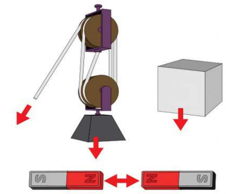
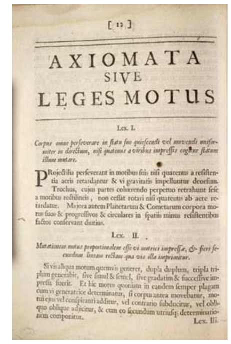
Sila



slov. od 14. stor., úsilie

LAT vis (*vis major,* strength, force, power)
GB force (lat. fortis -> fr. force -> en. force)
DE Kraft
FR force
PL siła
HU erő
UA сила [sila]
RU сила [sila]
CZ síla

Isaac Newton: *Principia Mathematica*, 1687.
https://la.wikipedia.org/wiki/Leges_motus_Newtoni



Sila

- **Sila** je fyzikálna veličina, ktorá predstavuje veľkosť vzájomného pôsobenia telies.
- Značka **F** / jednotka Newton [N]
- 1 newton je sila, ktorá udelí telesu s hmotnosťou 1 kg zrýchlenie jeden meter za sekundu na druhú.
- $1N = kg.m.s^{-2}$

2. Newtonov zákon $F = m.a$

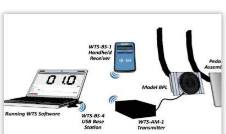
Presná definícia (aj vzhľadom na to, že je to jedna zo základných veličín) nie je jednoduchá.

Na makroskopickej úrovni môžeme vzájomné pôsobenie telies (ktoré pozorujeme na základe našej skúsenosti) našťastie opísať jedinou a jednoduchou vektorovou veličinou.

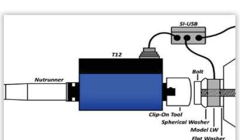
9.3. Snímače sily

- deformačné členy + snímanie :
  - mech. napätia - tenzometre
  - zmeny polohy - malé výchyľky [mm, um]
- piezoelektrické - nevhodné pre statické merania
- kapacitné
- magnetoanizotropné
- zmena elektrického odporu

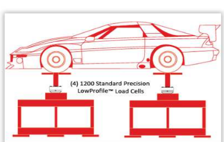
9.3. Snímače sily - aplikácie



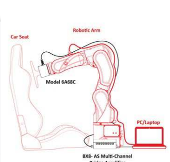
Pedal Force Testing



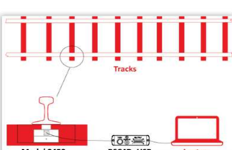
Bolt Fastening Force and Torque



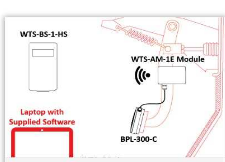
Race Car Suspension Testing



Seat Testing Machine



In-Motion Rail Weigh



WTS Brake Pedal Force Testing

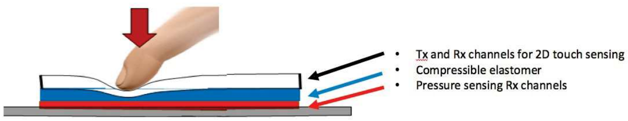
9.3. Snímače sily - aplikácie

		Measurement Range	Accuracy [%]	Output	Load direction
	**ALF304 Brake Pedal Force Sensor** Compact, low profile loadcell for measuring brake pedal application forces	2.5kN	±0.05% of F.S.	mV/V	Compression
	**ALF305 Seat Belt Tension Force Sensor** High performance loadcell for measuring seat belt tension forces	16kN	±3% of F.S.	mV/V	Tension
	**ALF319 Hand Brake Force Sensor** An excellent technical solution to measurement of an ergonomic force	1kN	±0.05% of F.S.	mV/V	Compression
	**ALF321 Gear Shift Force Sensor** Measures gear lever forces required to achieve gear selection	200N	±0.5% of F.S.	mV/V	Bi-directional

9.3. Snímače sily - aplikácie

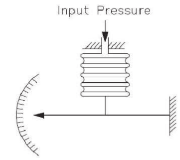
Force-sensing: A third dimension in automotive touch controls

Synaptics demonstration of a steering wheel touchpad with force sensing and haptics.



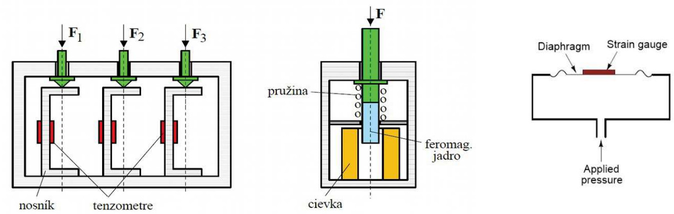
9.3. Snímače sily

Deformačné členy



Menia pôsobiacu silu na inú veličinu

- **nosníky** → deformácia, tenzometre
- **pružiny** → zmena polohy , snímač polohy (indukčný, fotoelektrický)
- **pružné podložky** → zmena polohy



