

Sila a zrýchlenie

Richard Balogh: Sila a zrýchlenie. Prednáška z predmetu MEMS Inteligentné senzory a aktuátory, 21. 4. 2020

9.3. Snímače sily

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

9.3. Snímače sily - aplikácie

9.3. Snímače sily - aplikácie

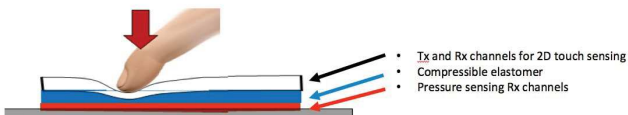
	ALF304 Brake Pedal Force Sensor Compact, low profile loadcell for measuring brake pedal application forces	Measurement Range 2.5kN	Accuracy [%] ±0.05% of F.S.	Output mV/V	Load direction Compression
	ALF305 Seat Belt Tension Force Sensor High performance loadcell for measuring seat belt tension forces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

9.3. Snímače sily - aplikácie

Force-sensing: A third dimension in automotive touch controls



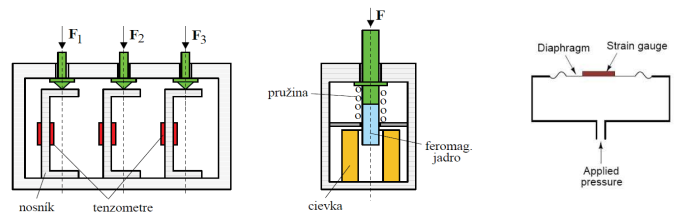
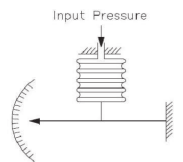
Synaptics demonstration of a steering wheel touchpad with force sensing and haptics.



9.3. Snímače sily Deformačné členy

Menia pôsobiacu silu na inú veličinu

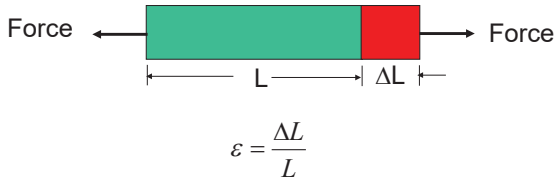
- **nosníky** → deformácia, tenzometre
- **pružiny** → zmena polohy, snímač polohy (indukčný, fotoelektrický)
- **pružné podložky** → zmena polohy



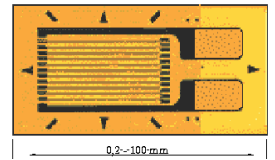
9.3.1 Deformačné členy

Tenzometer – Strain Gauge

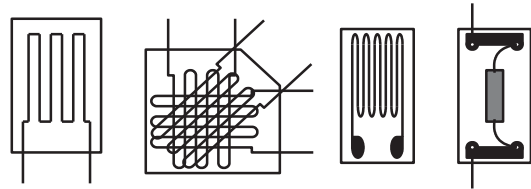
Definition of strain, ε



Tenzometre



a



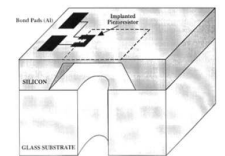
Tenzometre

Tab.1 Prehľad vlastností nalepených tenzometrov

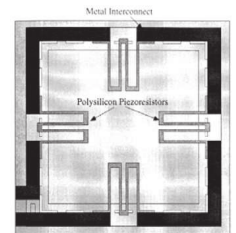
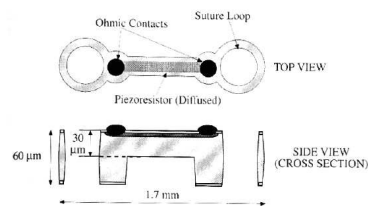
Tenzometre	Fóliové	Polovodičový	
Typ	KFC-2-D1-23 (R _C)	KFC-5-350-C1-23 (R _{SA} , R _{SB} , R _{SE})	KSP-2-E3 (R _{SD})
Odpor R [Ω]	119.9±0.4	350±0.6	110±2%
Súčiniteľ deformačnej citlivosti K	2.11	2.1±1%	124±3%
Teplotný súčiniteľ deformačnej citlivosti α _{0,0} [1/°C]	≈ 0	≈ 0	0.14%
Teplotný súčiniteľ elektrického odporu α _{0,0} [μm/m/°C, tj. %/°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 predženie ε [μm/m]	±3000	±3000	±2000
Dĺžka aktívnej mriežky [mm]	2	5	2
Poznámka	tepelná kompenzácia pre namáhaný materiál-hliník (23 μm/m/°C)	tepelná kompenzácia pre namáhaný materiál-hliník (23 μm/m/°C)	

