

5. SENZORI UBRZANJA I VIBRACIJA

5.1. Merne promenljive i merni principi

- Senzori ubrzanja pogodni su za primenu kod sistema:
 - **Kontrole detonativnog sagorevanja**
 - **Zaštite putnika**
 - *vazdušni jastuci, zatezači pojaseva.*
 - *aktivni sistemi za zaštitu pri prevrtanju vozila*
 - *inercioni zatezači pojaseva*
 - **ABS, ESP, HHC**
 - **Kontrole šasije i oslanjanja**
 - **Alarmne zaštite**
- Svi senzori ubrzanja zasnivaju se na drugom Njutnovom zakonu, po kome je ubrzanje ***a***, koje telo mase ***m*** ostvaruje, direktno srazmerno sili ***F*** koja na telo deluje, a obrnuto srazmerno masi tela ***m***.

$$F = m \cdot a$$

Merne promenljive i merni principi

1 Measuring range of acceleration sensors

Applications	Measuring range
Knock control	40 g
Passenger protection	
– Airbag, seat-belt pretensioner	35 to 100 g
– Side impact, front sensing	100 to 400 g
– Roll-over detection	3 to 7 g
ESP, HHC, ABS	0.8 to 1.8 g
Chassis and suspension control	
– Design	1 g
– Axle/damper	10 to 20 g
Car alarm	1 g

Izmerena promenljiva je ubrzanje a , koja se često navodi kao višekratnik gravitacionog ubrzanja g ($1 g \approx 9,81 \text{ m/s}^2$).

Table 1

g Acceleration
due to gravity

$1 g \approx 9.81 \text{ m/s}^2$

HHC Hill hold control

ABS Antilock brake
system

ESP Electronic stability
program

Merne promenljive i merni principi

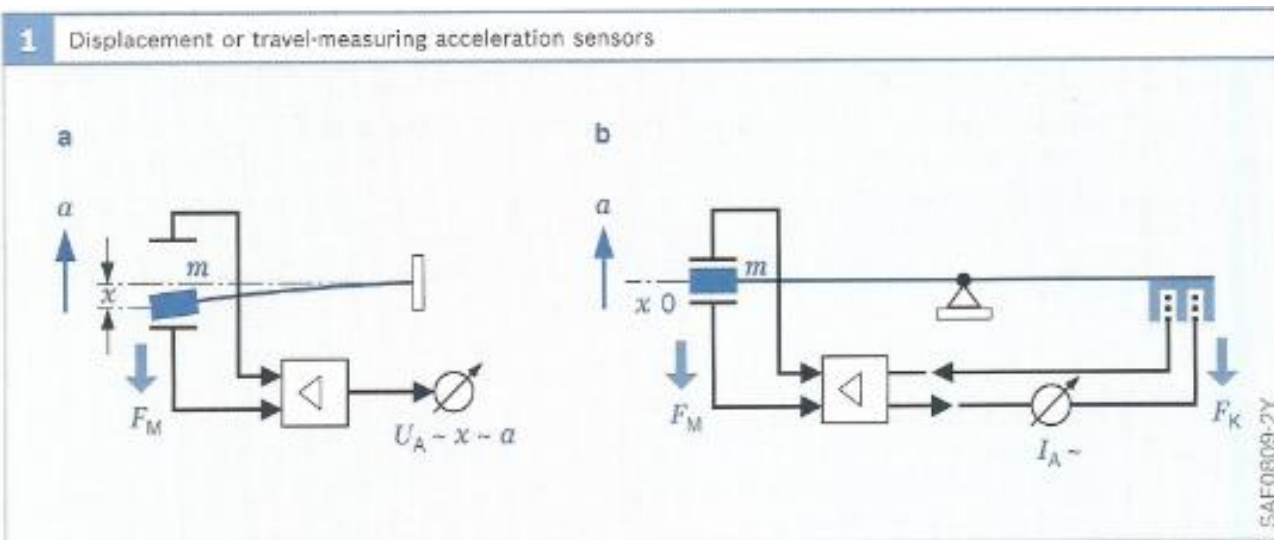


Fig. 1

Schematic:

- a Excursion-measuring
- b Closed-loop position controlled
- a Measured acceleration
- x System excursion
- F_M Measuring force (inertial force on the mass m)
- F_K Compensating force
- I_A Output current
- U_A Output voltage

- Kao i u slučaju merenja sile, koriste se pozicioni sistemi i mehanički merni sistemi naprezanja.
- Pozicioni merni sistemi koriste kompenzacioni metod u kojem pobudni sistem izložen ubrzanju biva kompenzovan ekvivalentom silom, tako da sistem praktično uvek ostaje u blizini nulte tačke, koju karakteriše visoka linearnost, minimalna poprečna osetljivost i visoka temperaturna stabilnost.
- U cilju kompenzacije gravitacionog ubrzanja, svi senzori ubrzanja karakterišu se opružnom koncepcijom, pri čemu je inerciona masa elastično spojena sa telom čije se ubrzanje meri.
- To znači da je u stanju statičke ravnoteže, sila ubrzanja jednaka sili opruge, koja je istegnuta za dužinu x .

Merne promenljive i merni principi

$$(1) \quad F = m \cdot a$$

$$(2) \quad F = m \cdot a = c \cdot x$$

$$(3) \quad S = x/a = m/c$$

$$(4) \quad F = m \cdot a = c \cdot x + p \cdot \dot{x} + m \cdot \ddot{x}$$

$$(5) \quad \omega_0 = \sqrt{\frac{c}{m}}$$

$$(6) \quad \omega_0^2 \cdot S = 1$$

$$(7) \quad D = \frac{p}{2 \cdot c} \cdot \omega_0 = \frac{p}{2 \cdot \sqrt{c \cdot m}}$$

Merne promenljive i merni principi

2 Measuring principles			
Electrical pick-off	Principle	Technical implementation	Examples of application
Piezoresistive	Stress measurement via the change in resistance as a result of elongation caused by acceleration on the spring-mass system	Silicon volume micromechanics, thin-layer systems	Laboratory applications, previously also crash sensors
Piezoelectric	Charge shifts in the crystal as a result of the force applied (spring-mass system)	Ceramic material, PZT, quartz, PVDF	Knock sensors, previously also crash sensors
Capacitive	Excursion of the spring-mass system is determined through capacitance measurement of a plate capacitor	Silicon volume micromechanics, surface micromechanics	Used throughout the motor vehicle
Thermal	Lateral excursion of a heated gas zone and detection of the asymmetry with respect to the heated zone	Volume micromechanics	Rollover sensing