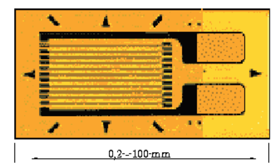
9.3.1 Deformačné členy

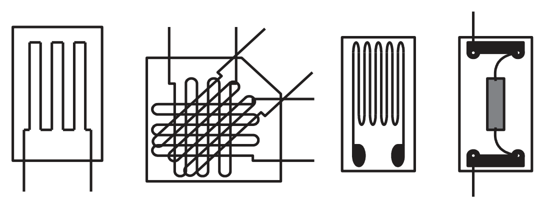
Tenzometer – Strain Gauge

Definition of strain, ε

$$\varepsilon = \frac{\Delta L}{L}$$

Tenzometre





Tenzometre

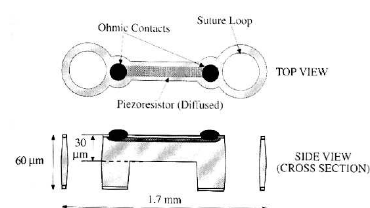
Tab.1 Prehľad vlastností nalepených tenzometrov

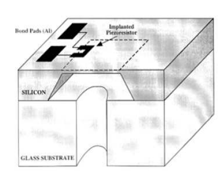
Tenzometre	Fóliové		Polovodičový
Typ	KFC-2-D1-23 (R_{xC})	KFC-5-350-C1-23 (R_{xA}, R_{xB}, R_{xE})	KSP-2-E3 (R_{xD})
Odpor R [Ω]	119.9±0.4	350±0.6	110±2%
Súčiniteľ deformačnej citlivosti K	2.11	2.1±1%	124±3%
Teplotný súčiniteľ deformačnej citlivosti $\alpha_{k0,u}$ [1/°C]	≈ 0	≈ 0	0.14%
Teplotný súčiniteľ elektrického odporu $\alpha_{R0,\upsilon}$ [μm/m//°C, tj. ε/°C]	1.8	1.8	13.8
Súčiniteľ teplotnej rozťažnosti materiálu tenzometra α_S[μm/m//°C]	≈ 0	≈ 0	7÷22
Výrobca	Kyowa Tokyo	Kyowa Tokyo	Kyowa Tokyo
Max. relatívne predĺženie ε [μm/m]	±3000	±3000	±2000
Dĺžka aktívnej mriežky [mm]	2	5	2
Poznámka	tepelná kompenzácia pre namáhaný materiál-hlinik(23μm/m//°C)	tepelná kompenzácia pre namáhaný materiál-hlinik(23μm/m//°C)	

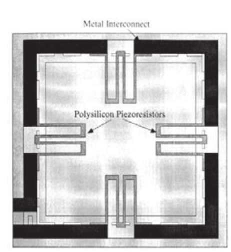
Membrane type gauges: typical pressure sensor

MEMS Tenzometre

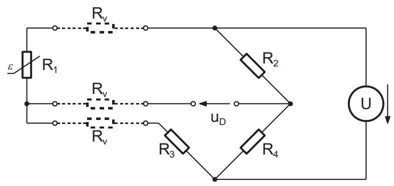
Implantable strain gauge

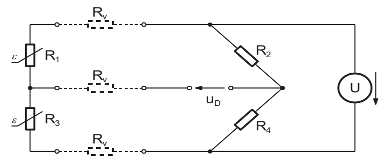




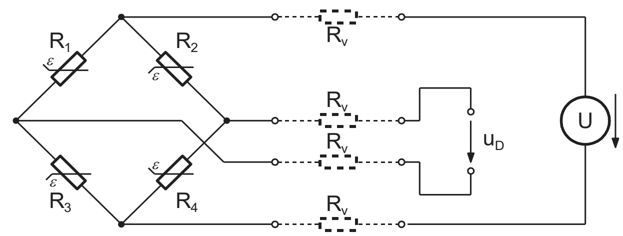


Tenzometre





Tenzometre



Využitie tenzometrov

Sila

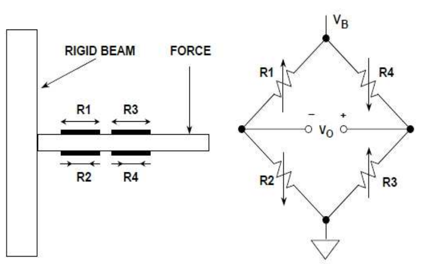


Figure 3.83: A beam force sensor using a strain gage bridge

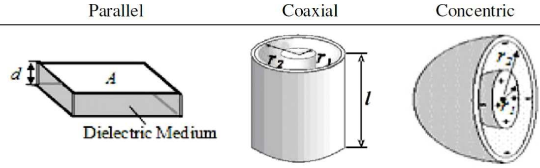
Využitie tenzometrov

Váženie

9.3. Snímače sily

Kapacitné snímače

Table 5.1 Fundamental types of capacitive force transducers (CFTs)

Type	Flat Parallel	Cylindrical Coaxial	Spherical Concentric
Layout			
Formula	$C = \frac{\varepsilon_r \cdot \varepsilon_0 \cdot A}{d}$	$C = \frac{2\pi\,\varepsilon_r \cdot \varepsilon_0 \cdot l}{\ln(r_2/r_1)}$	$C = \frac{4\pi\,\varepsilon_r \cdot \varepsilon_0 \cdot r_1 \cdot r_2}{r_2 - r_1}$