Membrane type gauges: typical pressure sensor

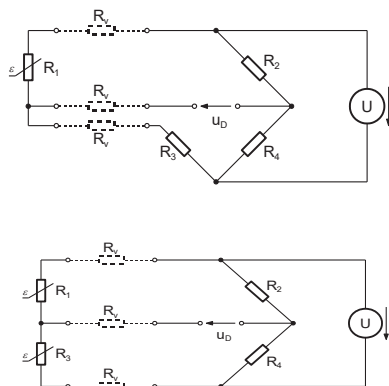
MEMS Tenzometre



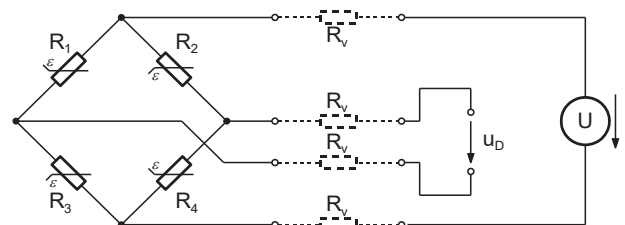
Implantable strain gauge



Tenzometre



Tenzometre



Využitie tenzometrov Sila

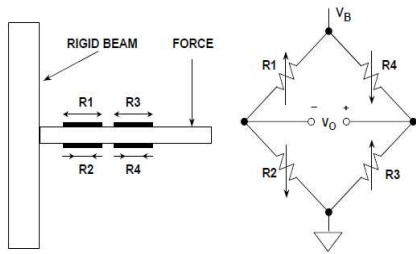


Figure 3.83: A beam force sensor using a strain gage bridge

Využitie tenzometrov Vázenie



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	$C = \frac{\epsilon_r \cdot \epsilon_0 \cdot A}{d}$	$C = \frac{2\pi \epsilon_r \cdot \epsilon_0 \cdot l}{\ln(r_2/r_1)}$	$C = \frac{4\pi \epsilon_r \cdot \epsilon_0 \cdot r_1 \cdot r_2}{r_2 - r_1}$

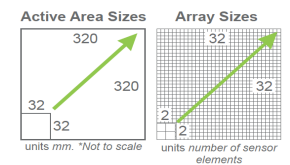
9.3. Snímače sily Kapacitné snímače

PPS - TactArray



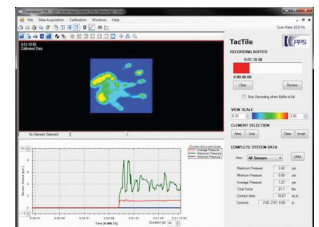
CTA's are flexible and can be molded over complex shapes like a head

SENSOR MODELS & METRICS



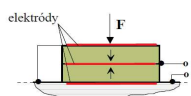
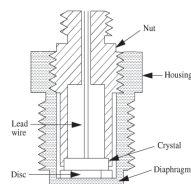
Sensor Characteristics & Performance*

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)

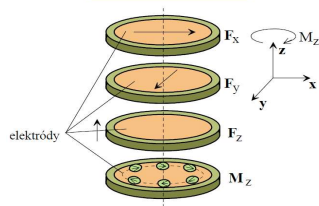
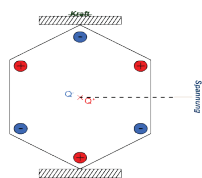


9.3. Snímače sily Piezoelektrické snímače

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

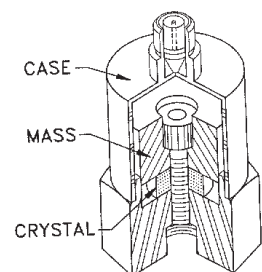
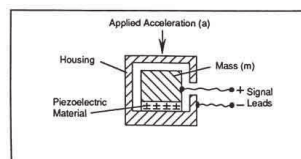