Merne promenljive i merni principi

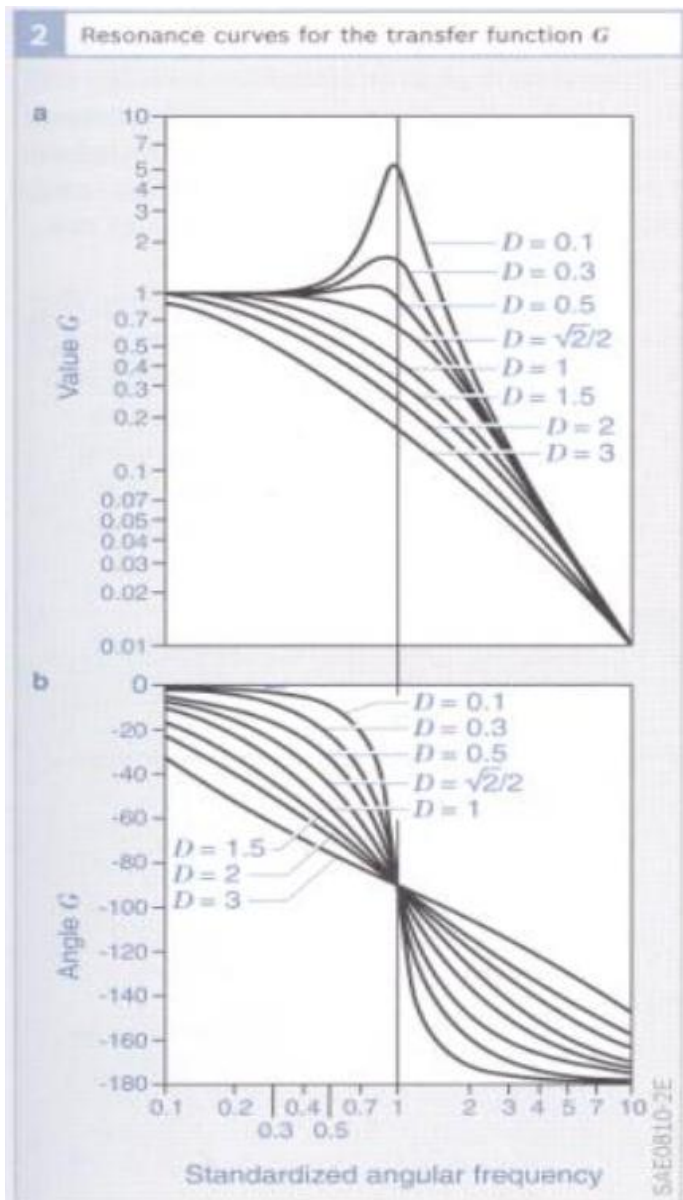


Fig. 2

a Amplitude resonance curve

b Phase resonance curve of the complex transfer function $G(i\Omega) = [x(i\Omega)]/[a(i\Omega)]$

$x(i\Omega)$

Deflection amplitude

$a(i\Omega)$

Acceleration excitement amplitude

$\Omega = \omega/\omega_0$

Standardized circular frequency

D Damping

- Ukoliko se zanemari trenje ($p \approx 0$), rezonantna frekvencija sistema iznosi prema relaciji (5).
- Prema jednačinama (3) i (5), moguće je uspostaviti relaciju (6), na osnovu koje se može zaključiti da u području rada sistema ispod rezonantne frekvencije, za slučaj kada se rezonantna frekvencija dvostruko poveća, merna osetljivost biva smanjena četiri puta.
- Faktor prigušenja D definisan je jednačinom (7).
- U cilju dobijanja što šireg frekvencijskog područja rada, kompromisno rešenje postiže se za vrednosti faktora prigušenja u opsegu $D = 0,5 - 0,7$.