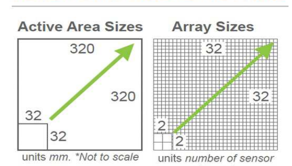
9.3. Snímače sily

Kapacitné snímače

PPS - TactArray

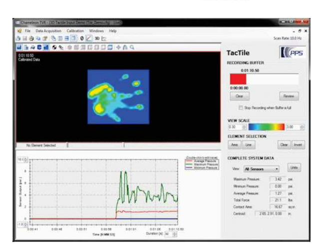
CTA's are flexible and can be molded over complex shapes like a head

SENSOR MODELS & METRICS

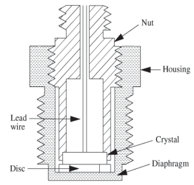


Sensor Characteristics & Performance*

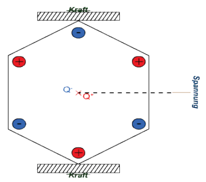
Full Scale Range	2-80 psi
Thickness	< 1 mm (< 0.04 in)
Signal-to-Noise (SNR)	> 500:1
Minimum Sensitivity	10 Pa (0.0015 psi)
Linearity	99.8%
Gain Non-Repeatability	0.35%
Weight	~ 1.5 lbs (650 g)

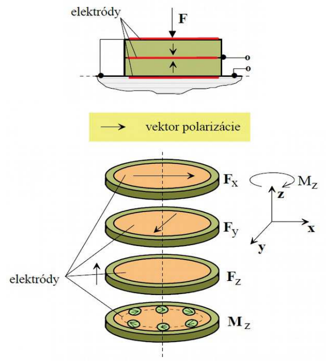


9.3. Snímače sily
Piezoelektrické snímače



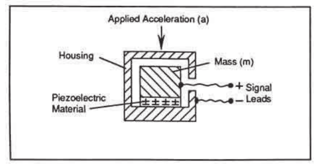
- **využívajú vznik náboja pri pôsobení sily** (U = Q/C)
- **smer polarizácie** - smer citlivosti
- **statické merania**
  - náboj po čase "zmizne"
- **materiál – piezokeramika**

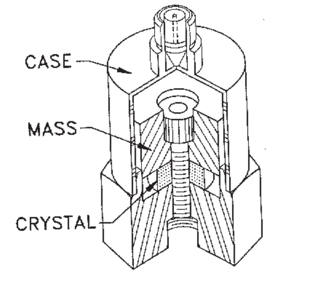




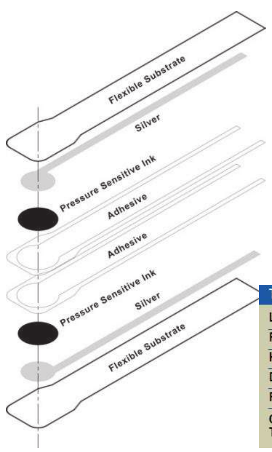
9.3. Snímače ~~sily~~ zrýchlenia
Piezoelektrické snímače

- **teliesko so známou hmotnosťou** *m*, **pri pôsobení sily**
  F = m.a
  → **snímač zrýchlenia**
- meranie vibrácií, diagnostika, monitoring



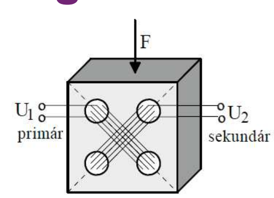


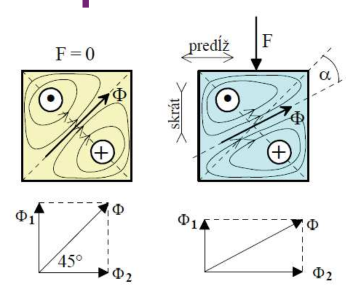
9.3. Snímače sily
Piezoelektrické snímače



Typical Performance	
Linearity (Error)	< ±3%
Repeatability	< ± 2.5% of Full Scale
Hysteresis	< 4.5% of Full Scale
Drift	< 5% per Logarithmic Time Scale
Response Time	< 5μsec
Operating Temperature	15°F - 140°F (-9°C - 60°C)

9.3. Snímače sily
Magnetoanizotropné snímače





hranol z feromagn. materiálu (permalloy) + dve vinutia prevlečené cez otvory s navzájom ⊥ osami, tvoria transformátor

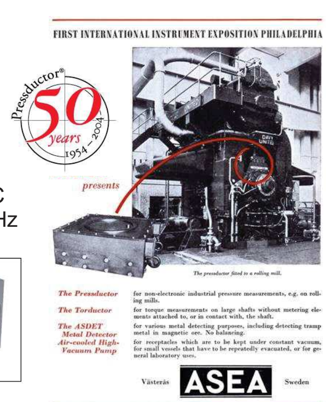
bez pôsobenia sily sekundár neviaže žiadny mag. tok, U2 je nulové

pri silovej deformácii nastanú tieto javy (obecne) :
ťah → +σ (predĺženie) → μ_r stúpa → mag tok Φ stúpa
tlak → - σ (skrátenie) → μ_r klesá → mag tok Φ klesá

