VIBRATION TESTING PART I

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WHY MAKE VIBRATION TESTS ?

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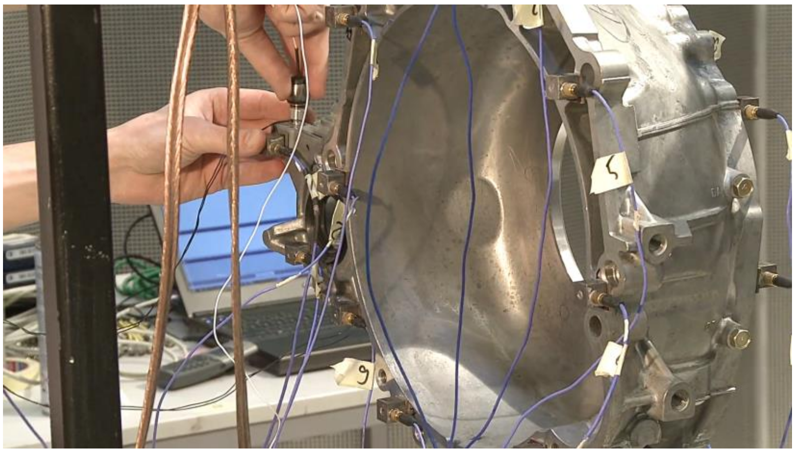
Modal testing of components



https://www.youtube.com/watch?v=Fn9xPMsrrBs

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Aircraft ground vibration testing

https://www.youtube.com/watch?v=tlbGhKGpthM

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Satellite qualification tests before launching

https://www.youtube.com/watch?v=2jh3ViOpKqY

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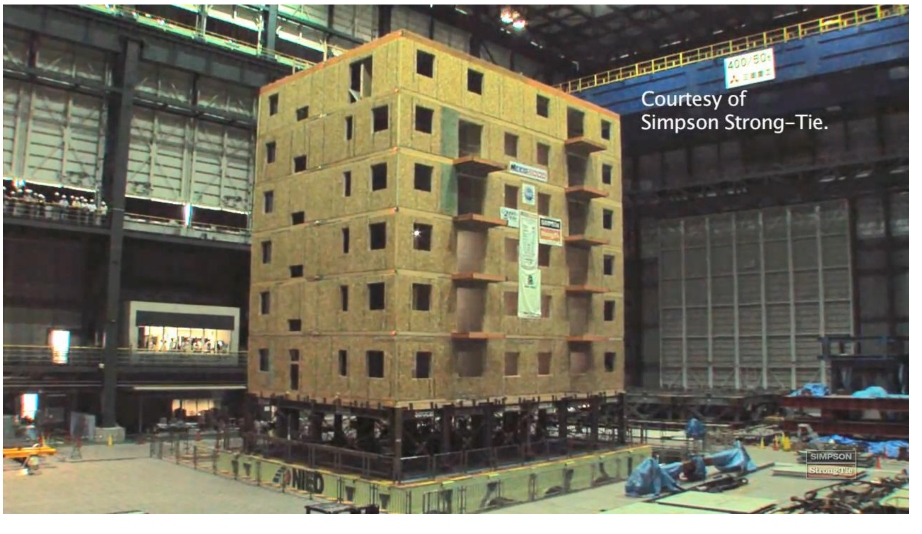
Test building resistance to earthquake



https://www.youtube.com/watch?v=hSwjkG3nv1c

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Vibration testing on a bridge

https://www.youtube.com/watch?v=CO0U3FPy9WY

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Condition monitoring of rotating machines

https://www.youtube.com/watch?v=MgJIETjuapM

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PHYSICAL SENSING MECHANISMS

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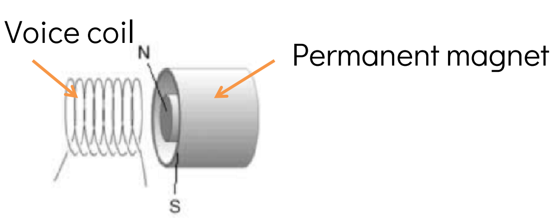
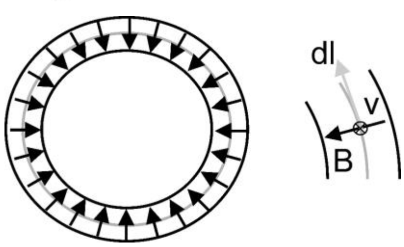
Electrodynamic sensor



$$V = Blv$$



B=magnetic induction
l=lenght of coil
v=velocity of coil

Voltage measurement on the voice coil (V) = measure of the relative velocity between the coil and the permanent magnet

