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 (HDC)**
  - **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 gravitacijonog ubrzanja ***g*** (1 $g \approx 9{,}81\ m/s^2$).

Table 1

g Acceleration due to gravity $1\ g \approx 9.81\ m/s^2$

HHC Hill hold control

ABS Antilock brake system

ESP Electronic stability program

Merne promenljive i merni principi

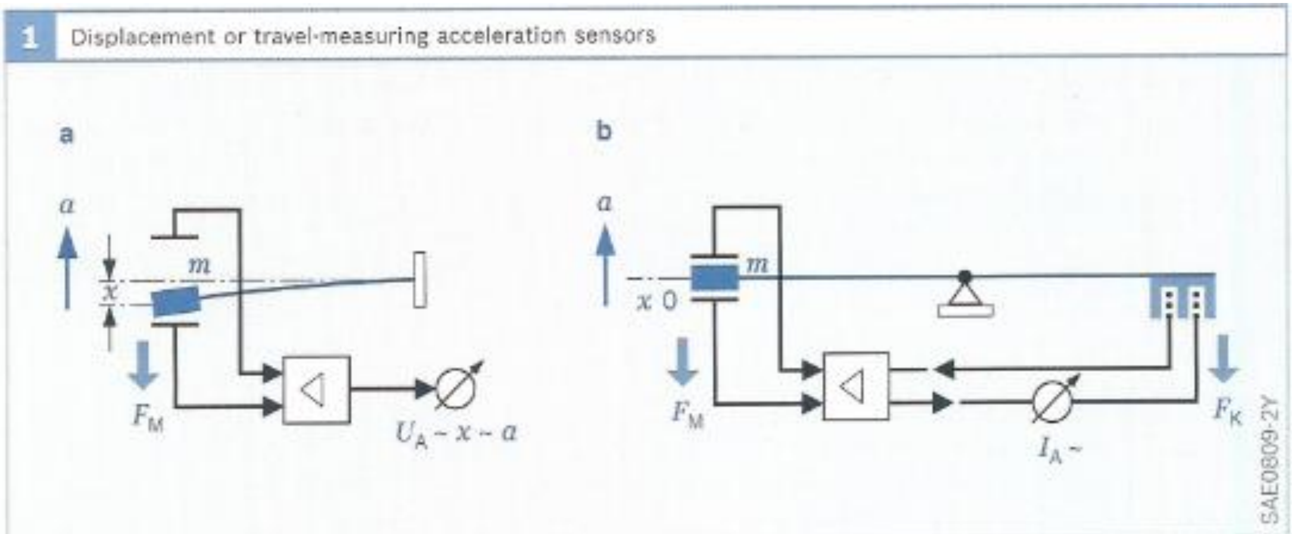


Fig. 1
Schematic:
a Excursion-measuring
b Closed-loop position controlled
a Measured acceleration
x System excursion
F_M Measuring force (inertial force on the mass m)
F_K Compensating force
I_A Output current
U_A Output voltage