9.3. Snímače sily
Magnetoanizotropné snímače

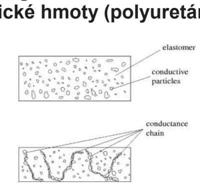
snímač pre F = 5000 kN
(fy ASEA Švédsko)

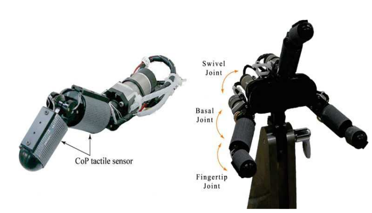
- linearita, presnosť 0,5 %
- hysteréza 0,2 %
- stlačenie 0,05 mm
- preťaženie 200 %
- rozsah teplôt +20 ÷ +80 °C
- napájacia f 50, 60, 400 Hz



9.3. Snímače sily
Zmena elektrického odporu

- **vodivá guma**
- **plastické hmoty (polyuretán)**





Materiály vykazujú zmenu odporu pri stláčaní
Miera stlačenia úmerná sile (niekedy pomocná pružina)

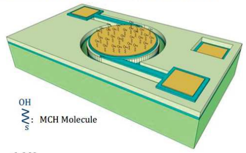
Poznámka: Materiály majú značnú časovú a teplotnú chybu

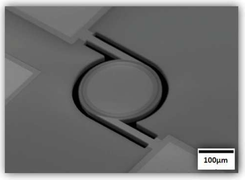
9.3.2 Rezonančné snímače sily

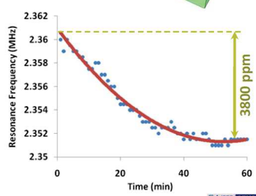
Detekcia DNA

Piezoelectric Disk Resonators for Direct Molecular Sensing

- ❑ Rotational mode disk resonators are demonstrated as direct real-time bio-molecule monitors
- ❑ Exposure to 1.0 mM MCH in aqueous solution
- ❑ Saturation is reached after 1hr

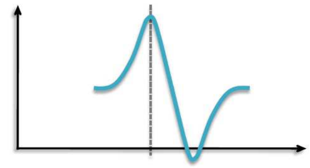






Experiments and Results

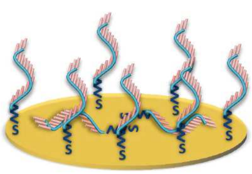
DNA Detection Mechanism

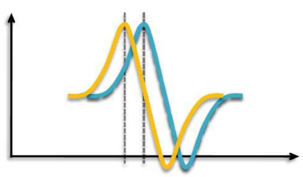


Blank gold surface
(I) Treatment with HS-ssDNA (2.0 µM/1.0 M KH_2PO_4, PH 4.2)
(II) Exposure to 1.0 mM Mercapto-Hexanol in aqueous solution
(III) Hybridization with Complementary DNA Solution (1.0 µM/1.0 M NaCl Tris-HCl 1.0 mM EDTA)

Experiments and Results

DNA Detection Mechanism





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Experiments and Results

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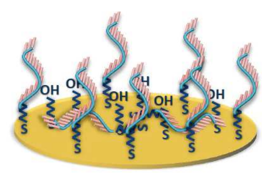

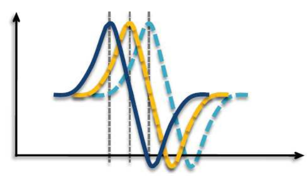

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9.4. Snímače zrýchlenia

$$\mathbf{a} = \lim_{\Delta t \to 0} \frac{\Delta \mathbf{v}}{\Delta t} = \frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t}$$

SI jednotka je m/s^2

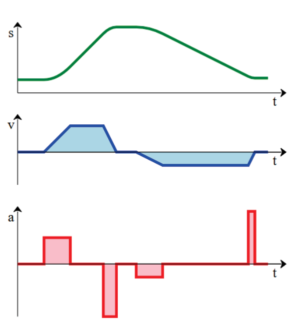
$$F = m \cdot a$$

$$F = k \cdot \Delta x$$

$$a = \frac{k}{m} \Delta x$$

$$a_g = \varkappa \frac{M}{R^2}$$

9,764 – 9,834 m/s^2

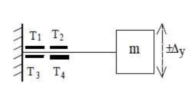


Zdola nahor:
časový priebeh zrýchlenia *a(t)*, integrál zrýchlenia je rýchlosť *v(t)*, a integrovaním rýchlosti získame priebeh dráhy *s(t)*.

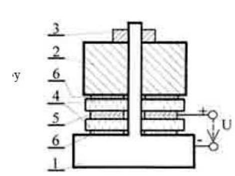
9.4. Snímače zrýchlenia

- Zrýchlenie $a = dv / dt$
- Newtonov zákon $F = m.a$

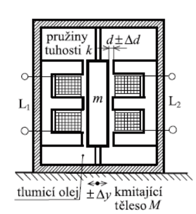
Pri známej hmotnosti telesa *m* je sila *F* merítkom zrýchlenia *a*.