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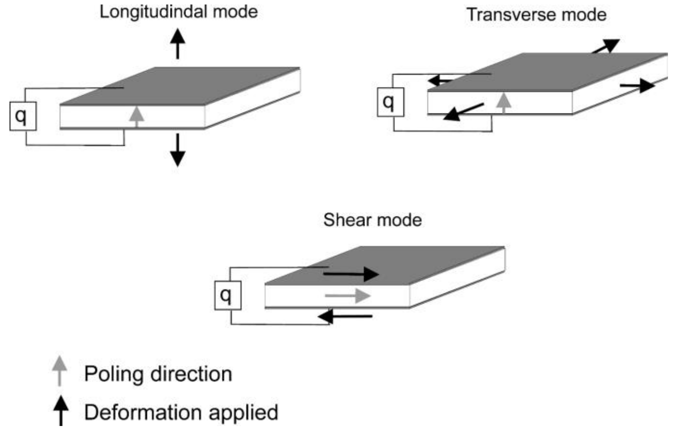
Piezoelectric sensor



- The electric charge is proportional to the strain
- This effect can only be used in dynamics

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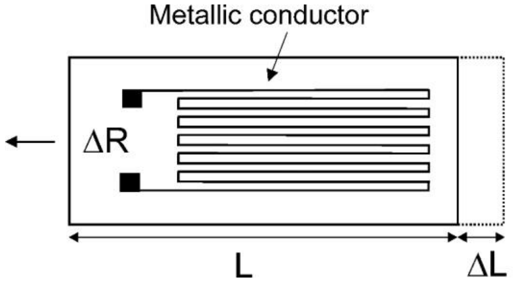
Piezoresistive sensors



$$\frac{\Delta R}{R} = k \frac{\Delta L}{L}$$

The change of resistance of the strain gauge is proportionnal to the applied strain

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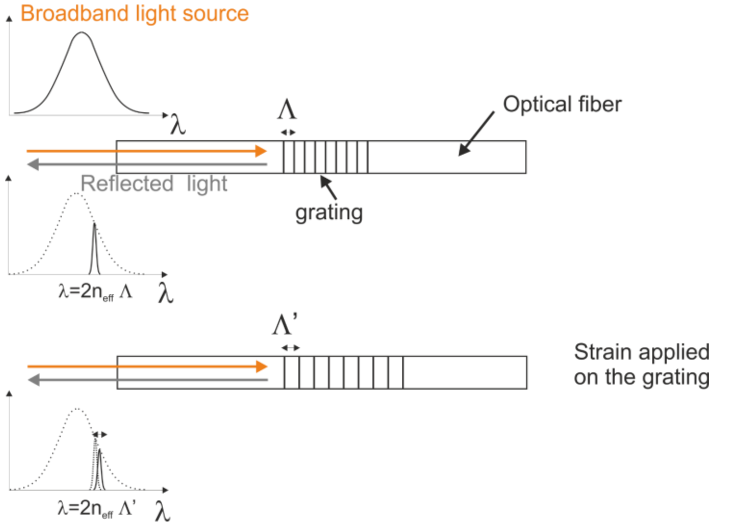
Fiber Bragg Grating (FBG) sensor



The change of reflected wavelength is proportionnal to the strain applied to the Bragg grating.

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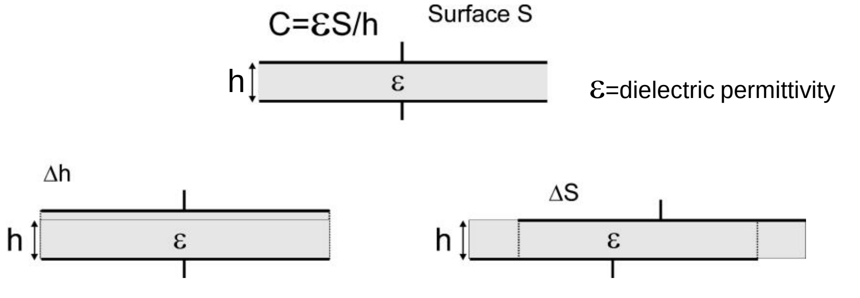
Capacitive sensor



