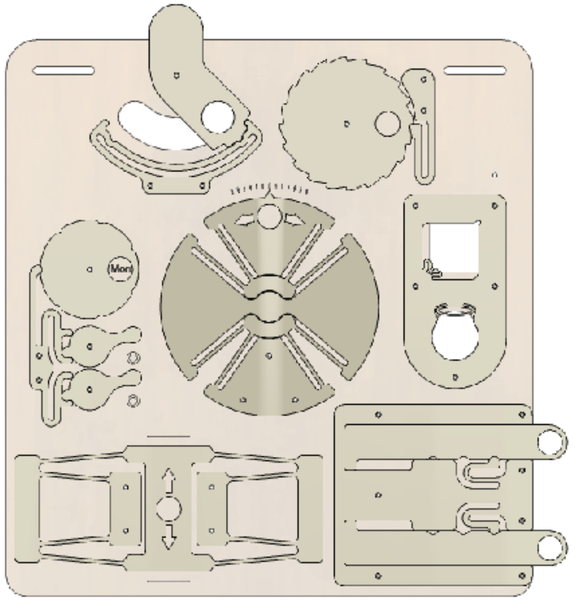
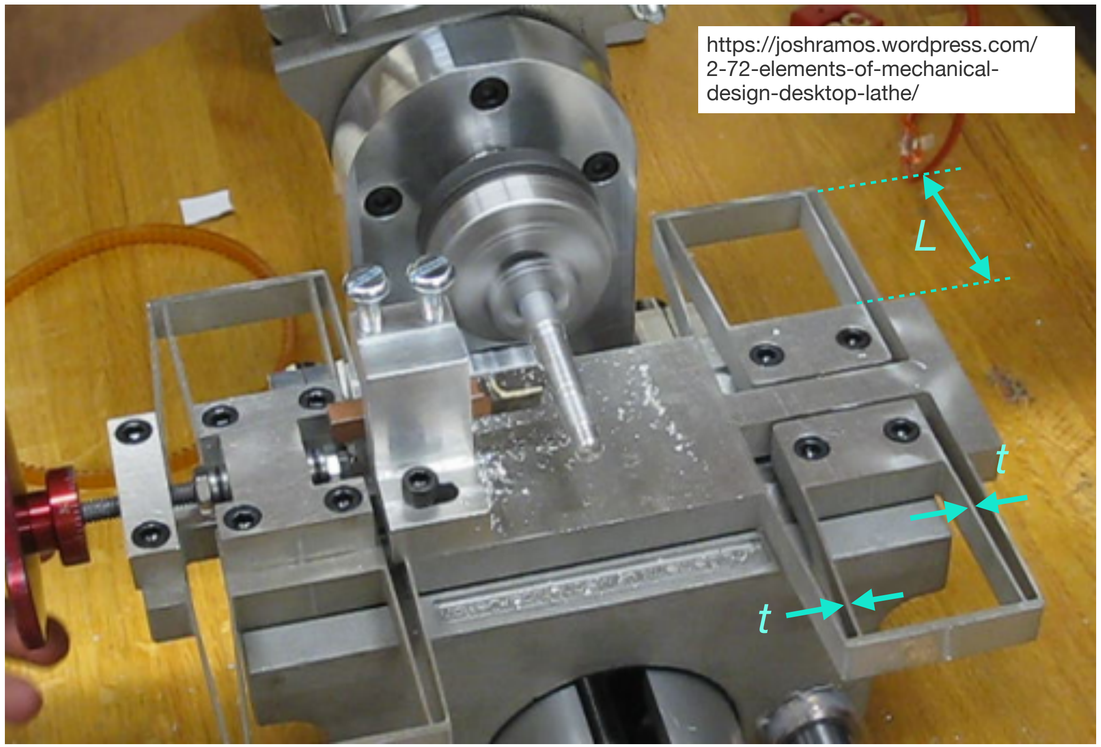


