Optomechanics

- The lab environment: temperature and vibration
- Optical tables and breadboards
- Optics hardware: selection and usage

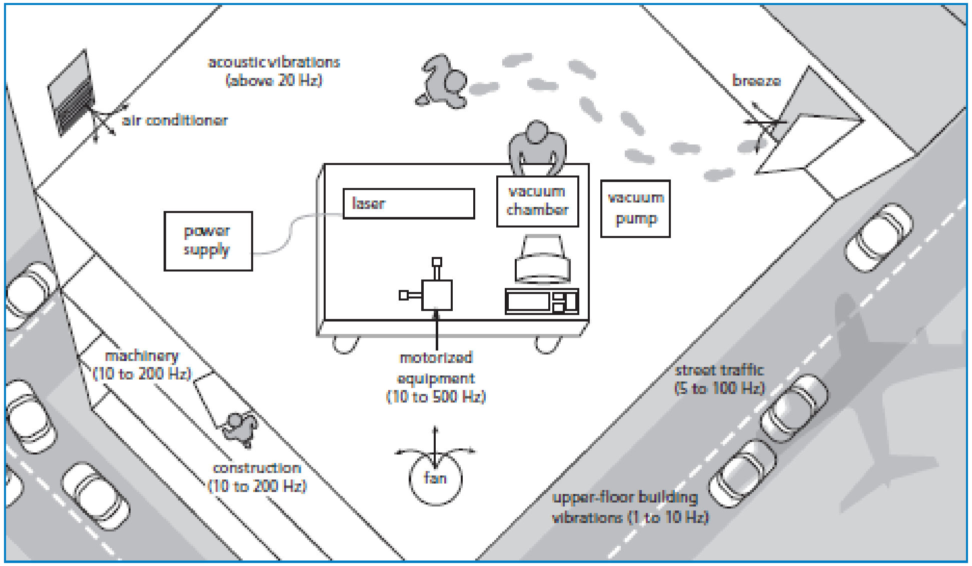
Mechanical Stability is Important

- Noise, drift, probe stability
- Important for
  - Waveguide coupling: fibers, diode lasers, PICs
  - Small targets: VCSEL pillars, single QDs, grains
  - Interferometry, coherent systems

Sources of Vibration and Drift

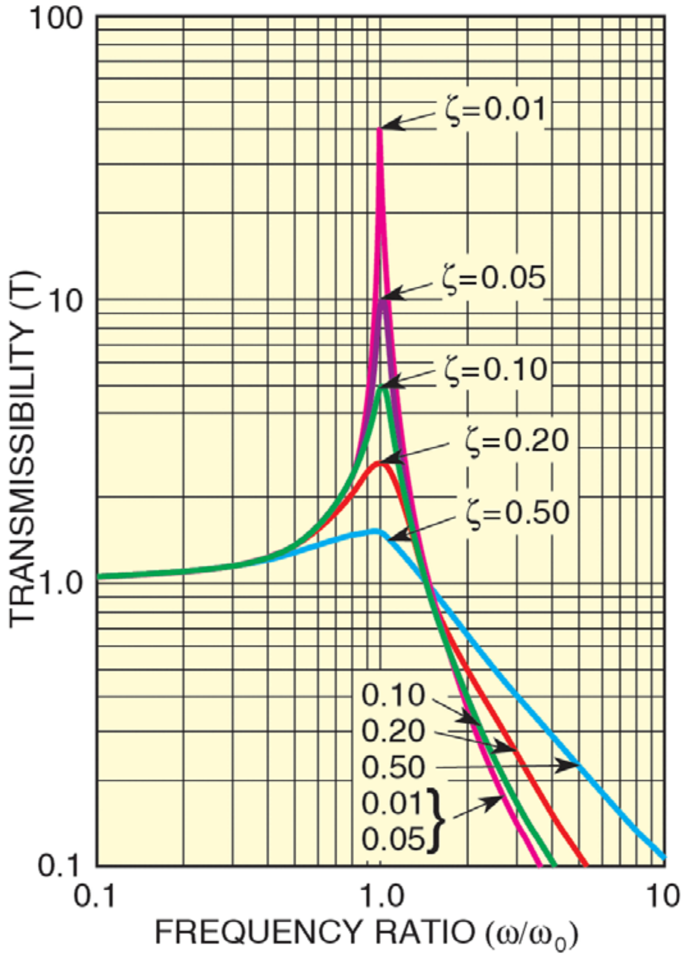
- Floor noise
- Instrument fans
- Air conditioning drafts
- Rap music
- Local heat sources: power supplies, hot plates, lamps