The change of capacitance is a measure of the relative displacement between the two electrodes

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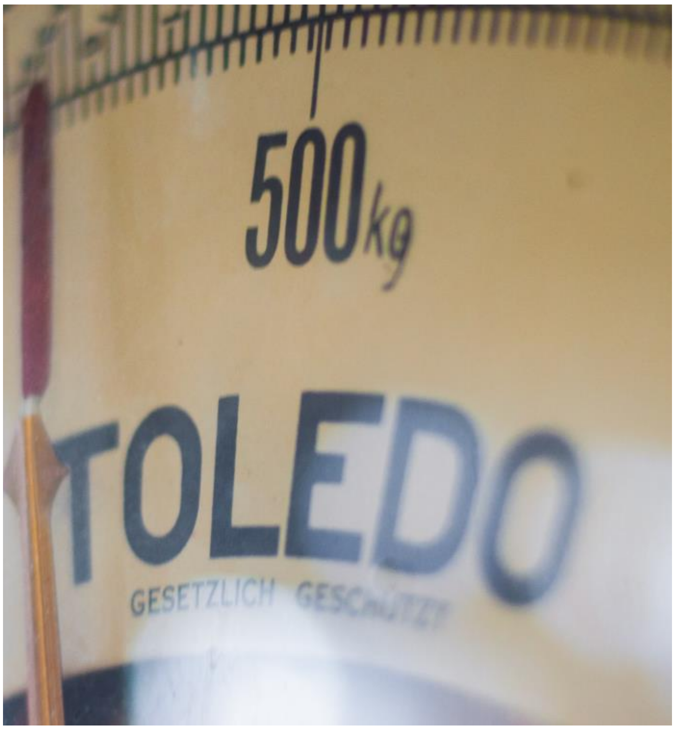
INERTIAL SENSORS



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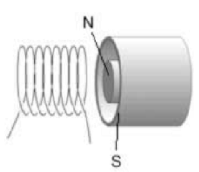
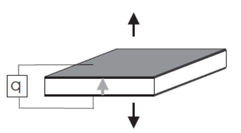
Measuring without a reference point

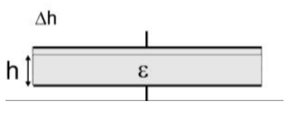
Electrodynamic sensor



Piezoelectric sensor



Capacitive sensor



Reference ?

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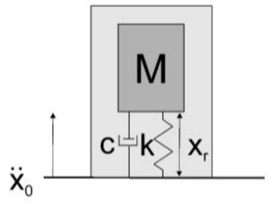
Accelerometer

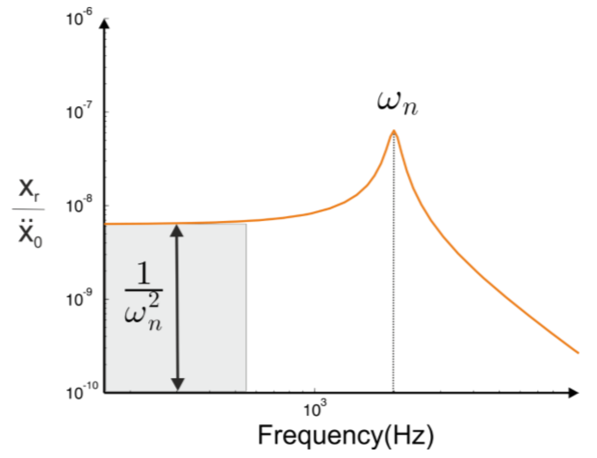


$$M\ddot{x}_r + c\dot{x}_r + kx_r = -M\ddot{x}_0$$

In the frequency domain :

$$\frac{x_r}{\ddot{x}_0} = \frac{-1}{-\omega^2 + \omega_n^2 + 2i\xi\omega\omega_n}$$

$$\omega << \omega_n \quad \longrightarrow \quad \frac{x_r}{\ddot{x}_0} \simeq \frac{-1}{\omega_n^2}$$