→ vektor polarizácie

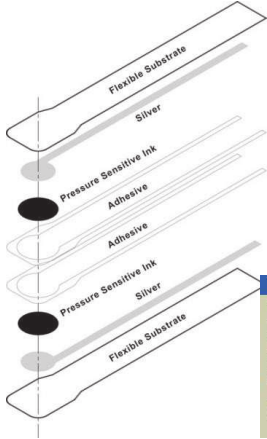


9.3. Snímače sily zrýchlenia Piezoelektrické snímače

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



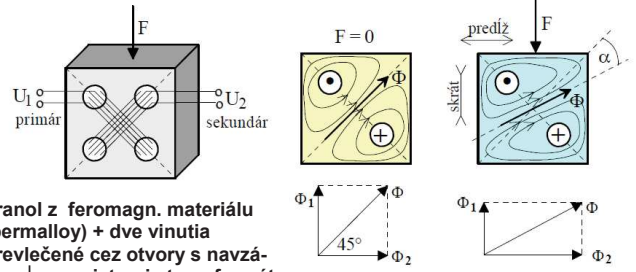
9.3. Snímače sily Piezoelektrické snímače



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

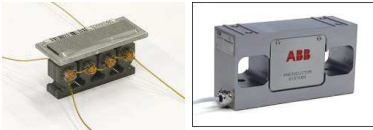
bez pôsobenia sily sekundár neviaže žiadny mag. tok, U2 je nulové

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

9.3. Snímače sily Magnetoanizotropné snímače

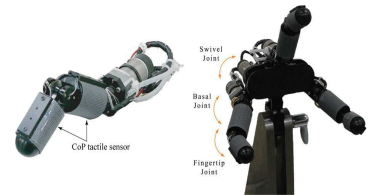
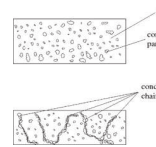
snímač pre F = 5000 kN
(fy ASEA Švédsko)

- 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 stlačení
Miera stlačenia úmerná sile (niekedy pomocná pružina)

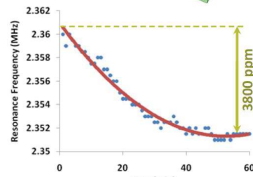
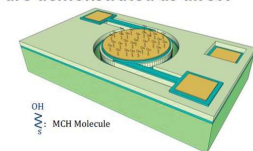
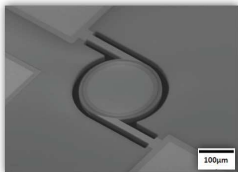
Poznámka: Materiály majú značnú časovú a teplotnú chybu



9.3.2 Rezonančné snímače sily Detekcia DNA

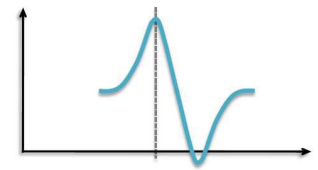
Piezoelectric Disk Resonators for Direct Molecular Sensing

- 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

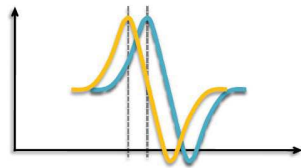
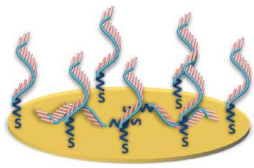


Blank gold surface

- (I) Treatment with HS-ssDNA (2.0 µM/1.0 M KH₂PO₄, 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

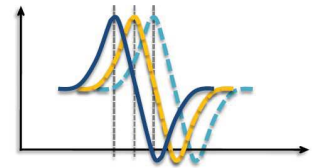
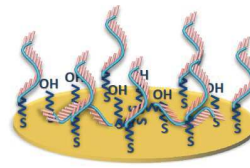


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Experiments and Results

DNA Detection Mechanism



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9.4. Snímače zrýchlenia

$$a = \lim_{\Delta t \rightarrow 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

SI jednotka je **m/s²**

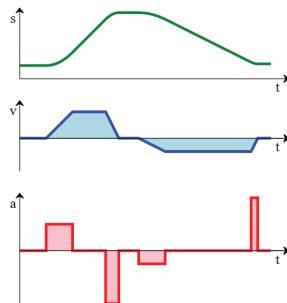
$$F = m \cdot a$$

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

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

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

9,764 – 9,834 m/s²

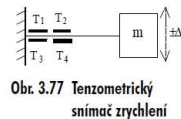


Zdola nahor: časový priebeh zrýchlenia $a(t)$, integrál zrýchlenia je rýchlosť $v(t)$, a integrovaním rýchlosti získame priebeh dráhy $s(t)$.