Vibration



Source	Frequency (Hz)	Amplitude (in.)
Air Compressors	4–20	10^{-2}
Handling Equipment	5–40	10^{-3}
Pumps	5–25	10^{-3}
Building Services	7–40	10^{-4}
Foot Traffic	0.55–6	10^{-5}
Acoustics	100–10,000	10^{-2} to 10^{-4}
Air Currents	Labs can vary depending on class	Not applicable
Punch Presses	Up to 20	10^{-2} to 10^{-5}
Transformers	50–400	10^{-4} to 10^{-5}
Elevators	Up to 40	10^{-3} to 10^{-5}
Building Motion	46/height in meters, horizontal	10^{-1}
Building Pressure Waves	1–5	10^{-5}
Railroads	5–20	±0.15g
Highway Traffic	5–100	±0.001g

Transmission of Vibrations

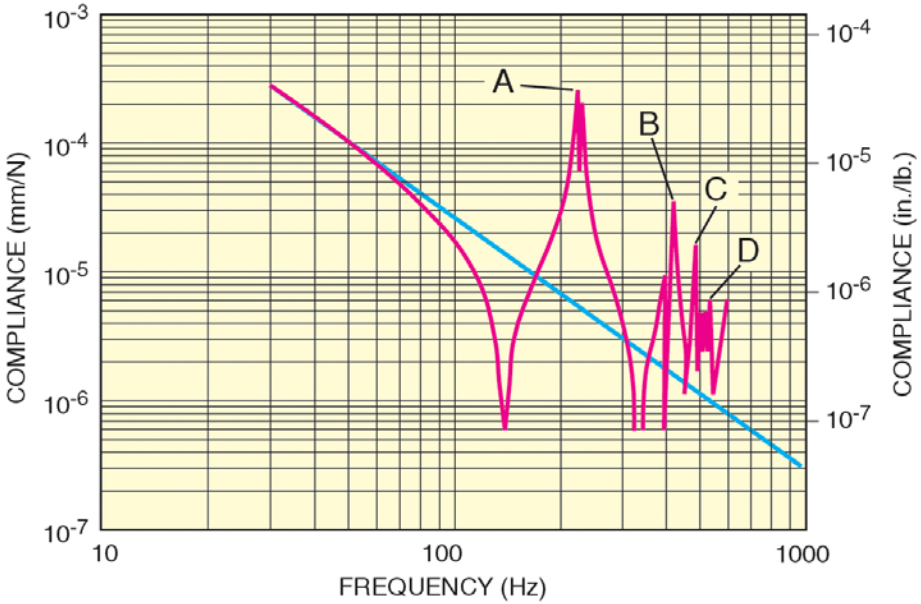


- T ≈ 1 well below resonance
- Amplification near resonance
- Strong attenuation above resonance

SO,

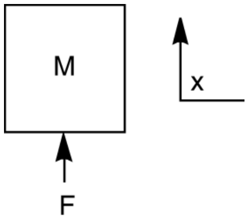
- Insure resonances are well above or well below vibration frequencies
- Use modulation techniques to shift measurement well beyond resonances