- 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) $$F = m \cdot a$$

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

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

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

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

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

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

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

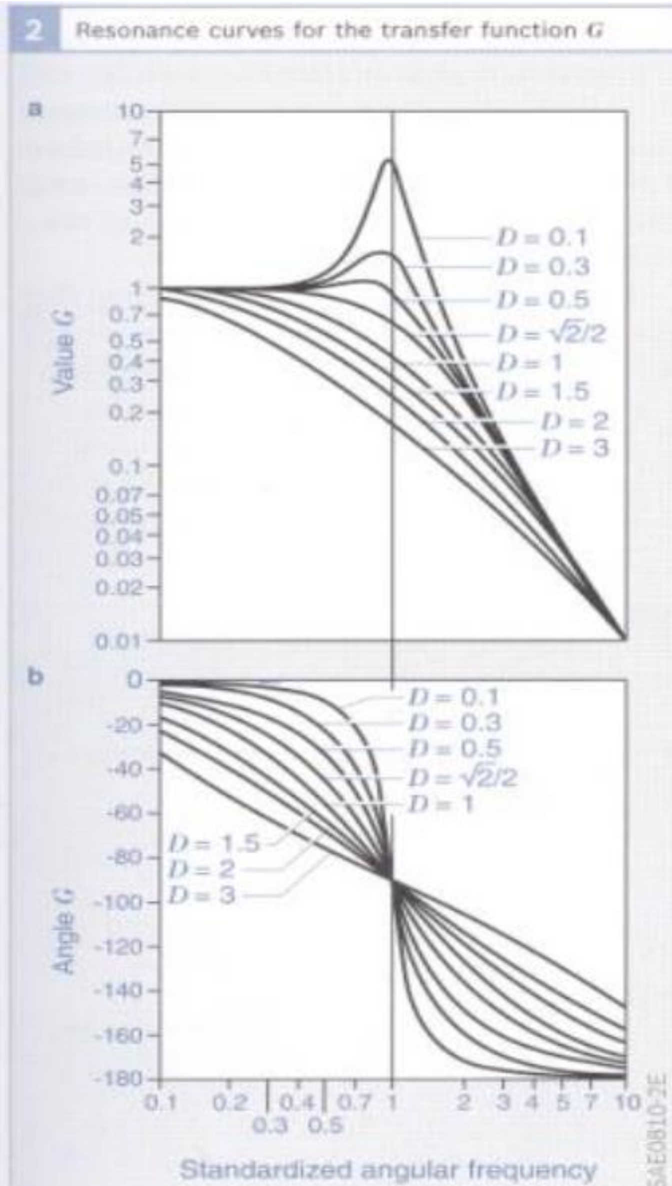


Fig. 2
a Amplitude resonance curve
b Phase resonance curve of the complex transfer function $G(i \cdot \Omega) = [x(i \cdot \Omega)]/[a(i \cdot \Omega)]$
$x(i \cdot \Omega)$ Deflection amplitude
$a(i \cdot \Omega)$ Acceleration excitement amplitude
$\Omega = \omega/\omega_0$ Standardized circular frequency
D Damping

- Ukoliko se zanemari trenje (p ≈ 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 četri 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