Sistemi za merenje mehaničkog naprezanja

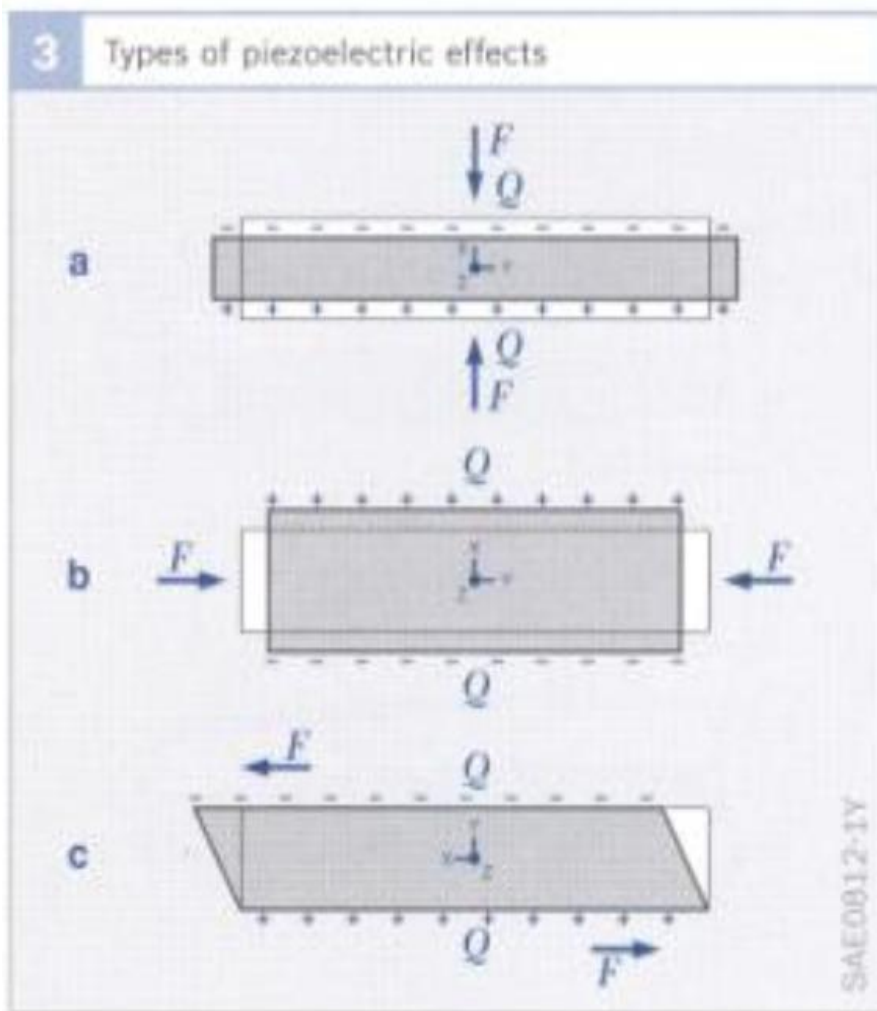


Fig. 3

a Longitudinal effect

b Transverse effect

c Tangential force

F Force

Q Charge

Pijezoelektrični senzori se koriste u motornom vozilu u sensorima ubrzanja i sensorima ugaone brzine skretanja.

Princip uzdužnog efekta

Pod dejstvom sile F , pijezoelektrični materijali generišu naelektrisanje Q na njihovim površinama na koje su pričvršćene elektrode (slika 3). Ovo naelektrisanje je proporcionalno mehaničkom naprezanju izazvano silom F .

Poprečni efekat i efekat smicanja

Sistemi za merenje mehaničkog naprezanja

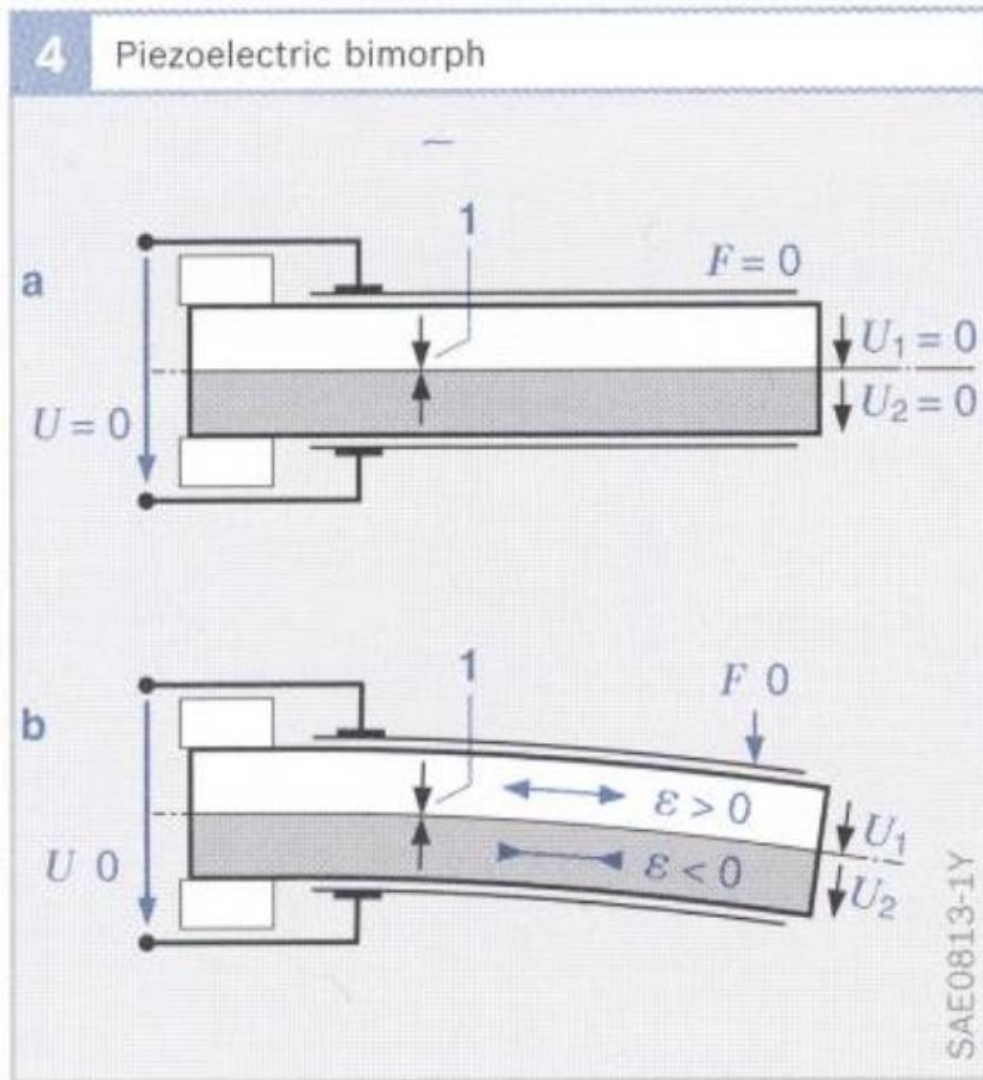


Fig. 4

- a Non-active state
- b When bent,
stretched on top
($\epsilon > 0$)
compressed below
($\epsilon < 0$)
- 1 Direction of
polarization
- F Measuring force
- U Total voltage
- U_1, U_2 Part voltages

Poprečni efekat se koristi na primer u **bimorfu**.

One se sastoje od dve suprotno polarizovane pijezeramike iskorišćene za merenje mehaničkih naprezanja.