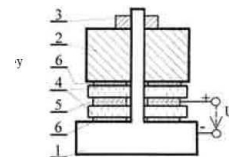
9.4. Snímače zrýchlenia

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

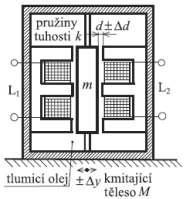
Pri známej hmotnosti telesa m je sila F merítkom zrýchlenia a .



Obr. 3.77 Tenzometrický snímač zrýchlení

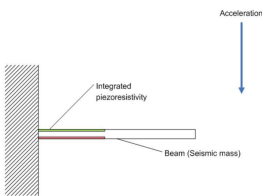


Obr. 3.78b Piezoelektrický tlakový snímač zrýchlení

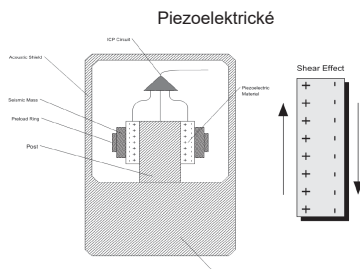


Obr. 3.79 Indukčnosťný snímač zrýchlení

9.4. Snímače zrýchlenia – akcelerometre



Piezorezistívne



9.4. Meranie zrýchlenia

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



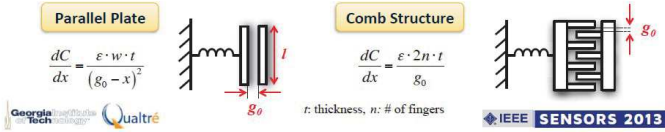
9. 4. Meranie zrýchlenia

Electromechanical Transduction

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

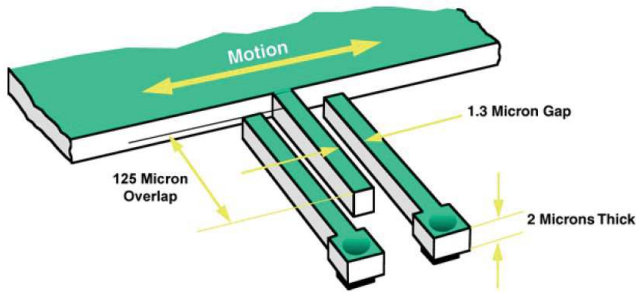


- Most popular: electrostatic (capacitive) sensing



9. 4. Meranie zrýchlenia

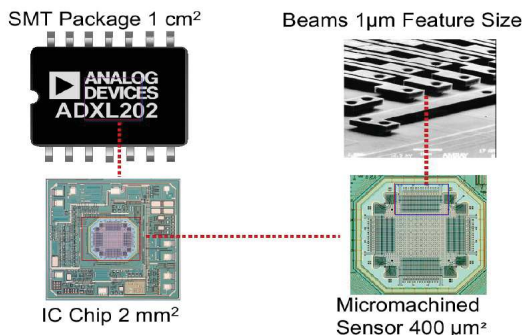
MEMS akcelerometer



9. 4. Meranie zrýchlenia

MEMS akcelerometer

ADXL 202: acceleration sensor