Optical Table Response



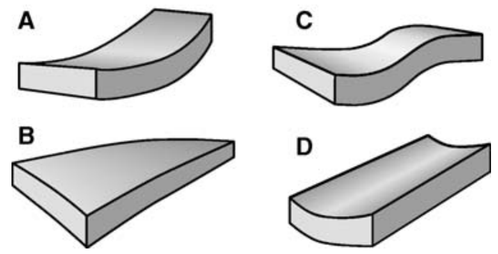
Aluminum Honeycomb

Ideal rigid body displacement

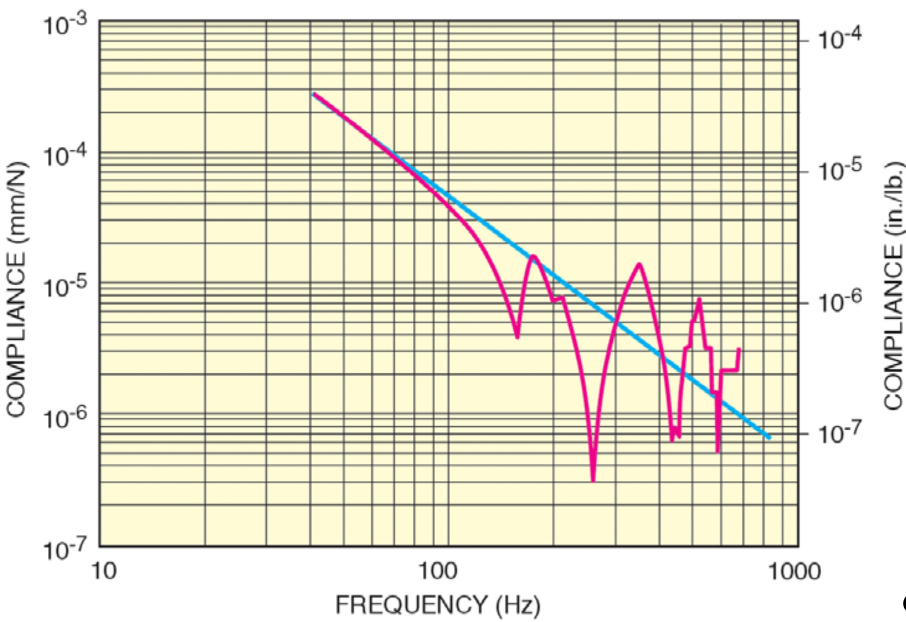


$$C = \frac{|x_0|}{|F_0|} = \frac{1}{M\omega^2}$$

Flexural Modes



Maximum Amplification at Resonance



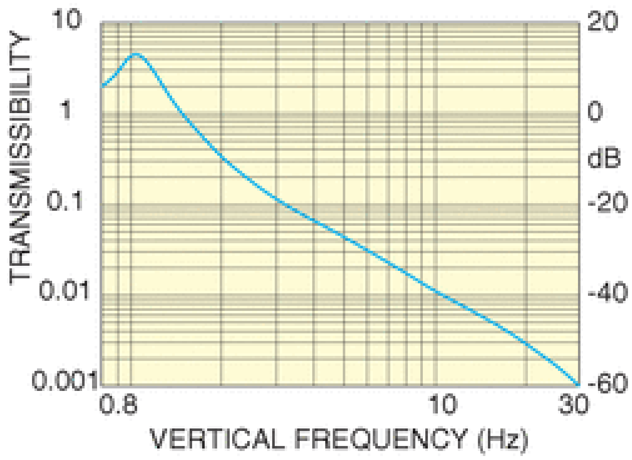
Damped Steel Honeycomb

$$Q = \frac{\text{Resonant Peak}}{\text{Rigid Body Response}}$$

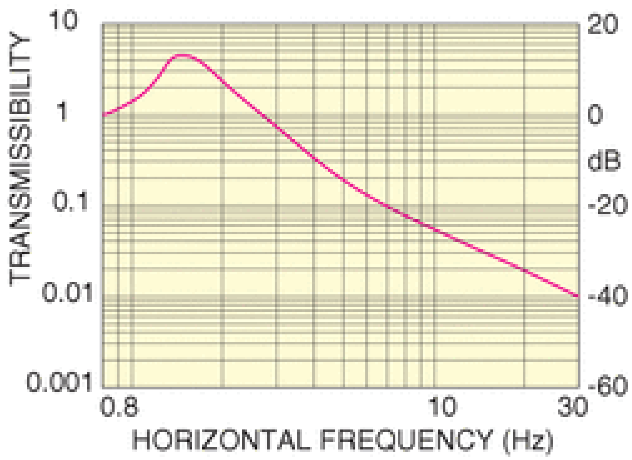
Lower is better

Steel honeycomb core	$Q \cong 4$
Aluminum core	$Q \cong 12$
Granite block	$Q \cong 460$

Pneumatic Isolator Performance

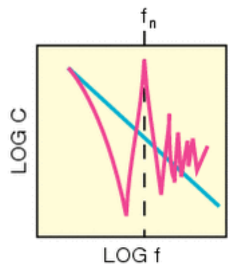


- Isolate table from low freq vibration
- Note resonances- isolators can amplify!
- Isolators can oscillate, if CG is too high

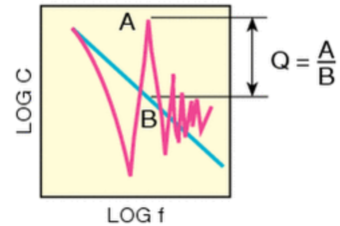


Maximum Relative Motion between two points on table surface

Minimum Resonant Frequency



Maximum Amplification at Resonance



Typical PSD Values*

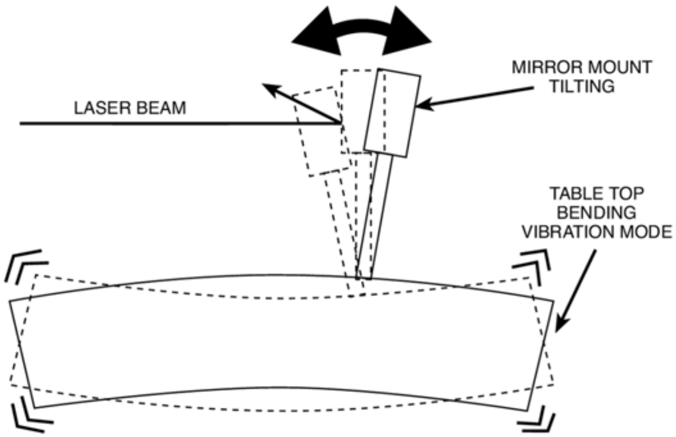
Relatively Quiet Lab	$<10^{-10}\ g^2/Hz$
Lab Next to Street	$<10^{-9}\ g^2/Hz$