Obr. 3.77 Tenzometrický snímač zrychlení



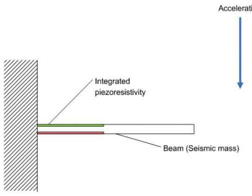
Obr. 3.78b Piezoelektrický tlakový snímač zrychlení



Obr. 3.79 Indukčnostní snímač zrychlení

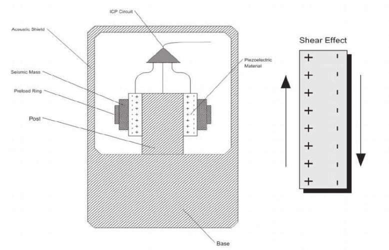
9.4. Snímače zrýchlenia

– akcelerometre



Piezorezistívne

Piezoelektrické



9. 4. Meranie zrýchlenia

2

Applications of MEMS Accelerometers

Industrial
- Platform stabilization
- Oil drilling orientation
- Robotic telepresence

Automotive
- Airbag deployment
- Rollover, anti-skid control

Consumer
- Interactive gaming
- Free-fall detection
- Camera stabilization
- Indoor navigation

Military
- Aircraft flight control
- Dead-reckoning

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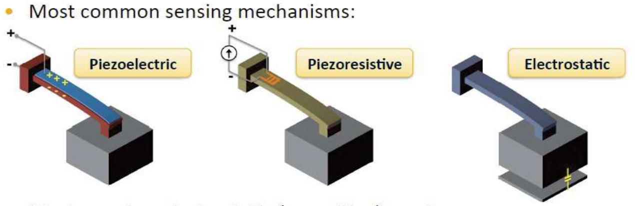
9. 4. Meranie zrýchlenia

7

Electromechanical Transduction

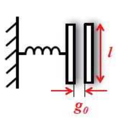
- Displacement has to be converted into electrical signal
- Most common sensing mechanisms:



- Most popular: electrostatic (capacitive) sensing

Parallel Plate

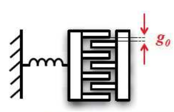
$$\frac{dC}{dx} = \frac{\varepsilon \cdot w \cdot t}{(g_0 - x)^2}$$



Comb Structure

$$\frac{dC}{dx} = \frac{\varepsilon \cdot 2n \cdot t}{g_0}$$

t: thickness, n: # of fingers



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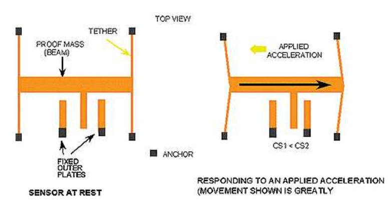
9. 4. Meranie zrýchlenia

MEMS akcelerometer

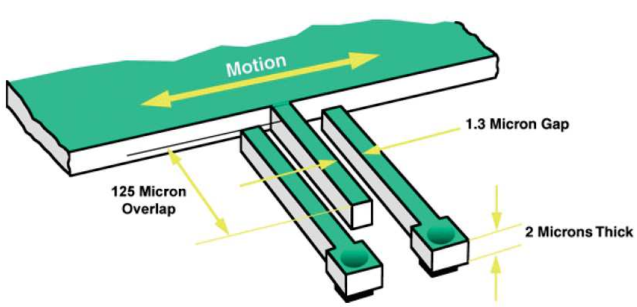
ADXL202: ±2 g Dual Axis Accelerometer

Features
- X and Y Axis on a single chip = Small size and lower cost
- 250uA per Axis = Low power battery operation
- 3.0V to 5.0V Operation = Low power battery operation
- Surface mount package = Small size and ease of use
- High resolution PWM converter = Direct interface to micro (No A/D)
- iMEMS = Low cost AND high performance