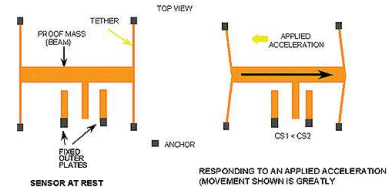
9. 4. Meranie zrýchlenia

MEMS akcelerometer

ADXL202: ±2 g Dual Axis Accelerometer

Features

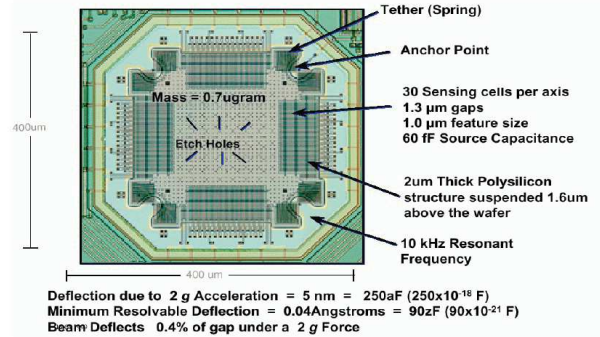
- X and Y Axis on a single chip = Small size and lower cost
- 250µA per Axis = Low power battery operation
- 3.0V to 5.0V Operation = Low power battery operation
- Surface mount package = Small size and ease of use
- High resolution PWM converter = Direct interface to micro (No A/D)
- iMEMS = Low cost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



9. 4. Meranie zrýchlenia

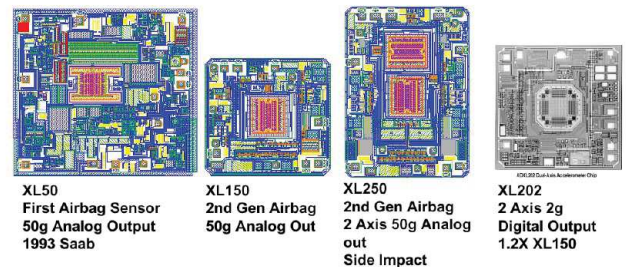
MEMS akcelerometer

ADXL 202: Micromachined Beam



9. 4. Meranie zrýchlenia

MEMS akcelerometer

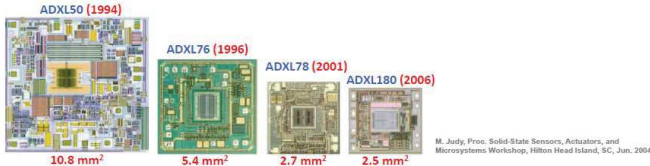


9. 4. Meranie zrýchlenia

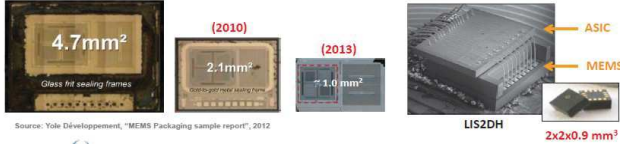
3

Evolution of MEMS Accelerometers

- Analog Devices Accelerometer (Automotive)

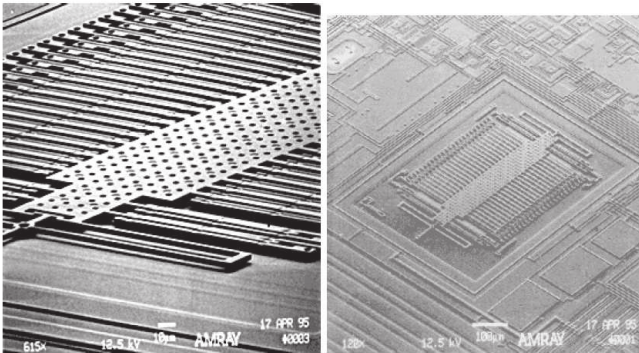
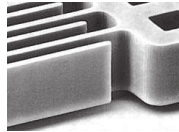


- STMicroelectronics Accelerometer (Consumer) (2008)