5 Pick-off on piezoelectric sensors

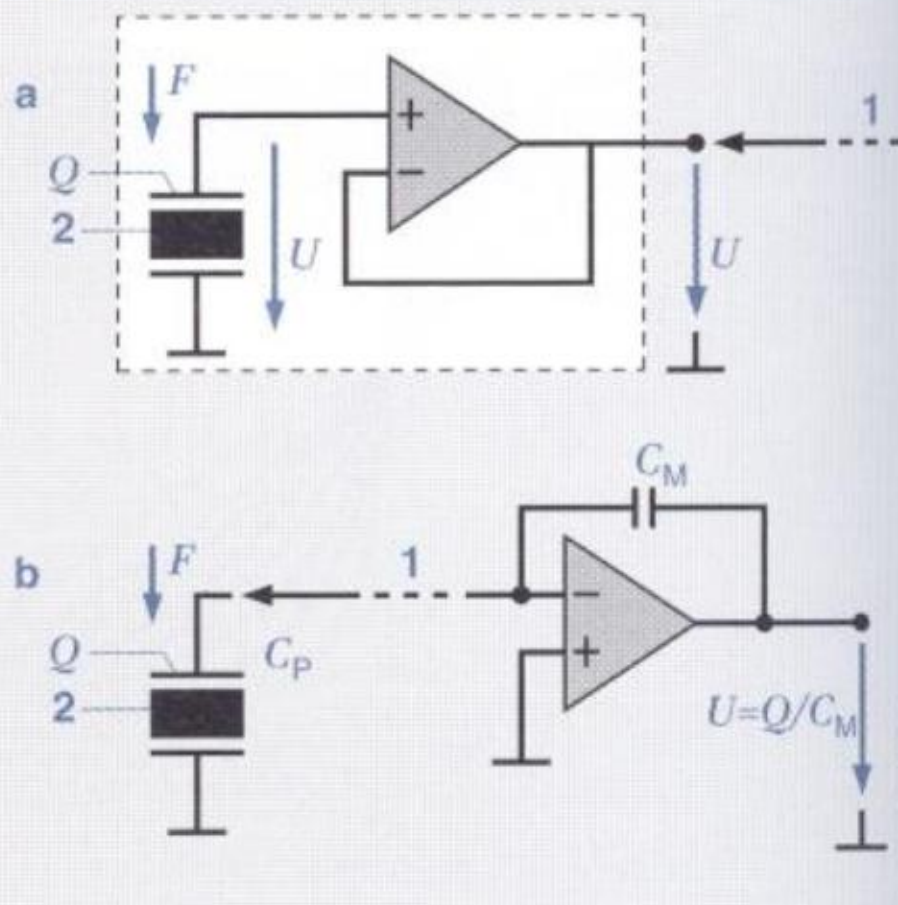


Fig. 5

a Voltage pick-off

b Charge pick-off

1 Supply lead

2 Piezoelectric specimen with capacitance C_p

C_M Measuring capacity

F Measuring force

Q Charge

U Voltage

Termički senzor ubrzanja

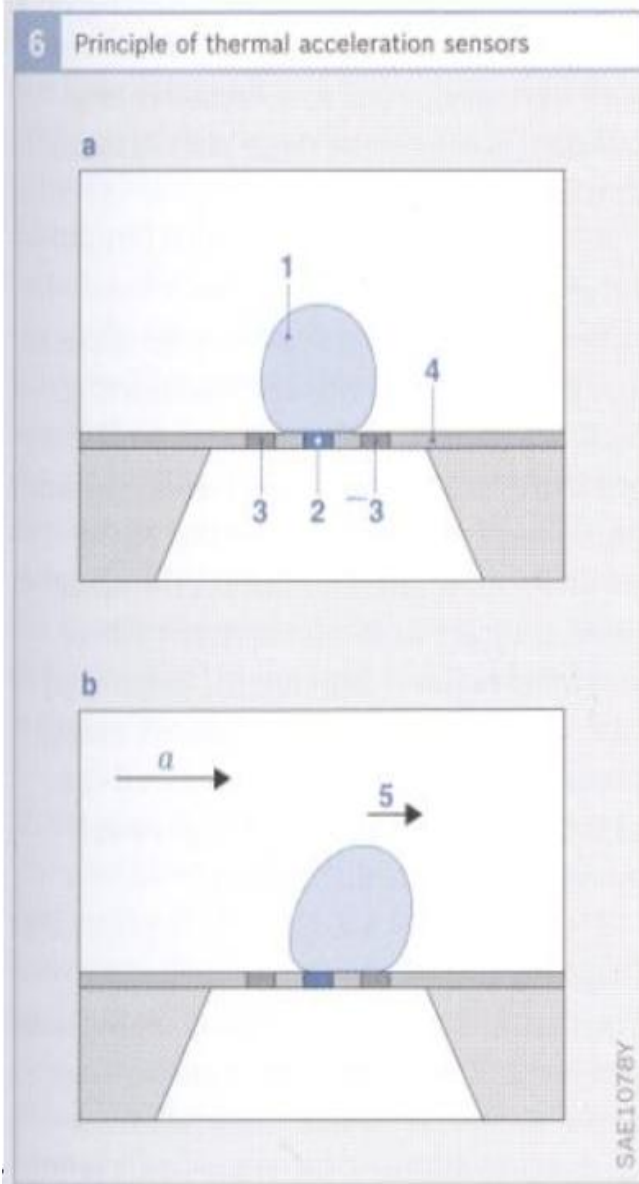


Fig. 6

a Acceleration $a = 0$

b Acceleration $a > 0$

1 Heated gas zone

2 Heater element

3 Temperature sensor

4 Substrate coating

5 Displaced heated zone

- Termički senzor ubrzanja pomoću grejača generiše "balon ugrijanog gasa".
- Taj mali tesni ugrijani prostor gasa ima veću gustinu od okolnog, hladnijeg gasa.
- U slučaju bočnog ubrzanja, oblast veće gustine gasa se pomera unutar okolnog, hladnijeg gasa.
- Asimetrija koja usledi detektuju termoelementi ili otpornici u mosnom kolu.
- Napon mosta predstavlja signal ubrzanja.