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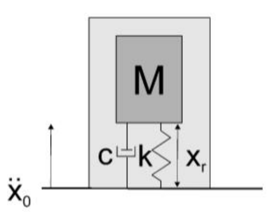
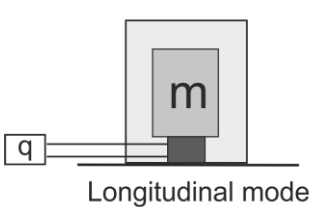
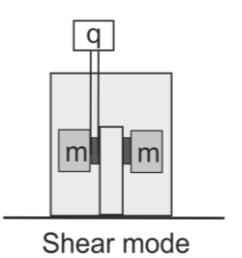
Piezoelectric accelerometer



$$\frac{x_r}{\ddot{x}_0} \simeq \frac{-1}{\omega_n^2}$$



Longitudinal mode



Shear mode

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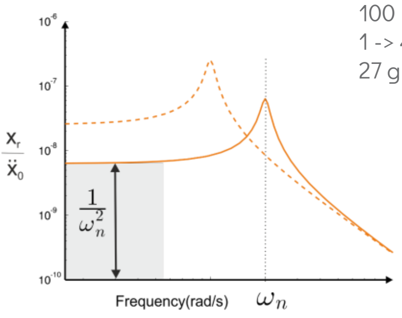
Accelerometer

High resonant frequency
Low sensitivity

5 mV/g
1 -> 10 000 Hz
3.1 g

100 mV/g
1 -> 4 000 Hz
27 g



Low resonant frequency
High sensitivity

10 V/g
0.1 -> 200 Hz
635 g

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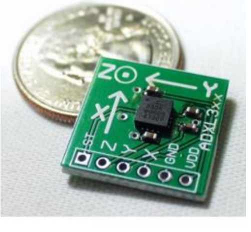
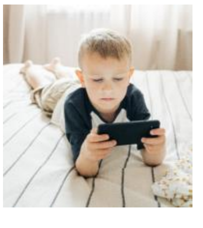
MEMS accelerometers



[https://www.analog.com]

Airbags



Phones, virtual reality head sets

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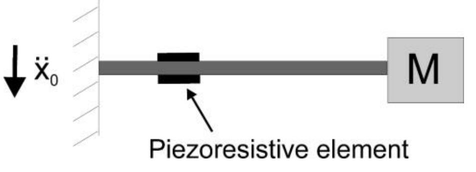
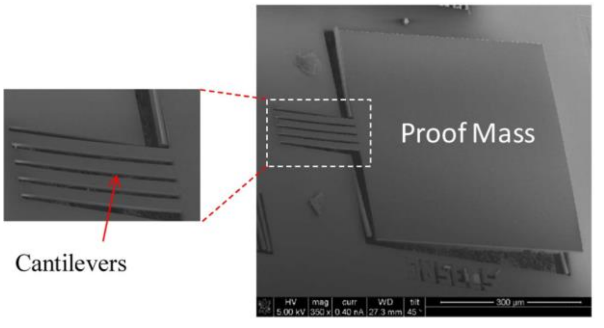
Piezoresistive MEMS accelerometers



Good linearity, wide frequency range

[Khir, 2011]



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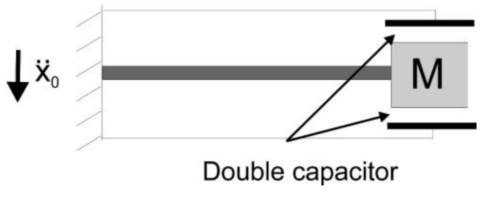
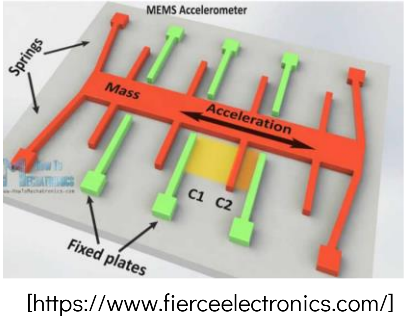
Capacitive MEMS accelerometers



Good temperature stability (no compensation needed)



[https://www.fierceelectronics.com/]

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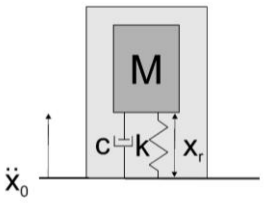
Geophone