Light Manufacturing	$<10^{-8}\ g^2/Hz$

*Assumes random vibration as found in real world environments

$$\text{Maximum Relative Motion at } f_n = \left(\frac{1}{32\pi^3}\right)^{\frac{1}{2}} \bullet \boxed{\left(\frac{Q}{f_n^{\,3}}\right)^{\frac{1}{2}}} \bullet \boxed{(PSD)^{\frac{1}{2}}} \bullet T \bullet 2$$

$\left(\frac{1}{32\pi^3}\right)^{1/2}$	$\left(\frac{Q}{f_n^3}\right)^{1/2}$	$(PSD)^{1/2}$	T	2
Constant [g = 386 in/sec^2 (9.8 m/sec^2)]	Dynamic Deflection Coefficient	Floor Vibration Level (g^2/Hz)	Isolator Trans-missibility (<0.01 Above 10 Hz Typical)	Multiplier For Worst-Case Motion Between Two Points

Laser Spot Deflection



$$\delta = 77 \times \frac{x}{L} \times \left(\frac{Q}{f_n^3}\right)^{\frac{1}{2}} \times PSD^{\frac{1}{2}}$$

Where:
δ = motion of the reflected spot in inches
x = distance of the reflected spot from the mirror, in inches
L = table length, in inches
Q/f_n^3 = dynamic deflection coefficient of table top or breadboard
PSD = power spectral density at table top's natural frequency