Pijezoelektrični senzor detonacije

2 Knock sensor (design and mounting)

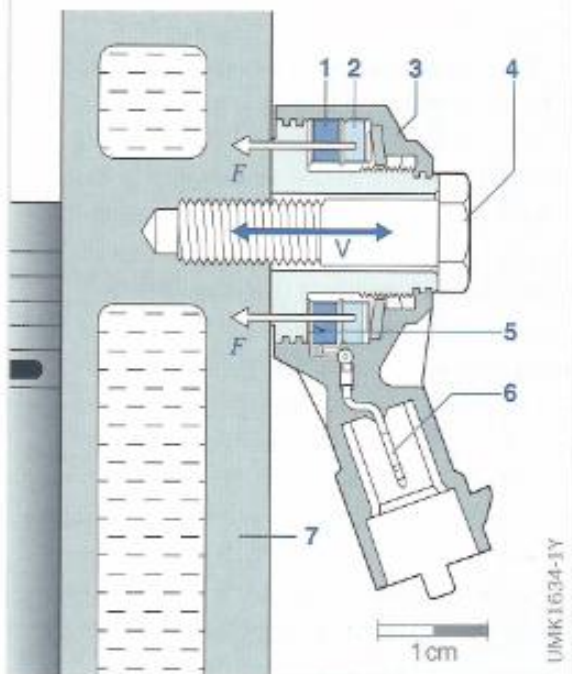


Fig. 2

- 1 Piezoceramic element
- 2 Seismic mass with compressive forces F
- 3 Housing
- 4 Bolt
- 5 Contact washer
- 6 Electric connection
- 7 Engine block
- V Vibration

1 Knock-sensor signals (oscilloscope display)

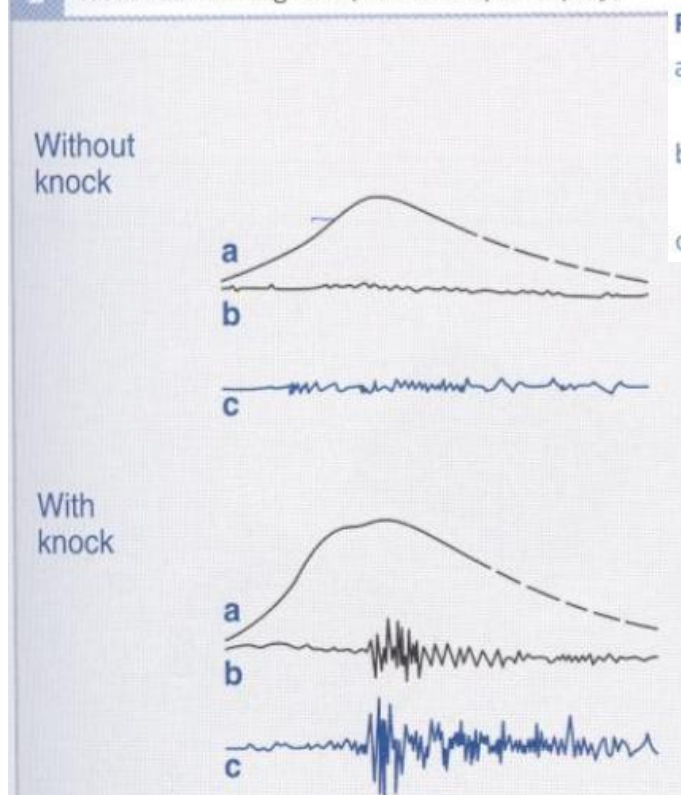


Fig. 1

- a Cylinder-pressure characteristic curve
- b Filtered pressure signal
- c Knock-sensor signal

Primenjuje se:

- na oto motorima za utvrđivanje detonativnog sagorevanja u cilindru, koje nastaje kao posledica nekontrolisanog paljenja smeše.
- kod dizel motora primenjuje se za praćenje kvaliteta sagorevanja po cilindrima.

Piezoelectric vibration sensor

Measurement of structure-borne sound and acceleration

Technical data

Permissible short-term vibration $\leq 400 \text{ g}$

Installation

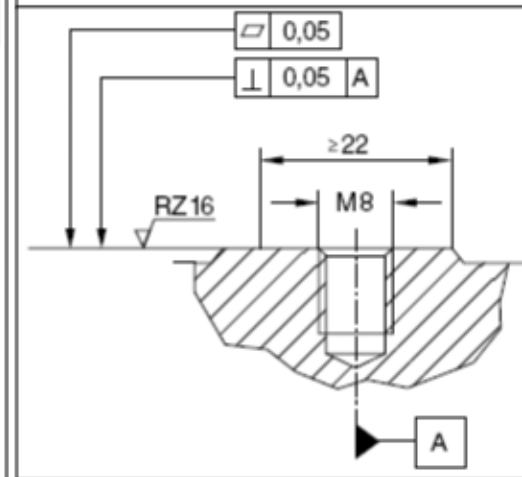
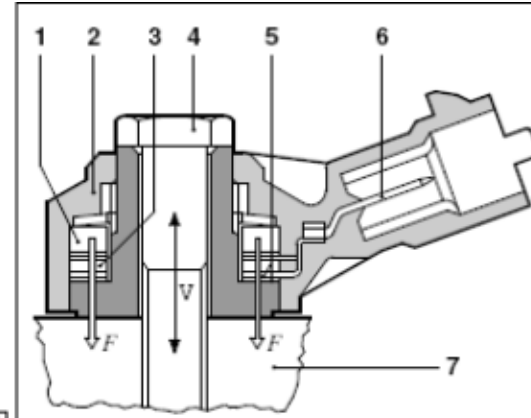
Grey cast iron bolt M 8 x 25 ; Quality 8.8
 Aluminium bolt M 8 x 30 ; Quality 8.8
 Tightening torque (possible with lubrication) $20 \pm 5 \text{ Nm}$

Technical data 0 261 231 148

Vibration sensors	2-pole, without cable
Frequency range	3 ... 22 kHz
Sensitivity at 5 kHz	$26 \pm 8 \text{ mV/g}$
Linearity between 5...20 kHz with resonance	15 %
Main resonance frequency	> 25 kHz
Self-impedance	> 1 M Ω
Capacitance range	800 ... 1400 pF
Temperature dependence of sensitivity	$\leq 0,06 \text{ mV/g} \cdot \text{K}$
Operating temperature range	- 40 ... + 150 °C
Permissible sustained vibration	$\leq 80 \text{ g}$

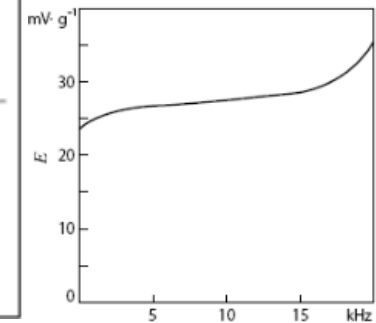
Installation

Installation position any



Pin 1, 2 Measurement signal
 Pin 3 Screen, dummy

1 Seismic element with compressive forces F
 2 Housing
 3 Piezoceramic element
 4 Screw
 5 Contact
 6 Electrical connection
 7 Machine block, V Vibration.



