Micro - 470

Mechanical Scaling Problem Set

Accelerometer design exercise

Problem 2: Design an accelerometer

- Your have maximum: 1 mm x 1 mm area (for cost reasons)
- Assume you are limited by thermal noise, and want to respond in 5 ms. Design an accelerometer: size of proof mass, and spring constant. Use Q=2
- What displacement would you have at the minimum detectable acceleration?
- Assuming your readout circuit can sense ΔC=5 aF, what is minimum number of fingers in readout capacitance (assuming single mask fabrication) to read a_{min}? Is this reasonable?
- Hints
  - as always, there is an infinite number of solutions: try to justify your choices from performance (sensitivity), fabrication feasibility, robustness, cost, etc.
  - Choose f_{res} to start the design
  - Use linear springs / assume linear behavior
  - How far would mass move at 10 g acceleration?

Accelerometer sensitivity and thermal noise

$$S_x = \frac{x}{a} = \frac{m}{k} \propto L^2$$

$$S_x = \frac{1}{\omega_0^{\,2}}$$

$$a_{\min} = \sqrt{\frac{4k_b T\omega_0}{mQ}}\sqrt{\Delta f}$$

Want low f_{res} for high sensitivity, ie high m, low k

If limit chip size, can only play with k (if we use full wafer thickness as the mass)

Want high m, and low f_{res} for low thermal noise

But

- low f_{res} means low bandwidth !
- Readout noise to be considered
- Mechanical robustness…

El Mansouri et al. *Microsystems & Nanoengineering* (2019)5:60
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High-resolution MEMS inertial sensor combining large-displacement buckling behaviour with integrated capacitive readout

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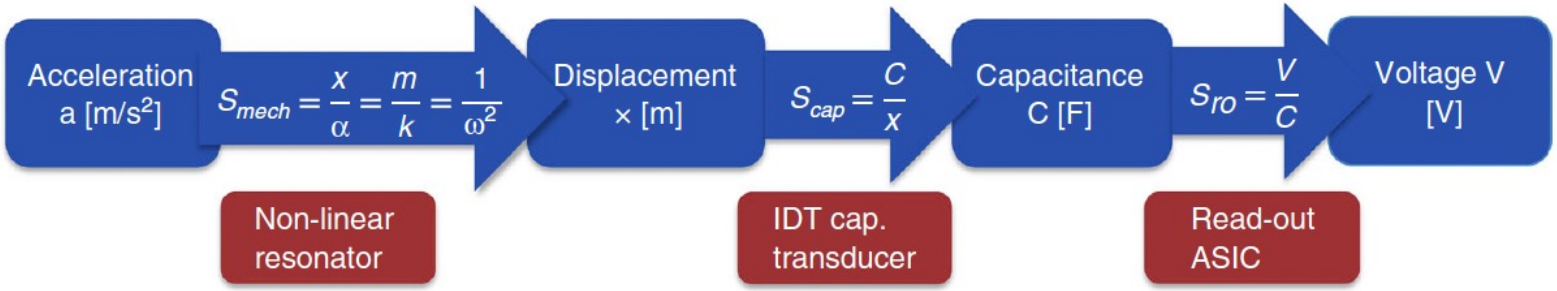

Fig. 1 System overview of the gravimeter; note the different sensitivities between every physical domain

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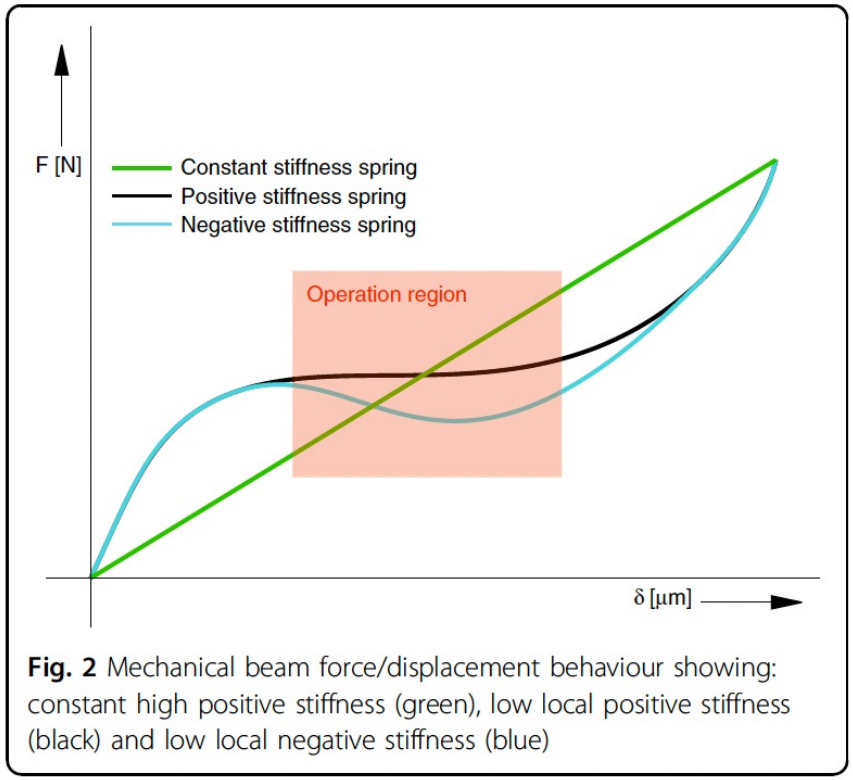
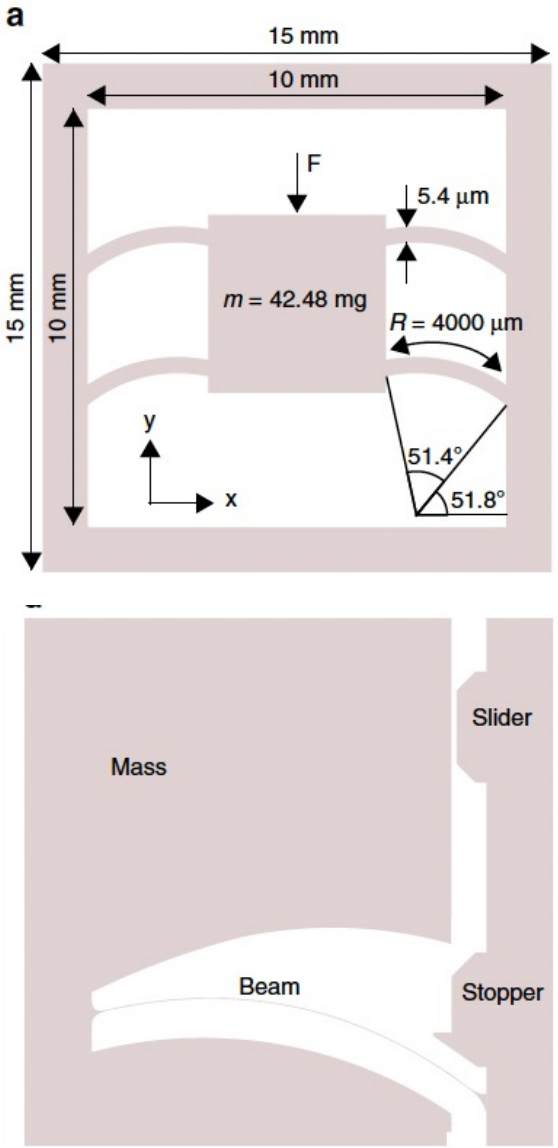