9. 4. Meranie zrýchlenia

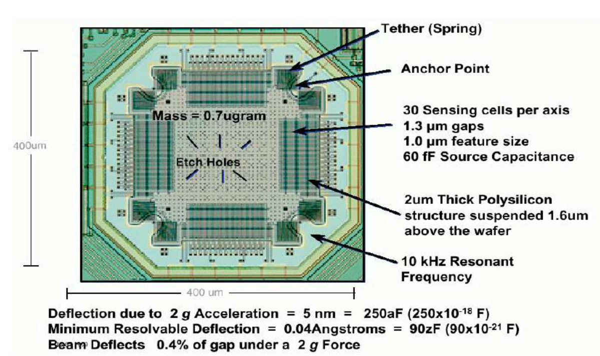
MEMS akcelerometer



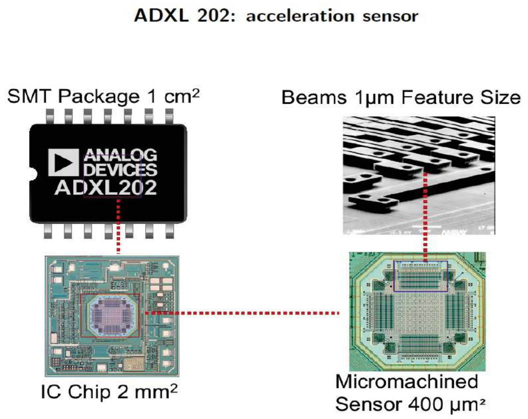
9. 4. Meranie zrýchlenia

MEMS akcelerometer

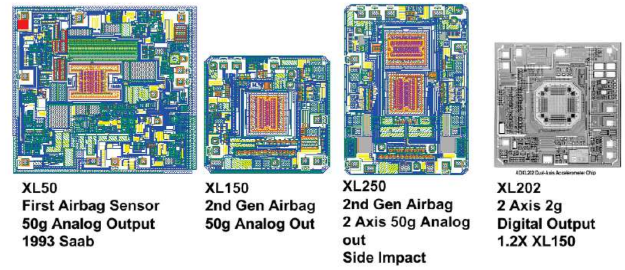
ADXL 202: Micromachined Beam



9. 4. Meranie zrýchlenia
MEMS akcelerometer



9. 4. Meranie zrýchlenia
MEMS akcelerometer

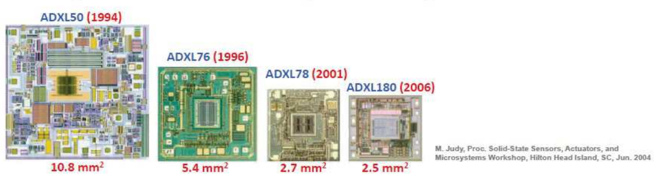


9. 4. Meranie zrýchlenia

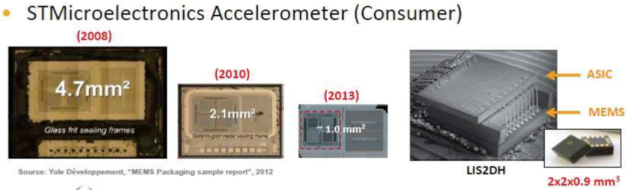
3

Evolution of MEMS Accelerometers

- Analog Devices Accelerometer (Automotive)



- STMicroelectronics Accelerometer (Consumer)