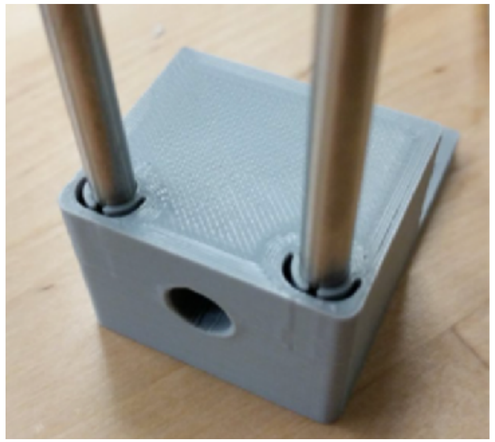
https://www.efunda.com/formulae/solid_mechanics/fatigue/fatigue_highcycle.cfm

Manufacturing benefits

- Easy to DIY (essentially 2D shapes)
    - Sheet material
    - Laser cut
    - 3D print
    - Waterjet
- Robust to crude processes
- Inexpensive







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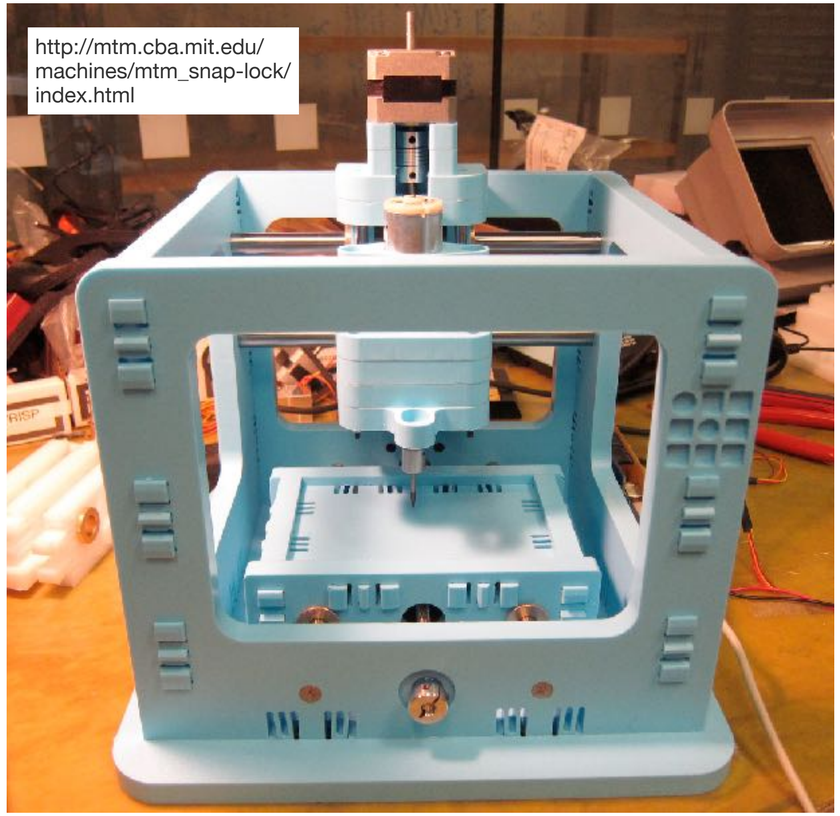
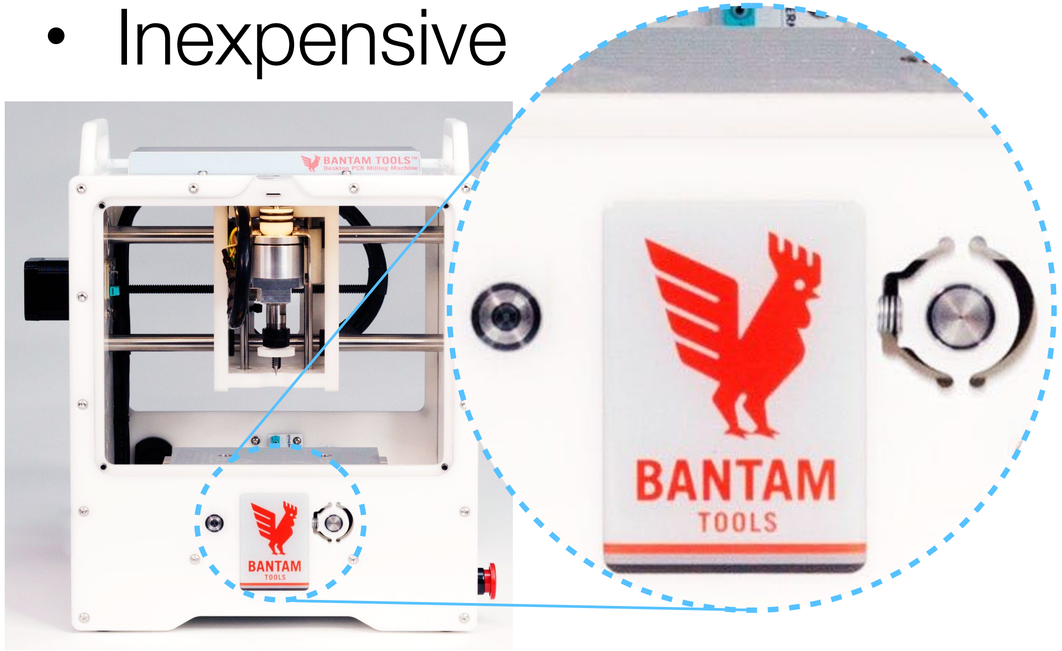
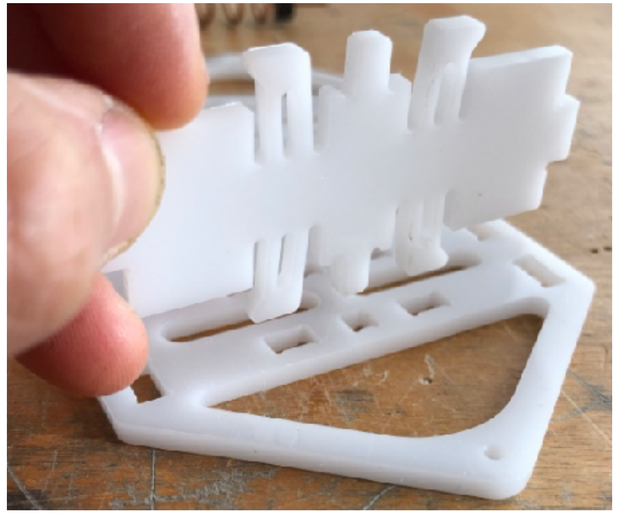
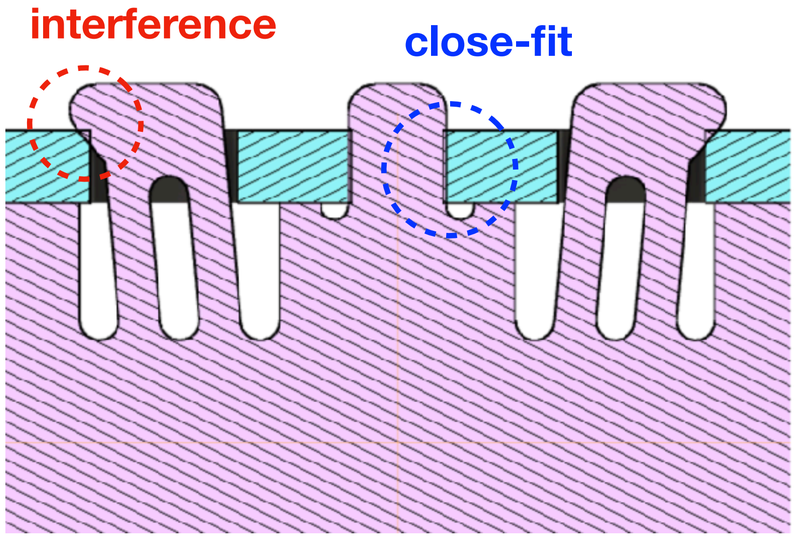
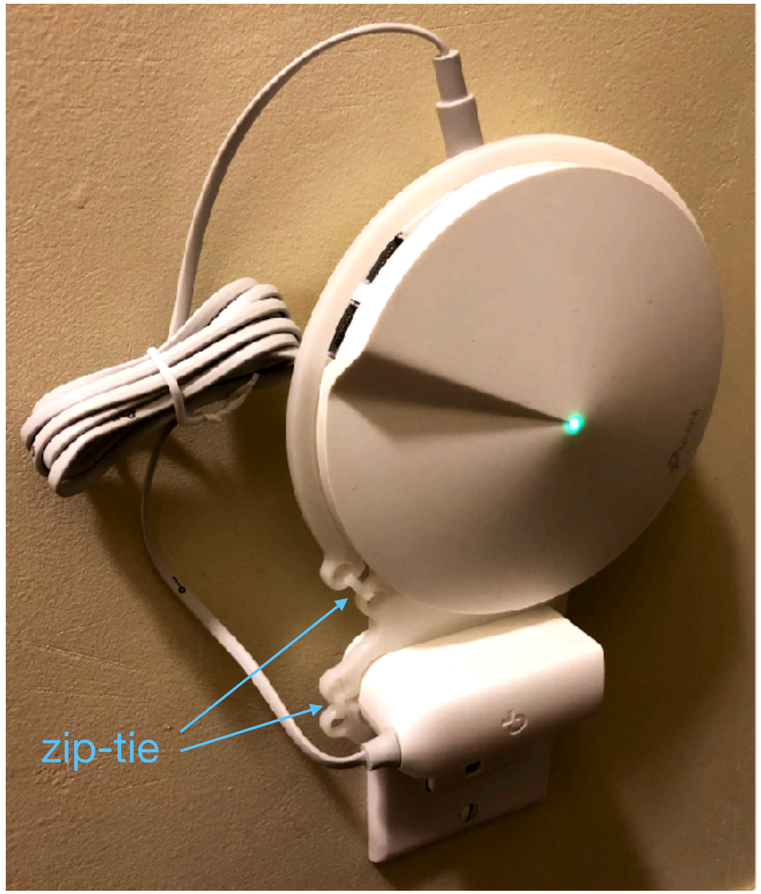