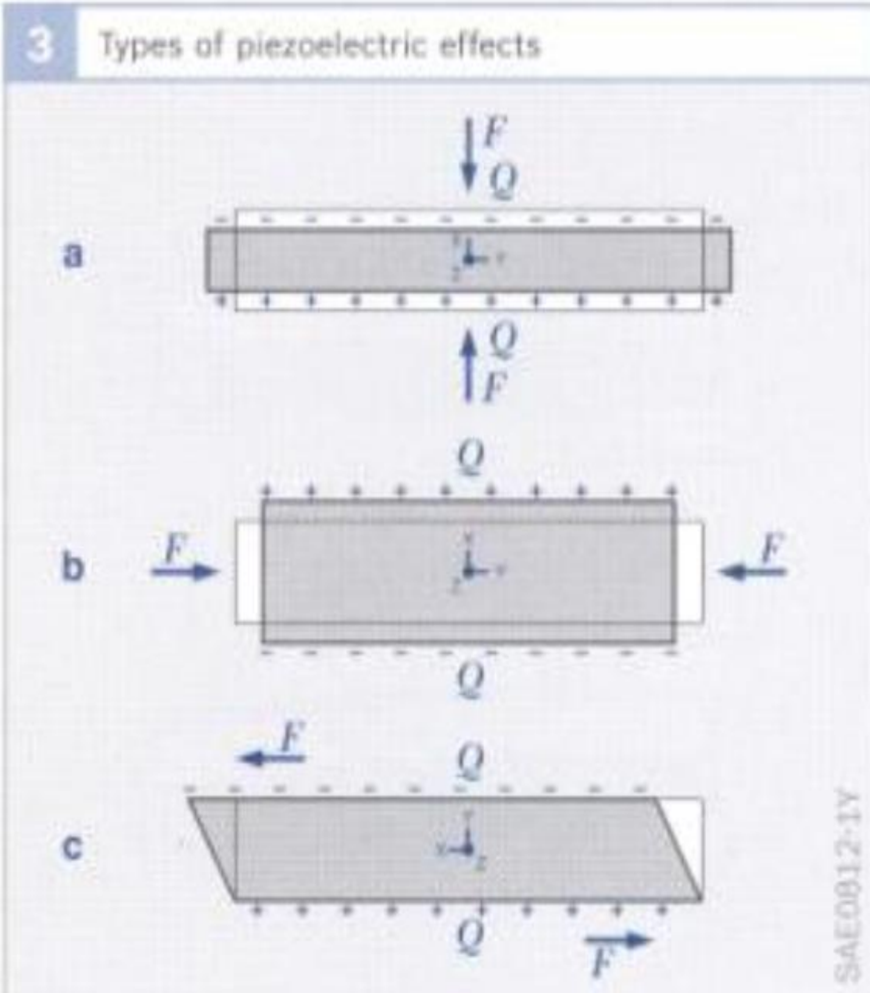


Fig. 3
a Longitudinal effect
b Transverse effect
c Tangential force
F Force
Q Charge

Pijezoelektrični senzori se koriste u motornom vozilu u senzorima ubrzanja i senzorima 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