9. 4. Meranie zrýchlenia

MEMS akcelerometer

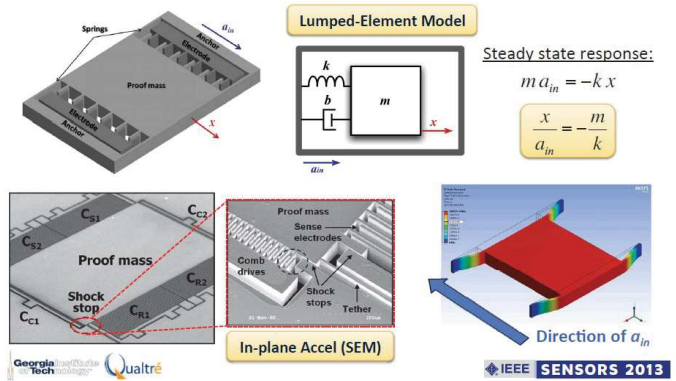


9. 4. Meranie zrýchlenia

6

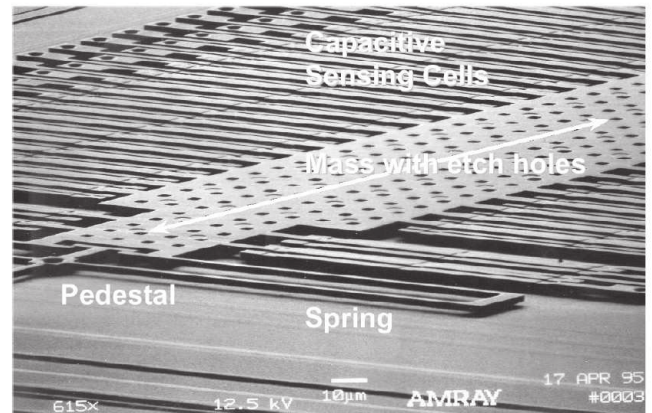
MEMS Capacitive Accelerometers

- Conventional MEMS accelerometer architecture



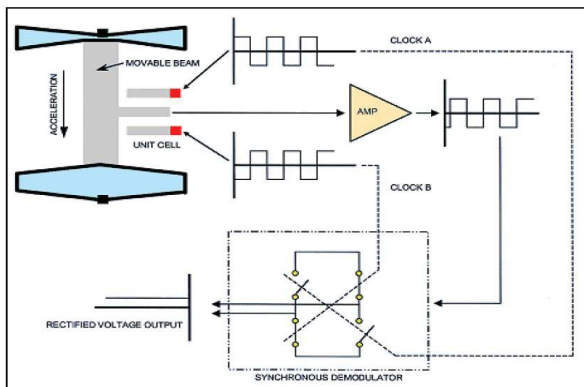
9. 4. Meranie zrýchlenia

MEMS akcelerometer



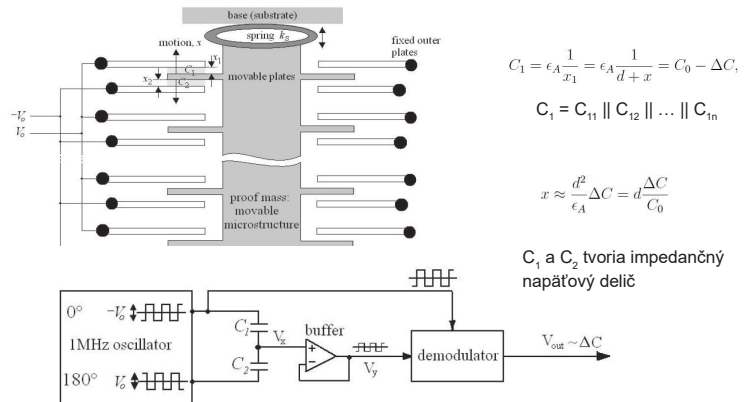
9. 4. Meranie zrýchlenia

MEMS akcelerometer



9. 4. Meranie zrýchlenia

MEMS akcelerometer



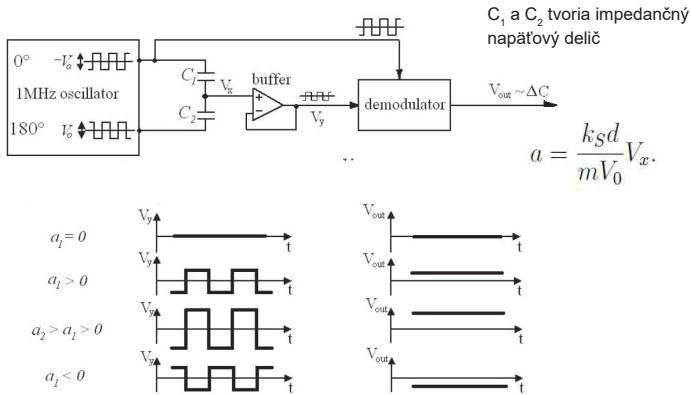
$$C_1 = \epsilon_A \frac{1}{x_1} = \epsilon_A \frac{1}{d+x} = C_0 - \Delta C,$$