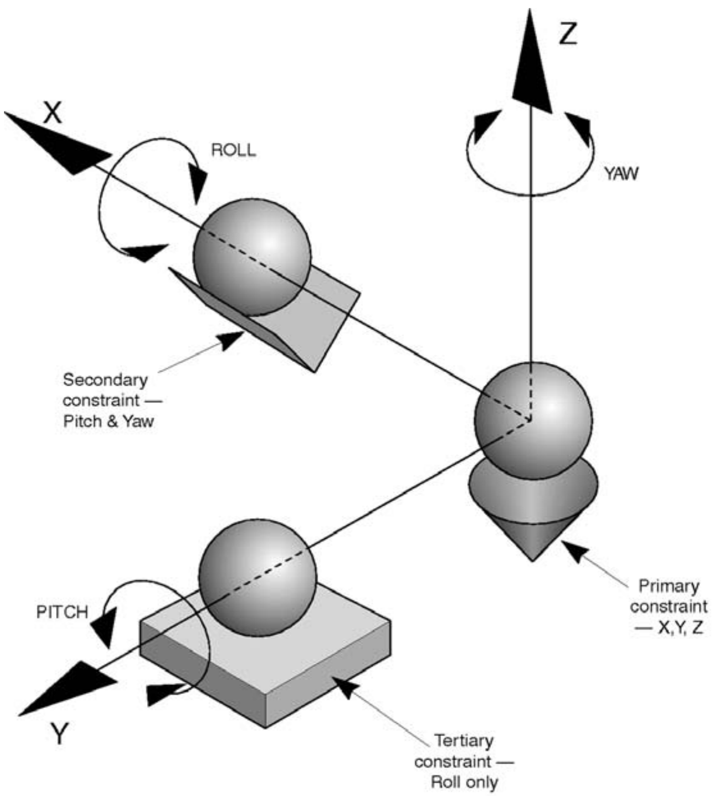
Mounts- Material Properties

Material Properties	Aluminum	Stainless Steel	Brass	Relevance to distortion
Stiffness, k (MPSI)	10.5	28	14	static load
Density, ρ (lb/in.^{3})	0.097	0.277	0.307	
Specific Stiffness, k/ρ (M in.)	108	101	45.6	vibration
Coefficient of Thermal Expansion, α (μ in./in./°F)	12.4	5.6	11.4	Room temperature change
Coefficient of Thermal Conduction, c (BTU/hr-ft-°F)	104	15.6	67	Heat dissipation
Relative Thermal Distortion (α/c)	0.12	0.36	0.17	Uneven heat load

Optical Tinkertoys

- Posts and post holders
  - Fatter is stiffer
  - Long posts = lower resonance frequency
- Lens and mirror mounts
  - nylon tipped screws lessen distortion of lens
  - double sided tape creeps
- Magnetic base plates can pinch
- Disappearing hex wrenches