4 Piezoelectric bimorph

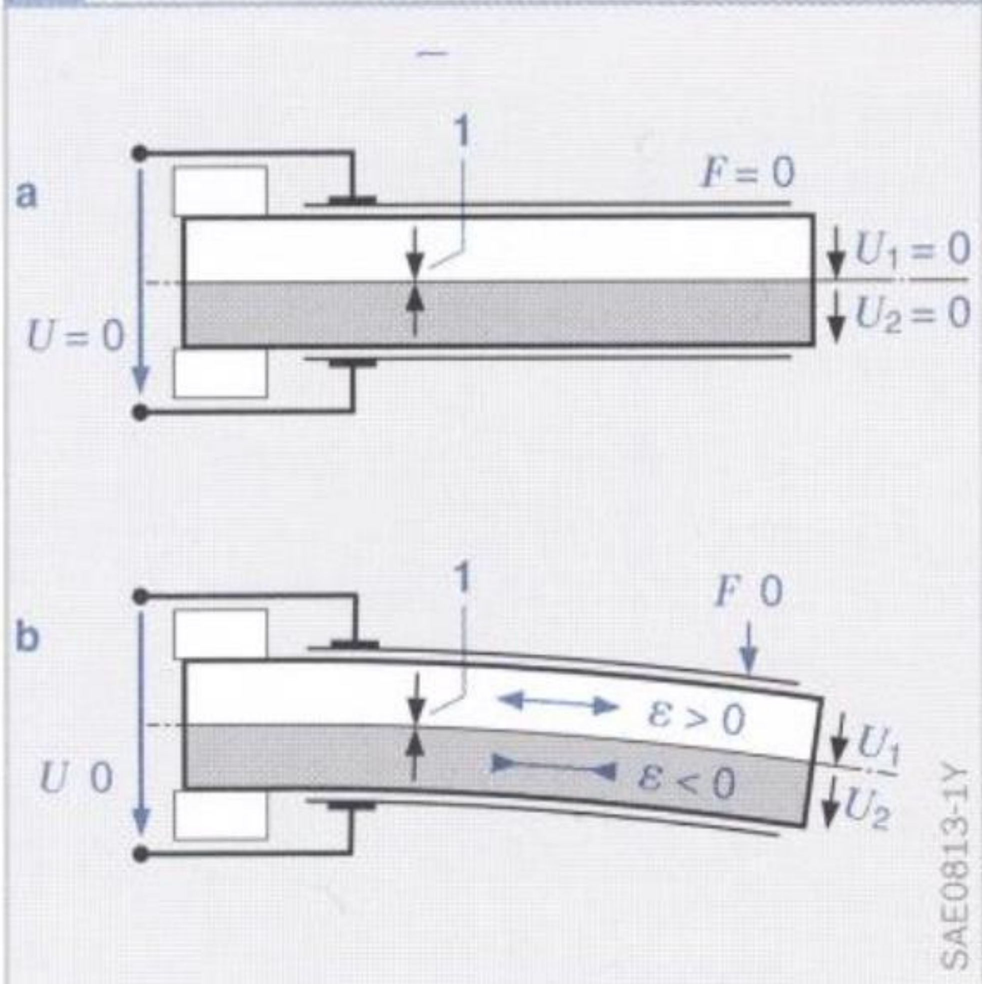


Fig. 4
a Non-active state
b When bent, stretched on top ($\varepsilon > 0$) compressed below ($\varepsilon < 0$)
1 Direction of polarization
F Measuring force
U Total voltage
U_1, U_2 Part voltages