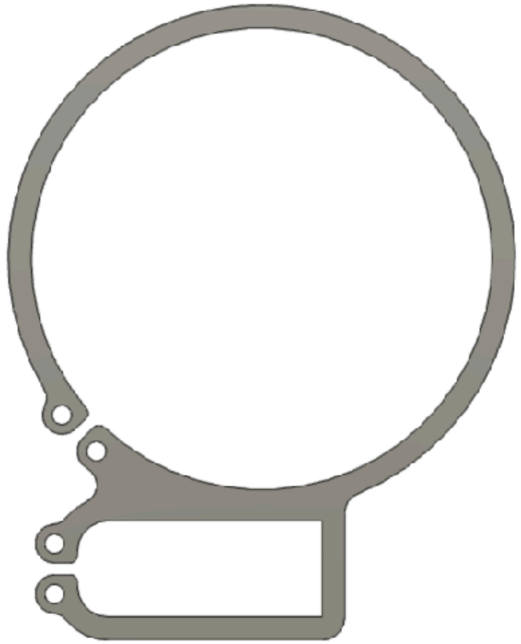




More Examples



not a spring



avoiding fatigue?

Learn more:

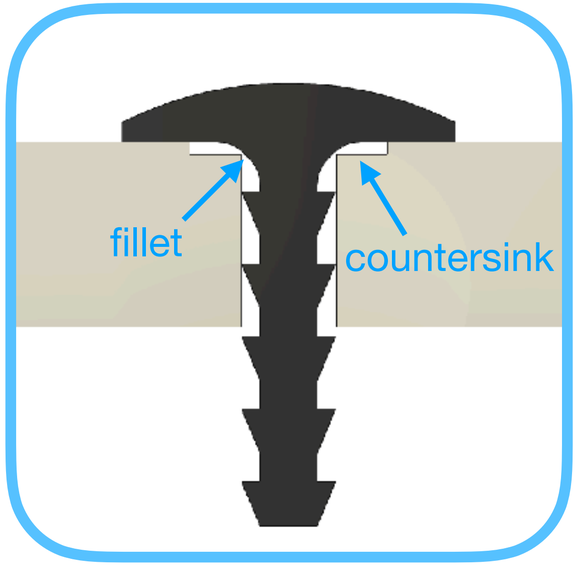
Why Machines That Bend Are Better
https://www.youtube.com/watch?v=97t7Xj_iBv0

BYU Compliant Mechanisms Research Group
https://www.compliantmechanisms.byu.edu

Compliant Mechanisms
by Larry L. Howell

Handbook of Compliant Mechanisms
by Larry L. Howell, Spencer P. Magleby, Brian M. Olsen