Obično se postavlja direktno na blok motora. U cilju što efektivnijeg merenja vibracija, prilikom montaže potrebno je ispuniti sledeće:

- Vijak za pričvršćenje treba zategnuti odgovarajućim momentom (obično između 18-22 Nm);
- Kontaktna površina bloka motora i navoj u bloku moraju imati potreban kvalitet obrade,
- Ne smeju se koristiti podloške.

Površinski mikromehanički (SMM) senzori ubrzanja

1 Surface micromechanical acceleration sensors for airbag triggering (example)

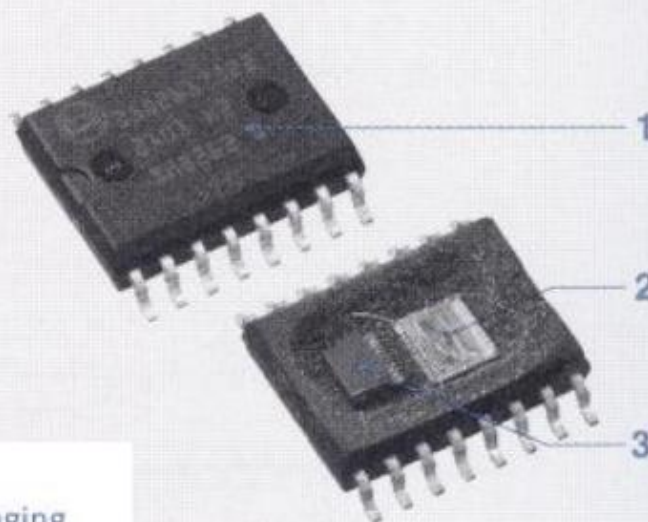
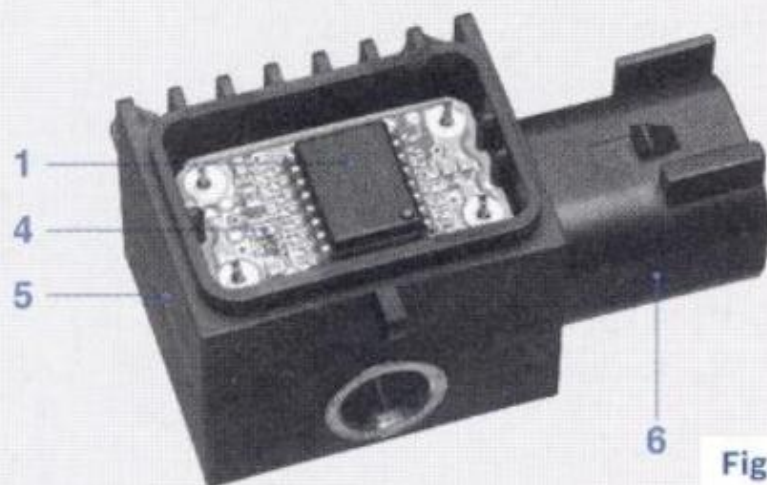


Fig. 1

- 1 First packaging stage (module) in SO16 housing
- 2 Evaluator chip (ASIC)
- 3 SMM sensor element
- 4 Populated PCB
- 5 Second packaging stage (device)

Površinski mikromehanički (SMM) senzori ubrzanja

2 Surface micromechanical acceleration sensors with capacitive pick-off

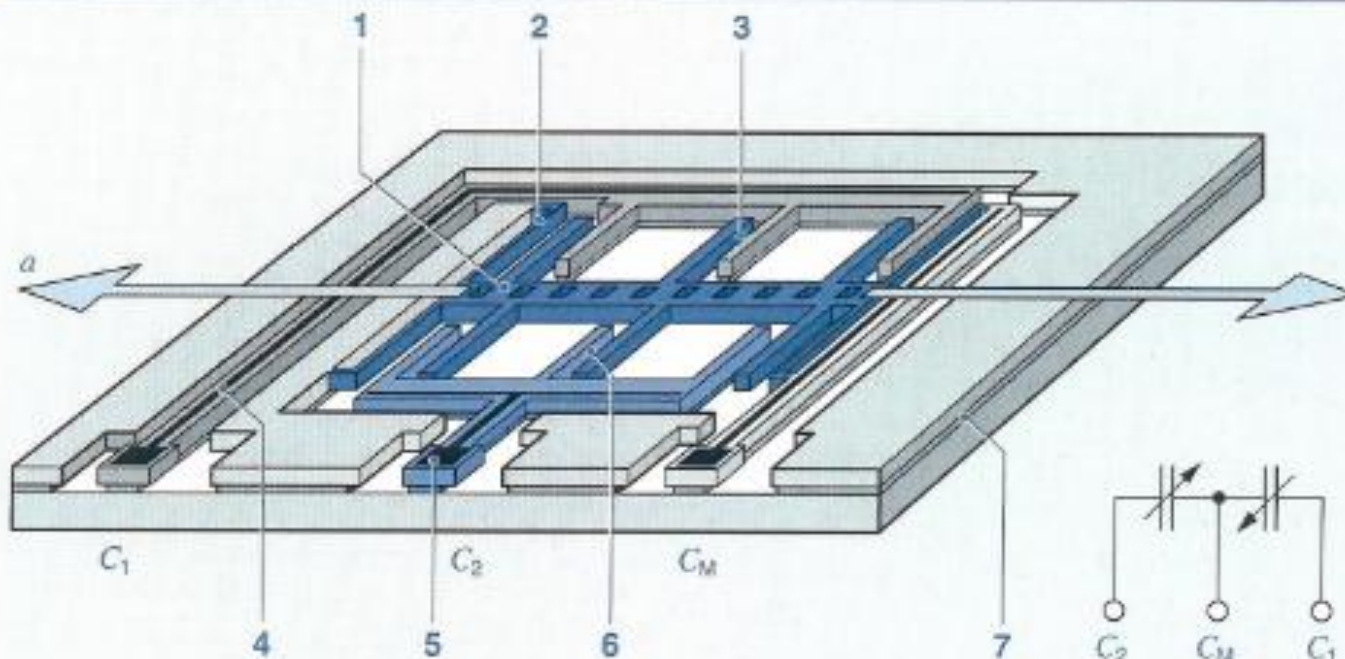


Fig. 2

- 1 Spring-mounted seismic mass with electrodes
- 2 Spring
- 3 Fixed electrodes with capacity C_1
- 4 Printed Al conductor track
- 5 Bond pad
- 6 Fixed electrodes with capacity C_2
- 7 Silicon oxide
- a Acceleration in the sensing direction
- C_M Measuring capacity