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

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

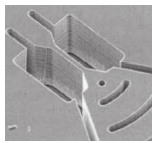
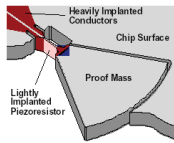
C_1 a C_2 tvoria impedančný napätový delič

9. 4. Meranie zrýchlenia MEMS akcelerometer



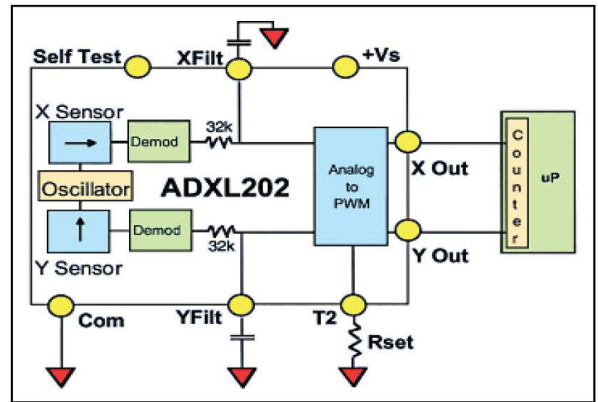
9. 4. Meranie zrýchlenia MEMS akcelerometer

- 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

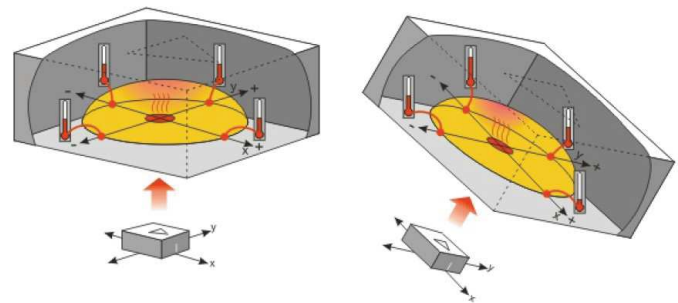


Courtesy of JP Lynch, U Mich.

9. 4. Meranie zrýchlenia MEMS akcelerometer



9. 4. Meranie zrýchlenia MEMS MX2125 hot bubble



1,331,359. A. H. PARROTT AND H. ROUND. AIR CUSHION. APPLICATION FILED MAR. 22, 1914. Patented Feb. 17, 1920.



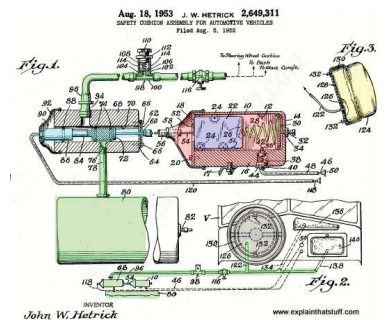
Fig. 1



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.



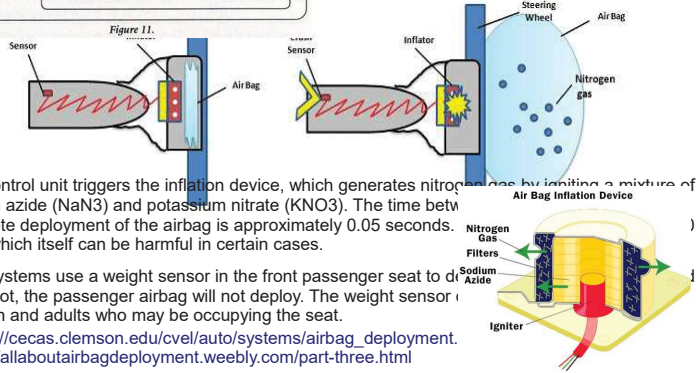
Bellis, Mary. "The History of Airbags." ThoughtCo, Feb. 11, 2020, thoughtco.com/history-of-airbags-1991232.