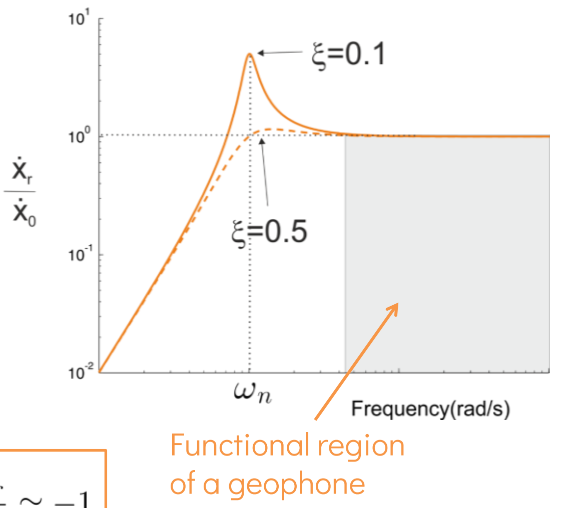


$$M\ddot{x}_r + c\dot{x}_r + kx_r = -M\ddot{x}_0$$

In the frequency domain :

$$\frac{\dot{x}_r}{\dot{x}_0} = \frac{\omega^2}{-\omega^2 + \omega_n^2 + 2i\xi\omega\omega_n}$$

$$\omega >> \omega_n \rightarrow \frac{\dot{x}_r}{\dot{x}_0} \simeq -1$$



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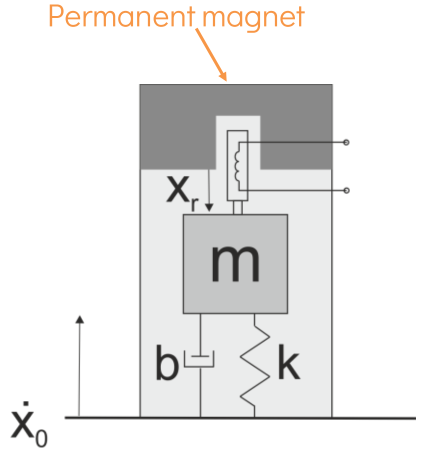
Geophone



Electrodynamic sensor to measure the relative velocity

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SURFACE SENSORS

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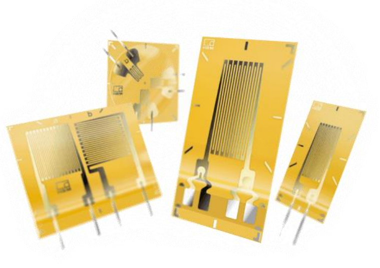
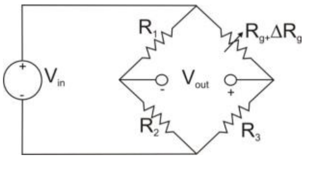
Strain gauges

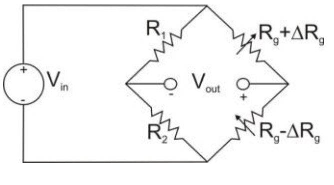


https://hbm.com/

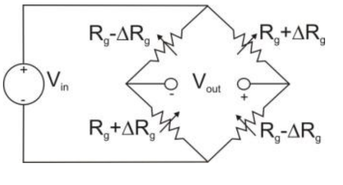
Quarter bridge



Half bridge



Full bridge



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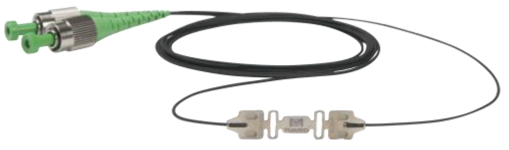
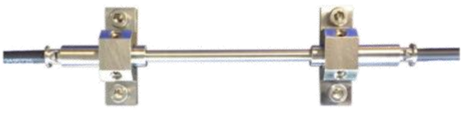
FBGS sensors

Surface gluing

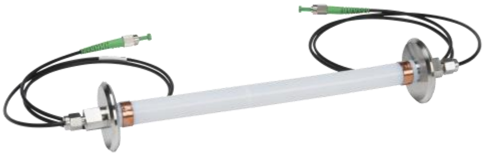


Surface mounting



Main advantages :
- Electromagnetic immunity
- Multiplexing capabilities
- Possibility to integrate inside structures

Embedding



https://lunainc.com

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Piezoelectric patches

PZT ceramic

-Large bandwidth
-Cheap

But brittle …

https://piceramic.de

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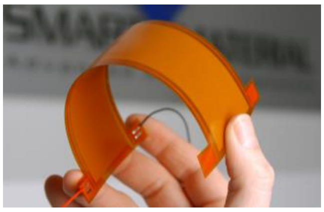
Flexible piezoelectric patches



https://smart-material.com

https://pifrance.fr

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NON CONTACT MEASUREMENTS

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Laser vibrometers

https://www.youtube.com/watch?v=yRxYIfZUxW8

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Laser vibrometers

https://www.youtube.com/watch?v=tmFczbSyKDk

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ACTUATORS

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Impact hammers

Impulse excitation

https://www.pcb.com

https://www.youtube.com/watch?v=tBRjPN8m6zE

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Electrodynamic shaker

Excitation :
- Harmonic
- Periodic
- Random
- ...