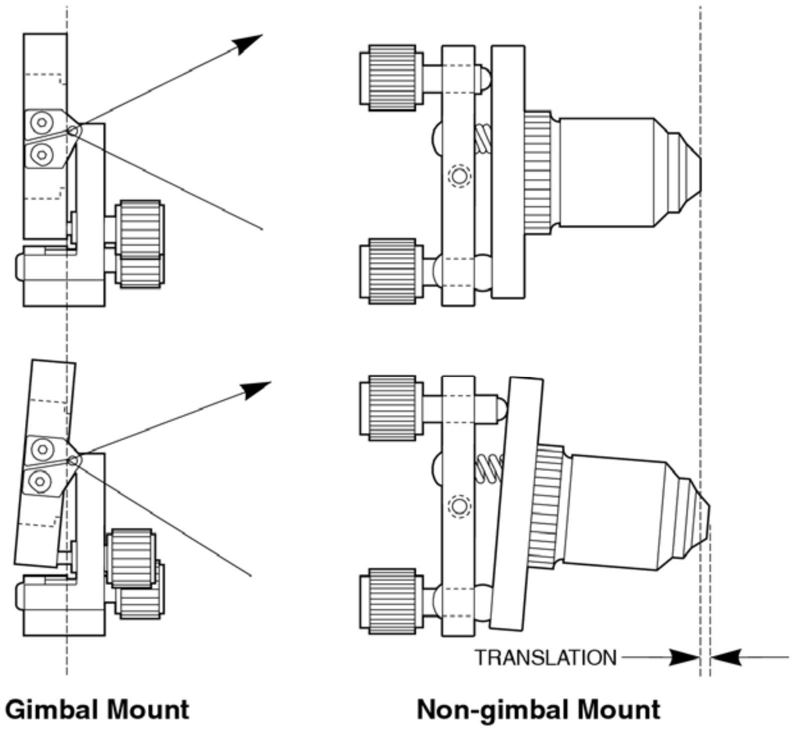
Kinematic Mounts



- Number of constraints = number of degrees of freedom
- Avoids distortion during thermal expansion
- Allows repeatable removal and replacement
- 1 ball in cone constrains x,y,z
- 1 ball in groove constrains pitch, yaw
- 1 ball on plane constrains roll

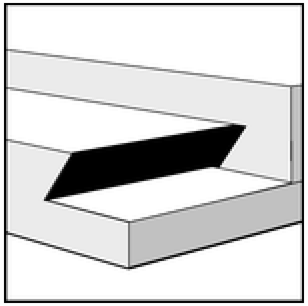
- For stability, surfaces are hardened
- Keep clean; do not lubricate

Gimbal Mounting

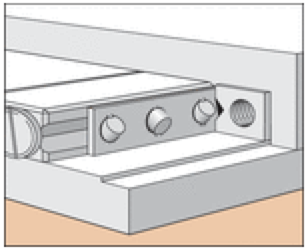


- Kinematic
- Rotates about optic surface, not ball pivot
- Mostly for mirror mounting

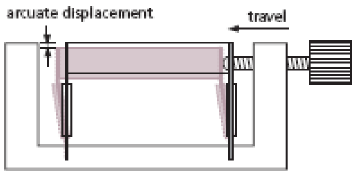
Translation Stage Types



- Dovetail slide
  - cheap, long travel
  - high stiction, poor linearity

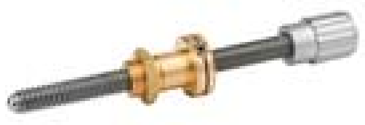


- Ball bearing and crossed roller bearings
  - Lower stiction, good linearity



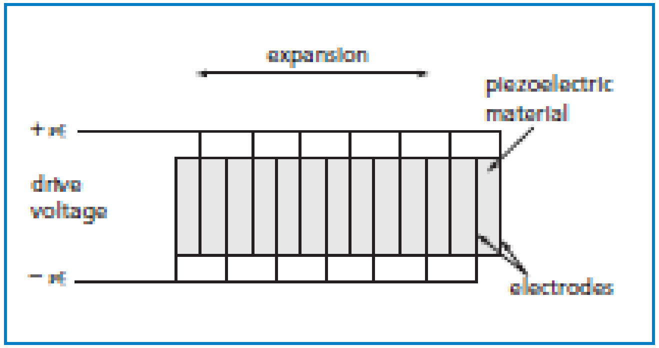
- Flexural Pivot
  - Very low stiction
  - Short travel