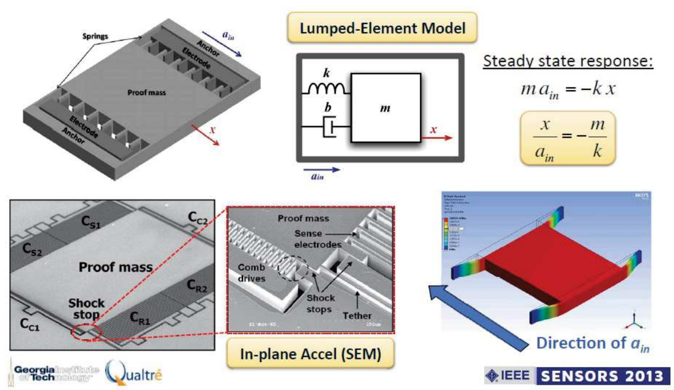


9. 4. Meranie zrýchlenia

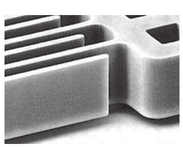
6

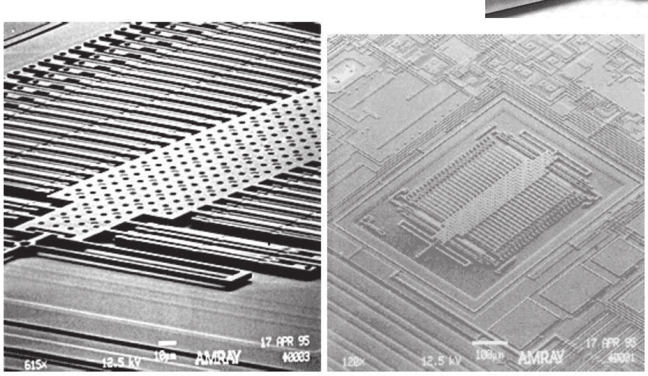
MEMS Capacitive Accelerometers

- Conventional MEMS accelerometer architecture

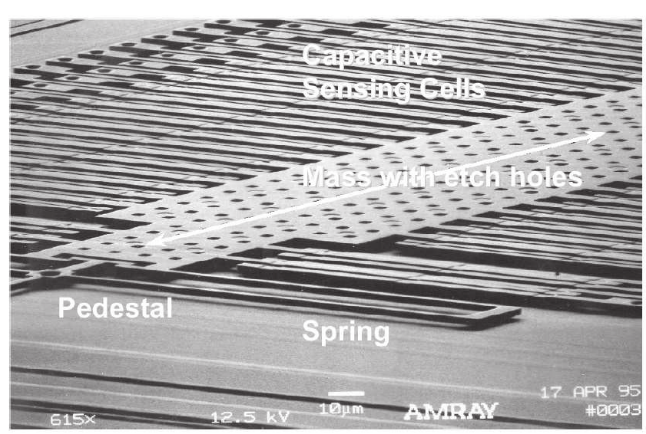


9. 4. Meranie zrýchlenia
MEMS akcelerometer



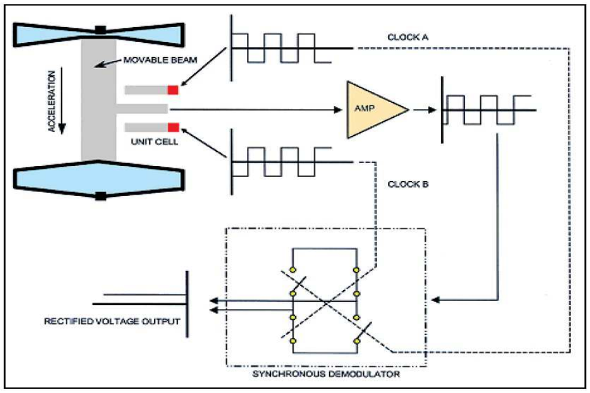


9. 4. Meranie zrýchlenia
MEMS akcelerometer



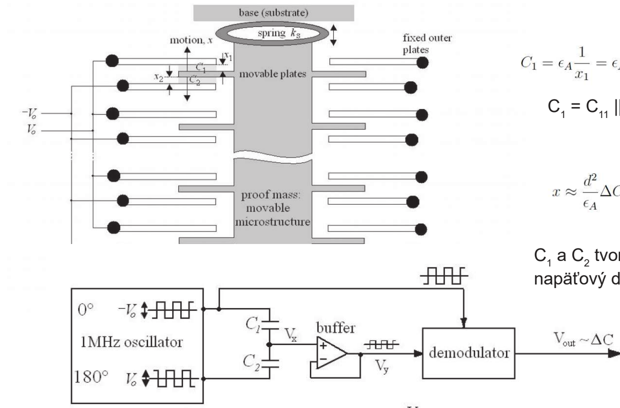
9. 4. Meranie zrýchlenia

MEMS akcelerometer



9. 4. Meranie zrýchlenia

MEMS akcelerometer



$$C_1 = \epsilon_A \frac{1}{x_1} = \epsilon_A \frac{1}{d+x} = C_0 - \Delta C,$$

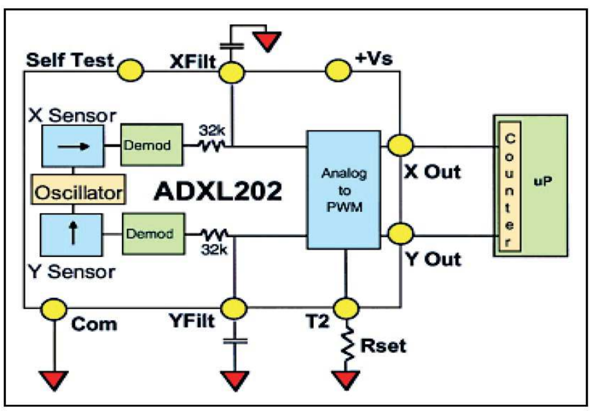
$C_1 = C_{11} \parallel C_{12} \parallel \ldots \parallel C_{1n}$

$$x \approx \frac{d^2}{\epsilon_A}\Delta C = d\frac{\Delta C}{C_0}$$

C_1 a C_2 tvoria impedančný napäťový delič

9. 4. Meranie zrýchlenia

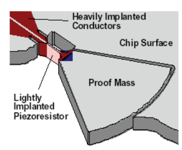
MEMS akcelerometer

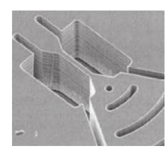


9. 4. Meranie zrýchlenia

MEMS akcelerometer

- Piezoresistive MEMS accelerometer
  - Operating Principle: a proof mass attached to a silicon housing through a short flexural element. The implantation of a piezoresistive material on the upper surface of the flexural element. The strain experienced by a piezoresistive material causes a position change of its internal atoms, resulting in the change of its electrical resistance
  - low-noise property at high frequencies

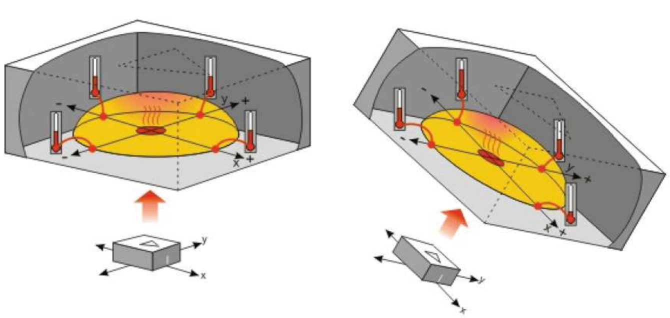


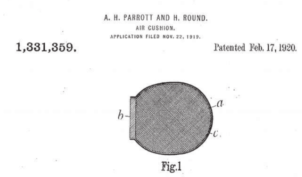


Courtesy of JP Lynch, U Mich.

9. 4. Meranie zrýchlenia

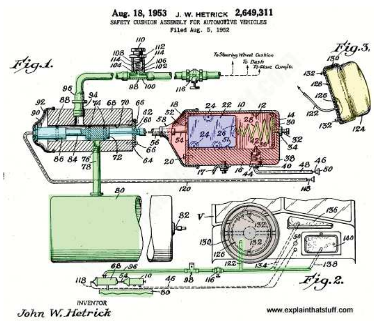
MEMS MX2125 hot bubble





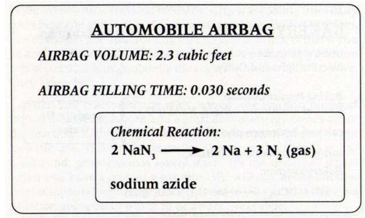
United States patent submitted in 1919 by two dentists, **Harold Round** & **Arthur Parrott** of Birmingham, England

John Hetrick's original airbag design from 1953



Allen K. Breed (1927–2000), who developed a variety of different ways of triggering the explosion of gas inside an airbag just before the impact of a crash.