Flexure Gripper Assembly



spring

washer x10

push rivet x10

Festo finger x2

has countersinks

link x2

slide

football

body center x2

body front

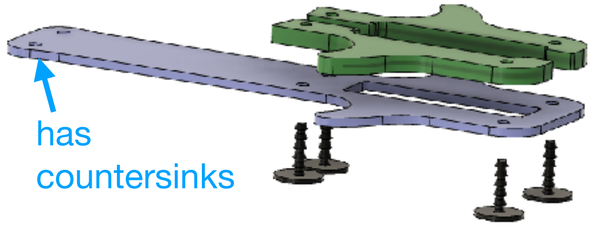
has countersinks

body back

Flexure Gripper Assembly

https://github.com/amymakesstuff/flexure-fun.git

1



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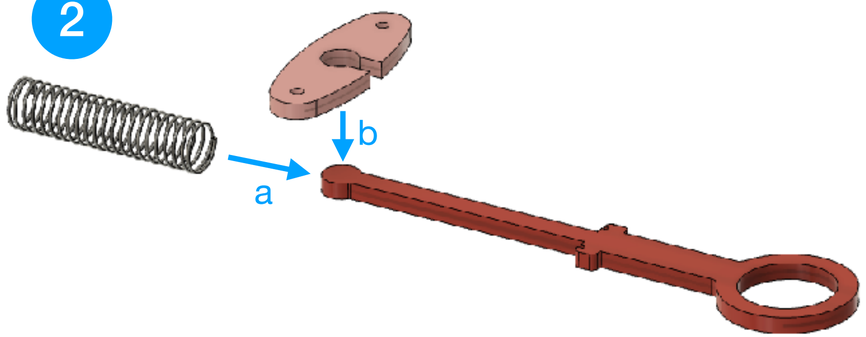


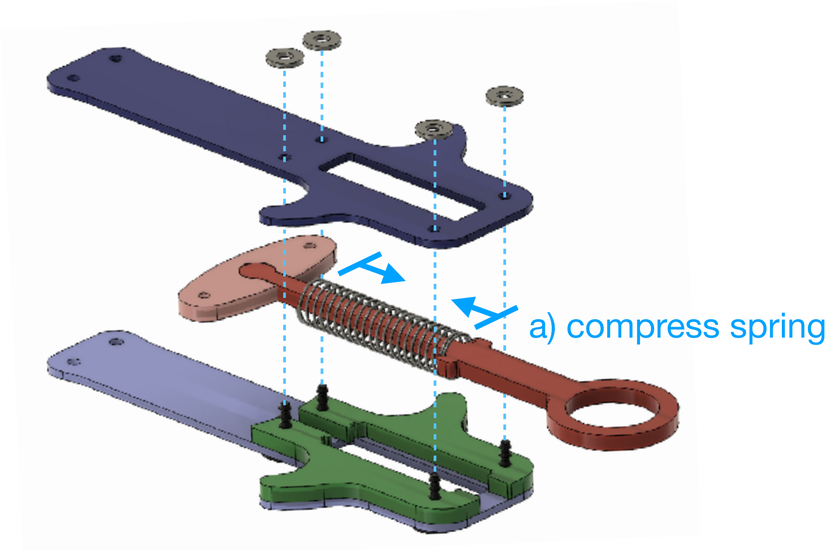
Amy Makes Stuff

www.amymakesstuff.com

@amyismakingstuff

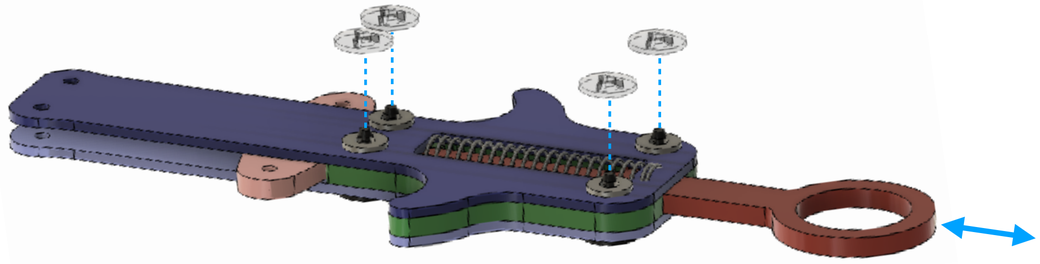
@amy_makes_stuff

3



4

Push rivets are hard to take apart! Cycle the spring to confirm it works before setting the rivet nuts!



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