John W. Hetrick www.explainthatstuff.com

AUTOMOBILE AIRBAG
AIRBAG VOLUME: 2.3 cubic feet
AIRBAG FILLING TIME: 0.030 seconds

Chemical Reaction:
 $2 \text{NaN}_3 \rightarrow 2 \text{Na} + 3 \text{N}_2 \text{ (gas)}$
sodium azide

Gas-Generator Reaction	Reactants	Products
First Reaction (Triggered by Sensor)	NaN_3	Na $\text{N}_2 \text{ (g)}$
Second Reaction	Na KNO_3	K_2O Na_2O $\text{N}_2 \text{ (g)}$
Final Reaction	K_2O Na_2O SiO_2	alkaline silicate (glass)

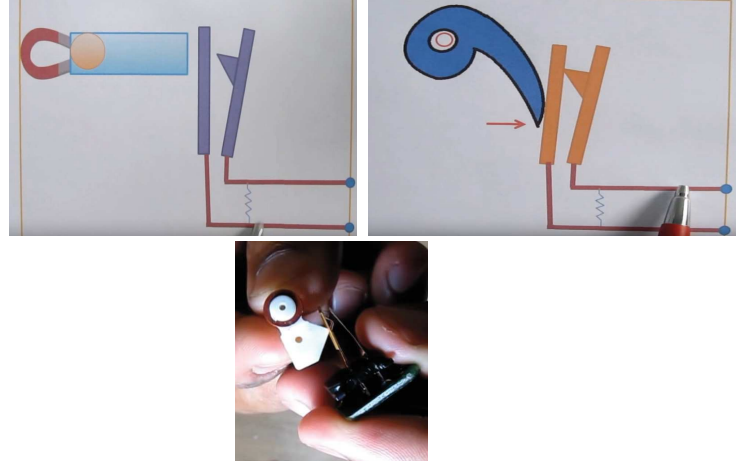


This control unit triggers the inflation device, which generates nitrogen gas by igniting a mixture of sodium azide (NaN_3) and potassium nitrate (KNO_3). The time between complete deployment of the airbag is approximately 0.05 seconds. The time to reach 50 mph, which itself can be harmful in certain cases.

Most systems use a weight sensor in the front passenger seat to determine if it is not, the passenger airbag will not deploy. The weight sensor is designed to detect children and adults who may be occupying the seat.

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

Mechanické



Mechanické

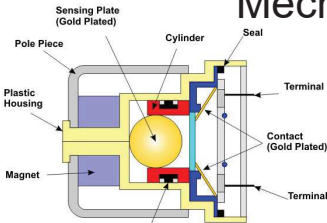


Figure 1. Structural components to an Inertia sensor. Source: Duffy, J.E. (2001). I-Car Professional Automotive Collision Repair. New York: Delmar, a division of Thomas Learning.

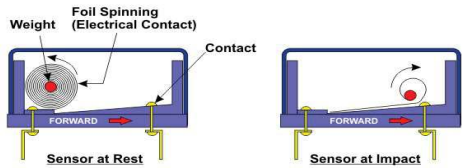
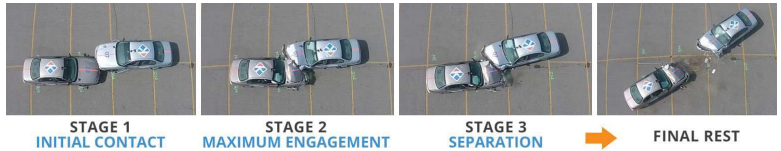
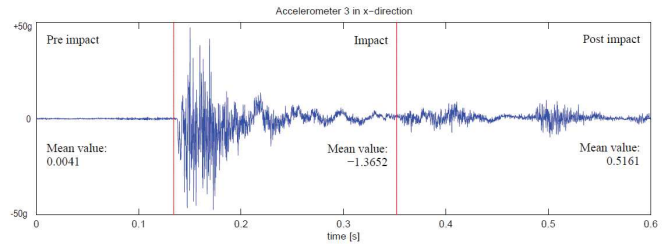


Figure 2. Functional principle to a typical roller type airbag sensor. Source: Erjavec, J. (2010). Automotive Technology: A Systems Approach. New York: Delmar, Cengage Learning.

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



the airbag deployment decision depends upon acceleration and jerk



Airbagy – deploy or not deploy?

Longitudinal Speed, Acceleration & Jerk
 Offset Head-on Crash Test - Bullet Vehicle (2016 Crash Test #2)