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

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

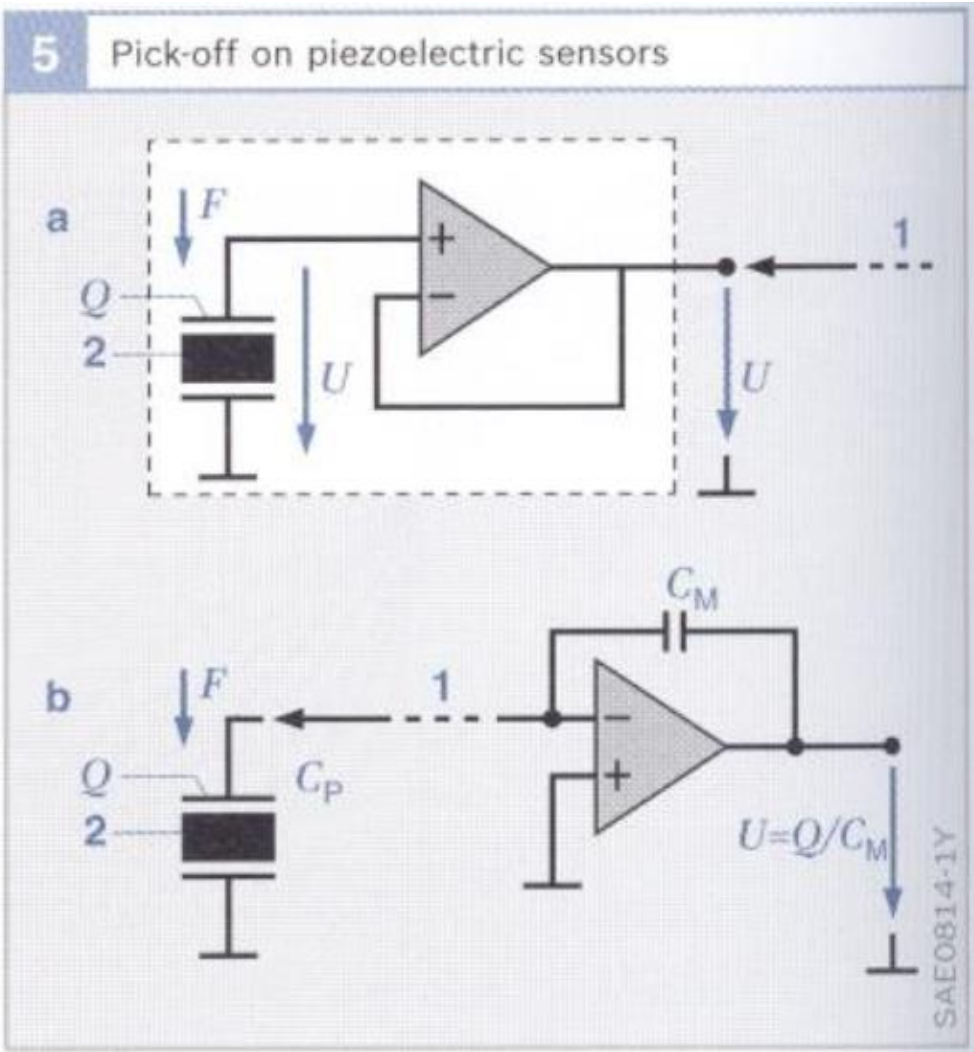


Fig. 5

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

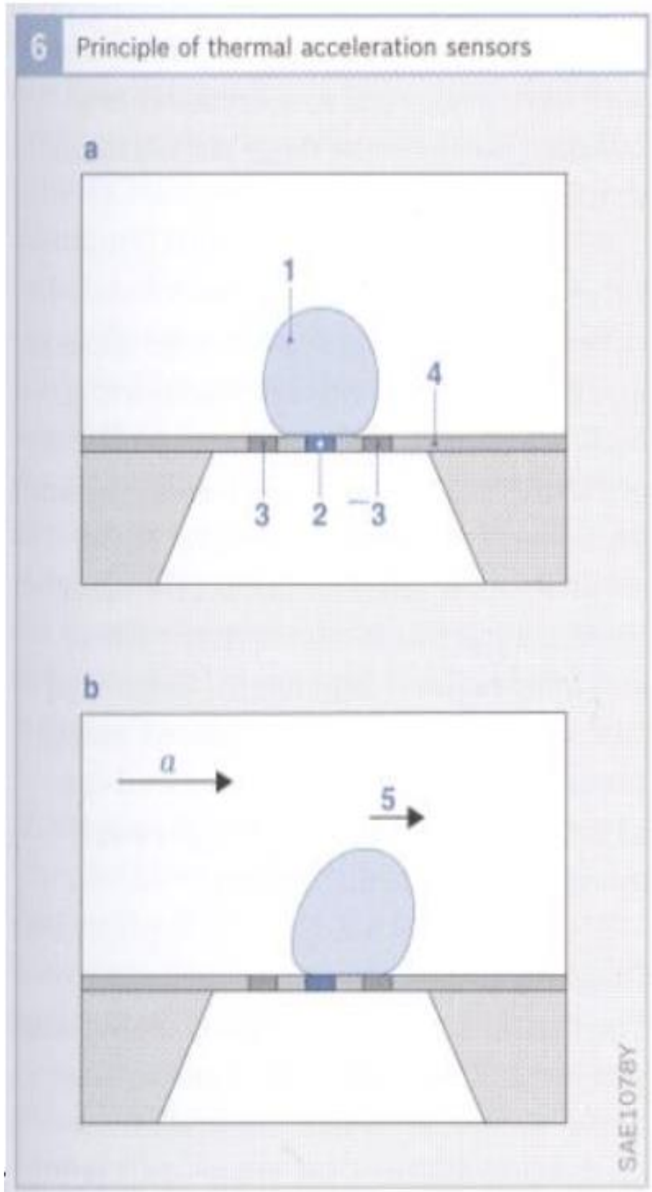


Fig. 6

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 ugrejanog gasa".
- Taj mali tesni ugrejani 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)

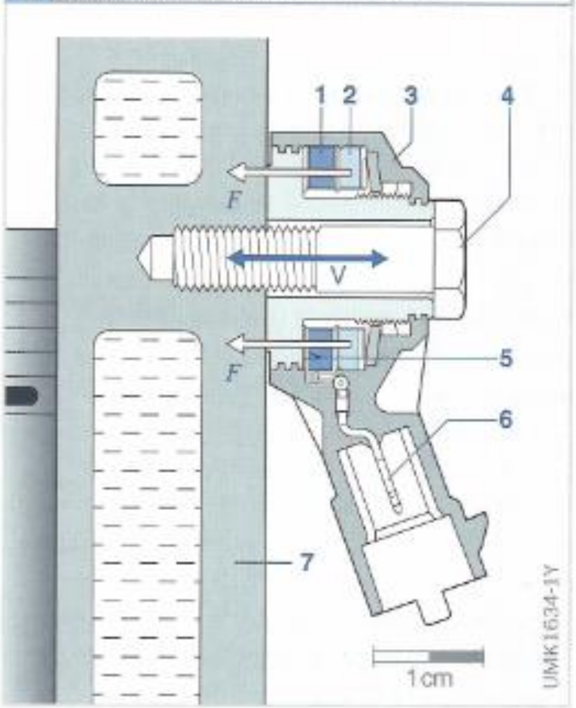


Fig. 2

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)