Fig. 2 Mechanical beam force/displacement behaviour showing: constant high positive stiffness (green), low local positive stiffness (black) and low local negative stiffness (blue)

They wanted really “soft” springs to have high sensitivity
The “trick” used by authors: buckling beams



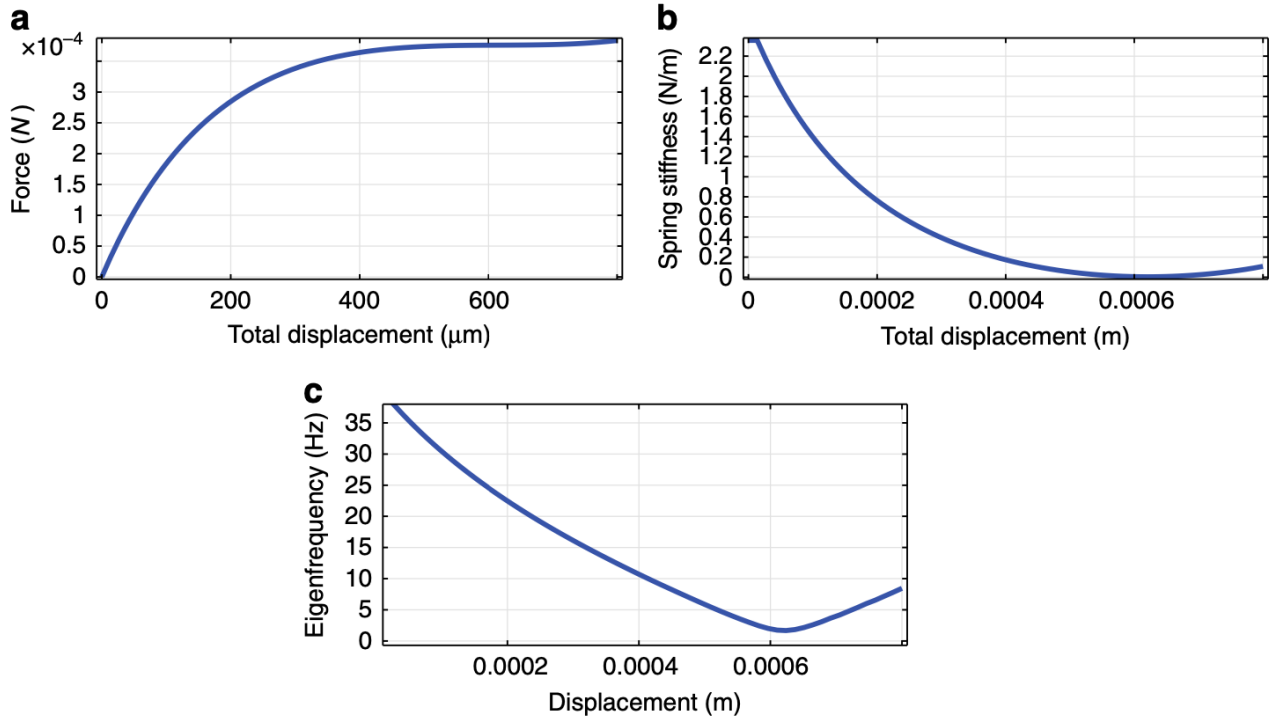


Fig. 4 FEM simulation results on the non-linear spring design. a Force vs. deflection of the proof mass in the *y* direction, **b** stiffness as a function of displacement in the *y* direction, **c** resonance (Eigen) frequency as a function of displacement