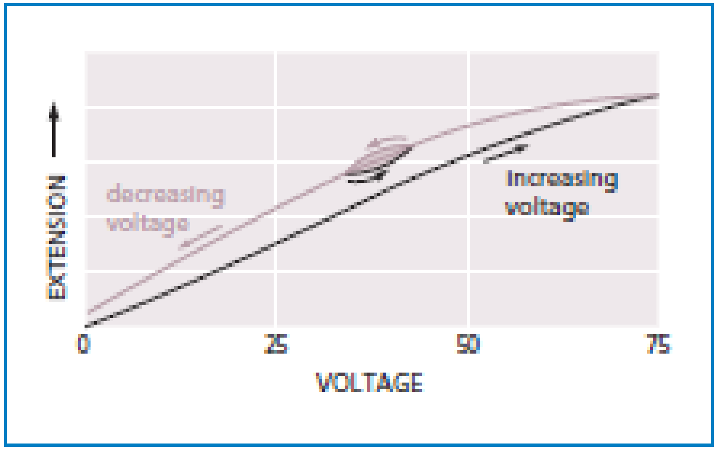
Adjustment Screw Types



- Fine thread adjustment screw
  - 80-100 threads per inch
  - good feel, sensitivity for small motion
- Micrometer
  - typ. 80 tpi
  - vernier scale for ~1 micron resolution
  - metric or imperial scales- be careful
- Differential micrometer
  - highest resolution ~ 0.1 micron
  - coarse back screw + fine front screw
- All: Adjust in one direction to limit backlash

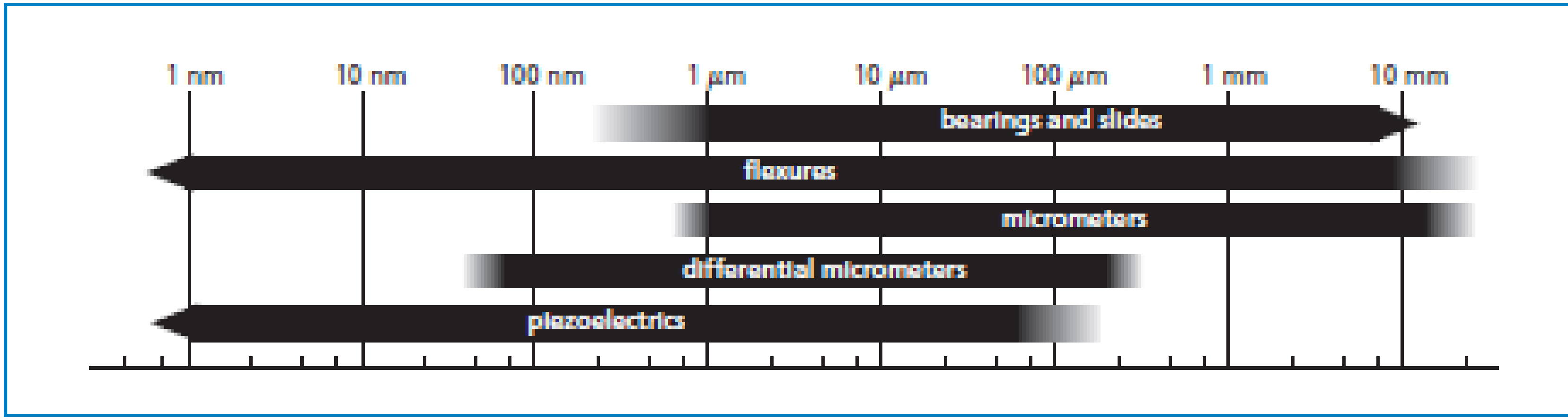
Piezoelectric Actuators





- Nanometer precision, but poor linearity and large hysteresis
- Available with strain gage feedback to eliminate hysteresis
- Usually built into flexural stages
- Costly and delicate

Actuator Resolution



- 80 TPI screws or standard micrometers for MM fiber coupling
- Differential micrometers or piezo stages for SM fiber coupling

Dos and Don’ts

DO

- Use washers under all screws
- Keep posts short to raise resonant frequencies
- Start alignment with a level beam parallel to table edges
- Decide beam height at beginning
- Adjust alignment screws in one direction to limit backlash

DON’T

- Drop XYZ stages- the bearings break, and toes break
- Use scotch tape or electrical tape- it leaves a mess
- Overtighten screws- it scratches posts, mounts

Credits

www.newport.com/promos/default.aspx?id=812
www.cvimellesgriot.com/products/Documents/TechnicalGuide/