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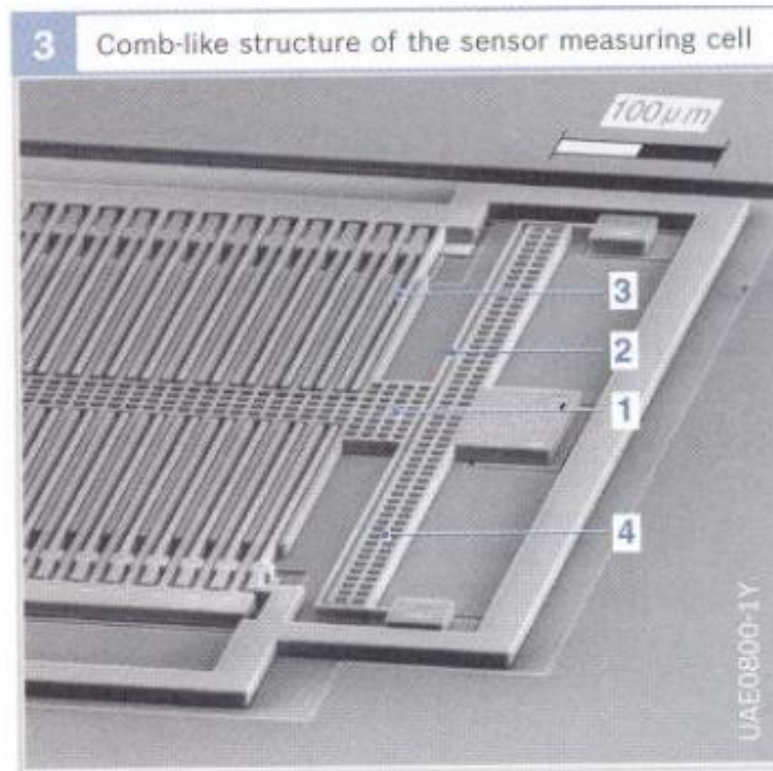


Fig. 3

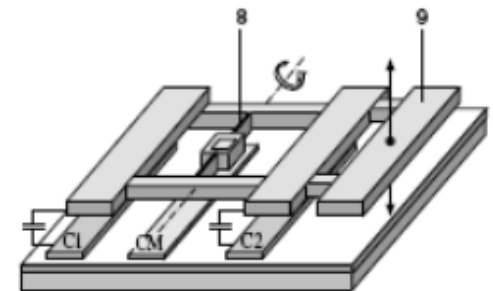
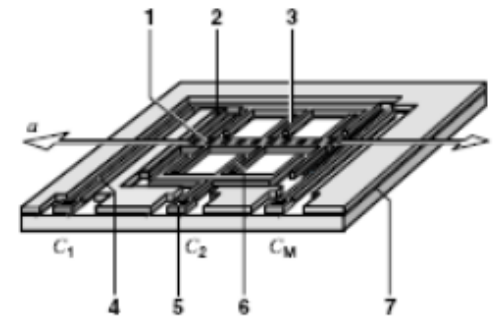
- 1 Spring-mounted seismic mass with electrode
- 2 Spring
- 3 Fixed electrodes
- 4 Anchor areas

Surface micromechanical acceleration sensor

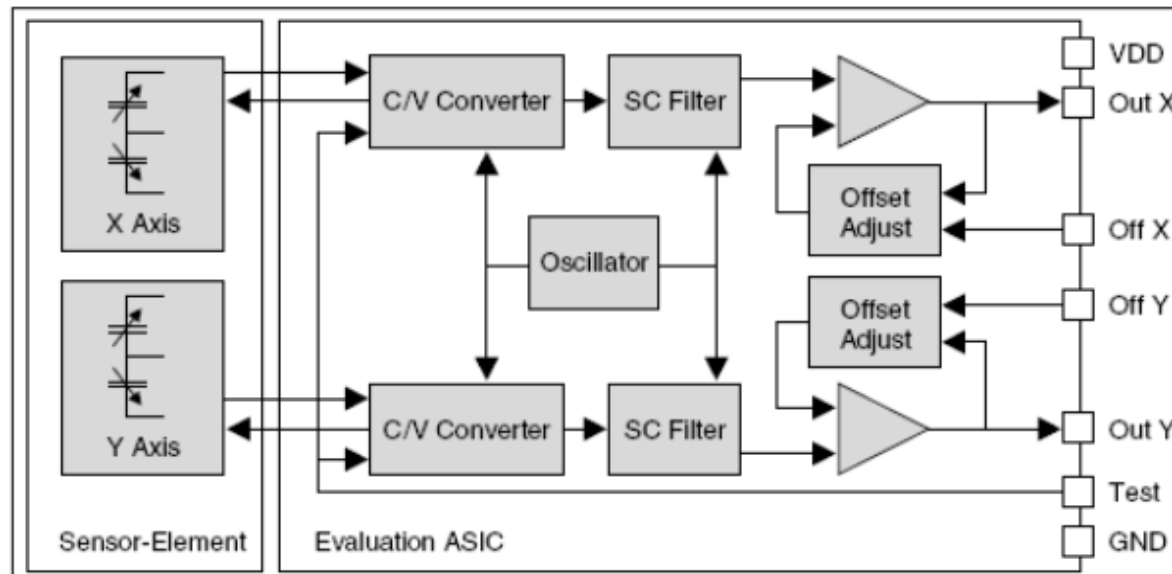
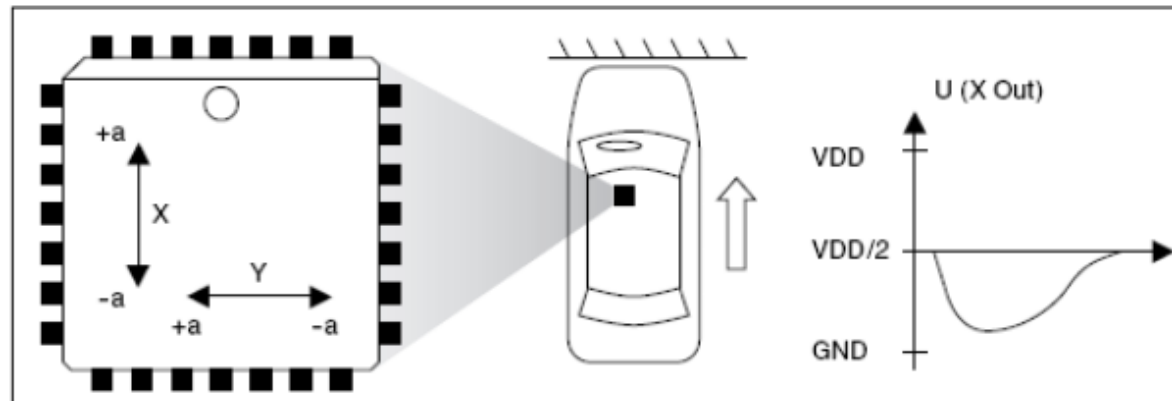
Measurement of ± 35 g or ± 50 g acceleration