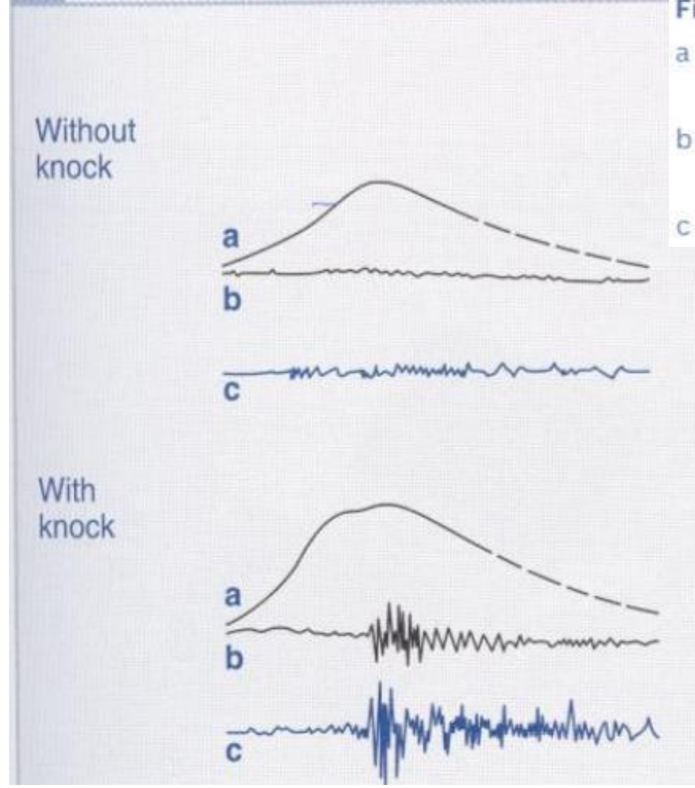


Fig. 1

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

Primenjuje se:

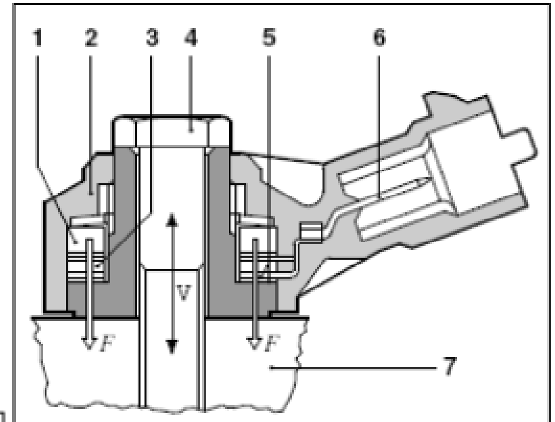
- na oto motorima za utvrđivanje detonativnog sagorevanja u cilindru, koje nastaje kao posledica nekontrolisanog paljenja smeše.
- kod dizel motora primenjuje se za praćenje kvaliteta sagorevanja po cilindrima.

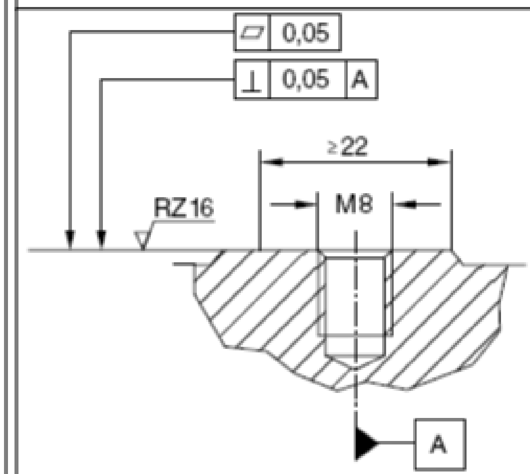
Piezoelectric vibration sensor

Measurement of structure-borne sound and acceleration

Technical data	
Permissible short-term vibration	≤ 400 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 ± 5 Nm