Bellis, Mary. "The History of Airbags." ThoughtCo, Feb. 11, 2020, thoughtco.com/history-of-airbags-1991232.



AUTOMOBILE AIRBAG

AIRBAG VOLUME: 2.3 cubic feet

AIRBAG FILLING TIME: 0.030 seconds

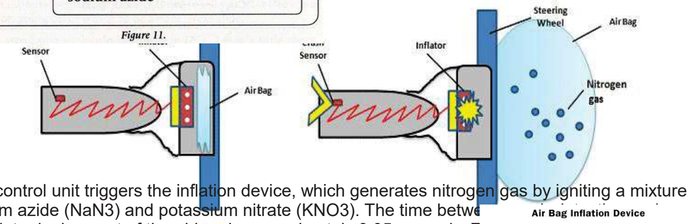
Chemical Reaction:

$2\ NaN_3 \longrightarrow 2\ Na + 3\ N_2$ (gas)

sodium azide

Figure 11.

Gas-Generator Reaction	Reactants	Products
First Reaction (Triggered by Sensor)	NaN_3	Na N_2 (g)
Second Reaction.	Na KNO_3	K_2O Na_2O N_2 (g)
Final Reaction.	K_2O Na_2O SiO_2	alkaline silicate (glass)

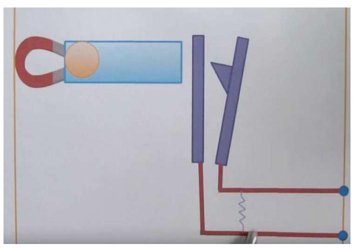


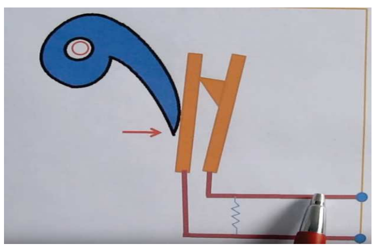
This control unit triggers the inflation device, which generates nitrogen gas by igniting a mixture of sodium azide (NaN3) and potassium nitrate (KNO3). The time betwe… complete deployment of the airbag is approximately 0.05 seconds. T… mph, which itself can be harmful in certain cases.

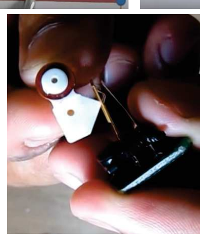
Most systems use a weight sensor in the front passenger seat to det… If it is not, the passenger airbag will not deploy. The weight sensor c… children and adults who may be occupying the seat.

https://cecas.clemson.edu/cvel/auto/systems/airbag_deployment.h
http://allaboutairbagdeployment.weebly.com/part-three.html

Mechanické







Mechanické

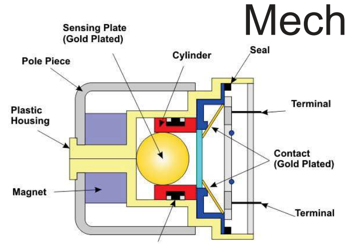


Figure 1. Structural components to an Inertia sensor. Source: Duffy, J.E. (2001). I-Car Professional Automotive Collision Repair. New York: Delmar, a division of Thomas Learning.

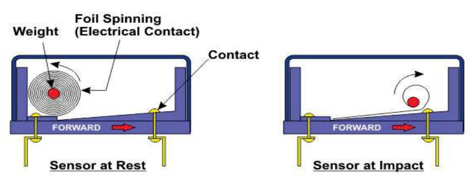
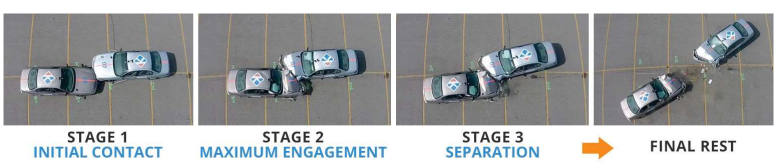
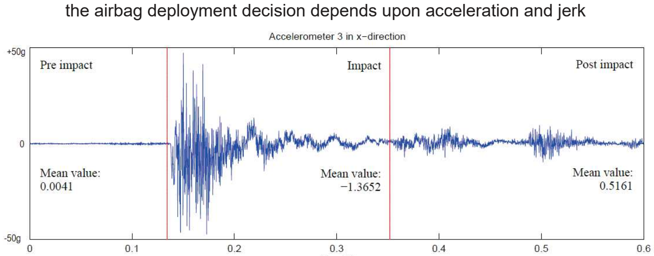


Figure 2. Functional principle to a typical roller type airbag sensor. Source: Erjavec, J. (2010). Automotive Technology: A Systems Approach. New York: Delmar, Cengage Learning.

https://www.azosensors.com/article.aspx?ArticleID=40



the airbag deployment decision depends upon acceleration and jerk



Airbagy – deploy or not deploy?