a Acceleration ($g_n = 9.81 \text{ m/s}^2$)
 V_{DD} Supply voltage
 V_{off} Offset voltage
 S Sensitivity
 V_{cut} Output voltage
 $V_{cut} = (V_{DD}/2) + (V_{off} + S \cdot a) \cdot (V_{DD}/5V)$



- 1 Horizontally sprung seismic element with electrodes
- 2 Spring
- 3 Fixed electrodes with capacitance C_1
- 4 Al printed conductor
- 5 Bond pad
- 6 Fixed electrodes with capacitance C_2
- 7 Silicon oxide
- 8 Torsion spring
- 9 Vertically sprung seismic element with electrodes. a Acceleration in sensing direction, C_M Measurement capacitance. $a \sim (C_1 - C_2) / (C_1 + C_2)$



Silicijumski mikromehanički senzori ubrzanja

1 Bulk silicon acceleration sensor with capacitive pick-off (schematic diagram)

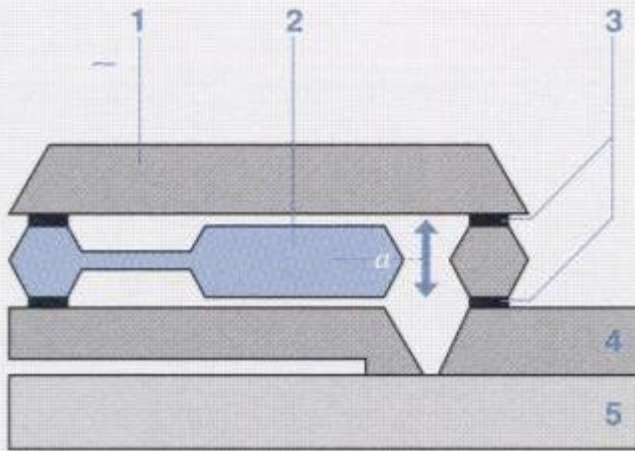
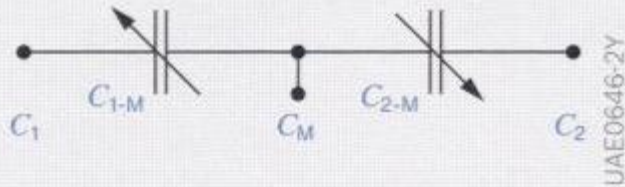


Fig. 1

- 1 Upper Si plate
- 2 Center Si plate (spring-held or seismic mass)
- 3 Si-oxide
- 4 Bottom Si plate
- 5 Glass substrate
- a Acceleration in the sensing direction
- C_M Measuring capacity



Pijezoelektrični senzor ubrzanja

1 Spring element in a piezoelectric acceleration sensor

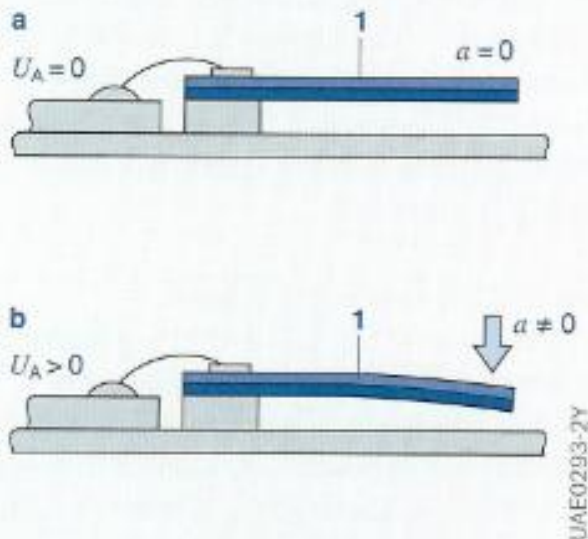


Fig. 1

- a Not under acceleration
- b Under acceleration a
- 1 Piezoceramic bimorphous spring element
- U_A Measurement voltage

- Pijezo-oscilatorni elementi ne zahtevaju dodatnu seizmičku masu.
- Njihova masa je prikladna za lako analiziranje signala.

2 Piezoelectric acceleration sensor (two channel sensor for PCB mounting)

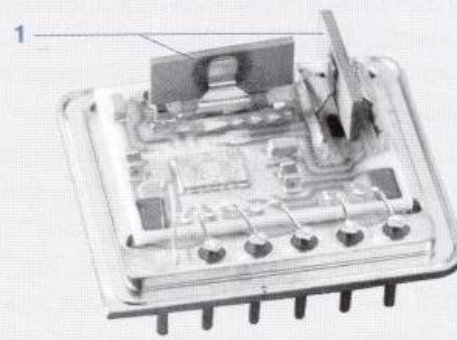


Fig. 2

- 1 Spring element

Koriste se kao senzori ubrzanja u sigurnosnim sistemima za pokretanje sigurnosnog pojasa, vazдушnim jastucima i sistemima za sprečavanje prevrtanja.