https://www.youtube.com/watch?v=nOEvs_q5Nhc

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Electrodynamic shaker

https://www.youtube.com/watch?v=u9CuzMAywbw

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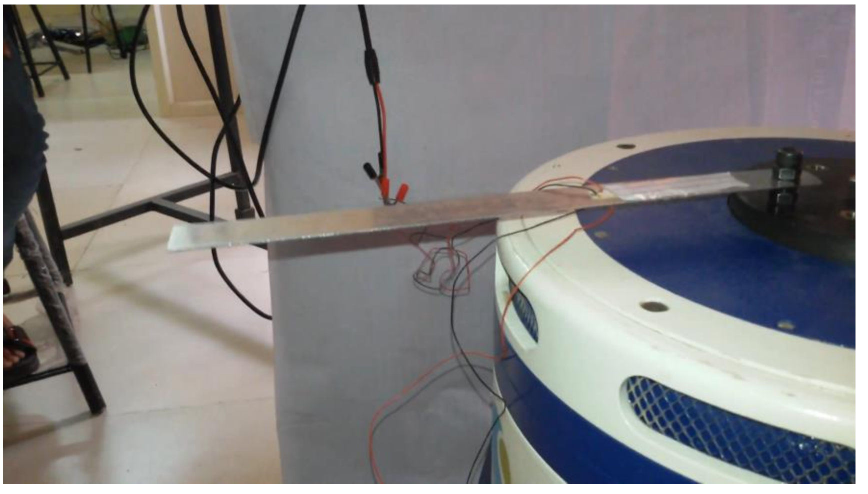
Piezoelectric actuators



https://www.youtube.com/watch?v=34Kvg_4sqxg

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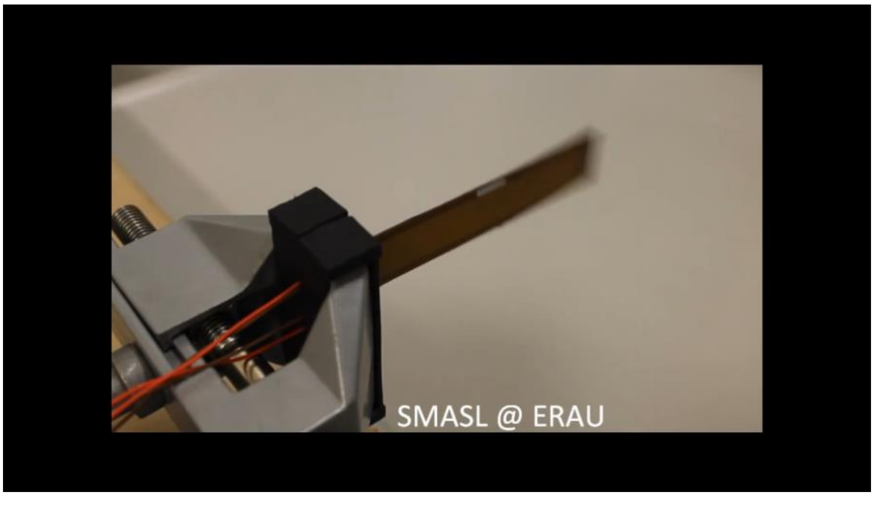
Piezoelectric actuators



https://www.youtube.com/watch?v=w79wTb2zOQQ

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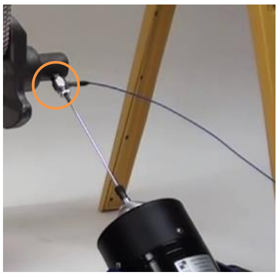
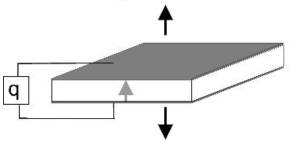
Force sensors



https://www.pcb.com



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Piezoelectric stack actuators

https://www.youtube.com/watch?v=ruSKLl_FQi0

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Morphing wing dancing

https://www.youtube.com/watch?v=L5KKumkXTqo

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