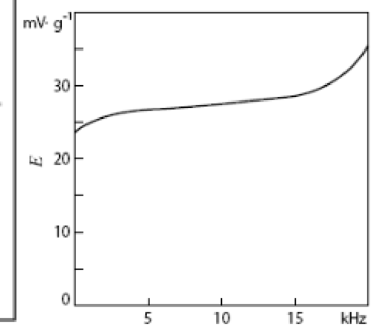
Technical data	0 261 231 148
Vibration sensors	2-pole, without cable
Frequency range	3 ... 22 kHz
Sensitivity at 5 kHz	26 ± 8 mV/g
Linearity between 5...20 kHz with resonance	15 %
Main resonance frequency	> 25 kHz
Self-impedance	> 1 MΩ
Capacitance range	800 ... 1400 pF
Temperature dependence of sensitivity	≤ 0,06 mV/g · K
Operating temperature range	- 40 ... + 150 °C
Permissible sustained vibration	≤ 80 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)

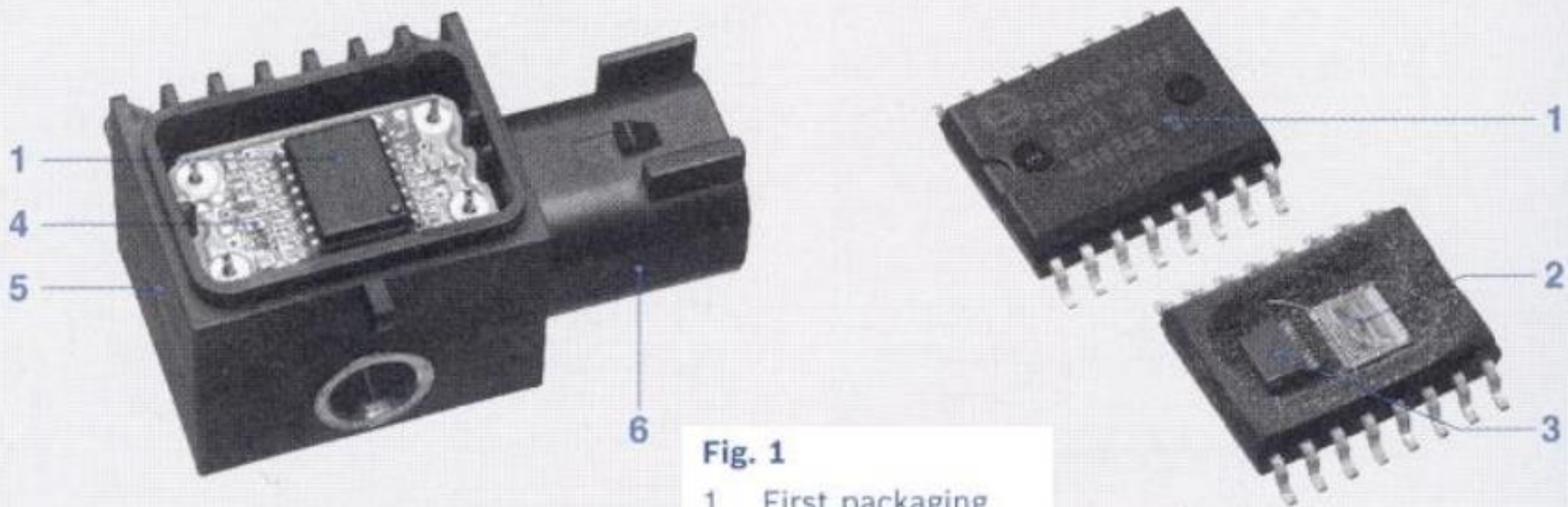


Fig. 1

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

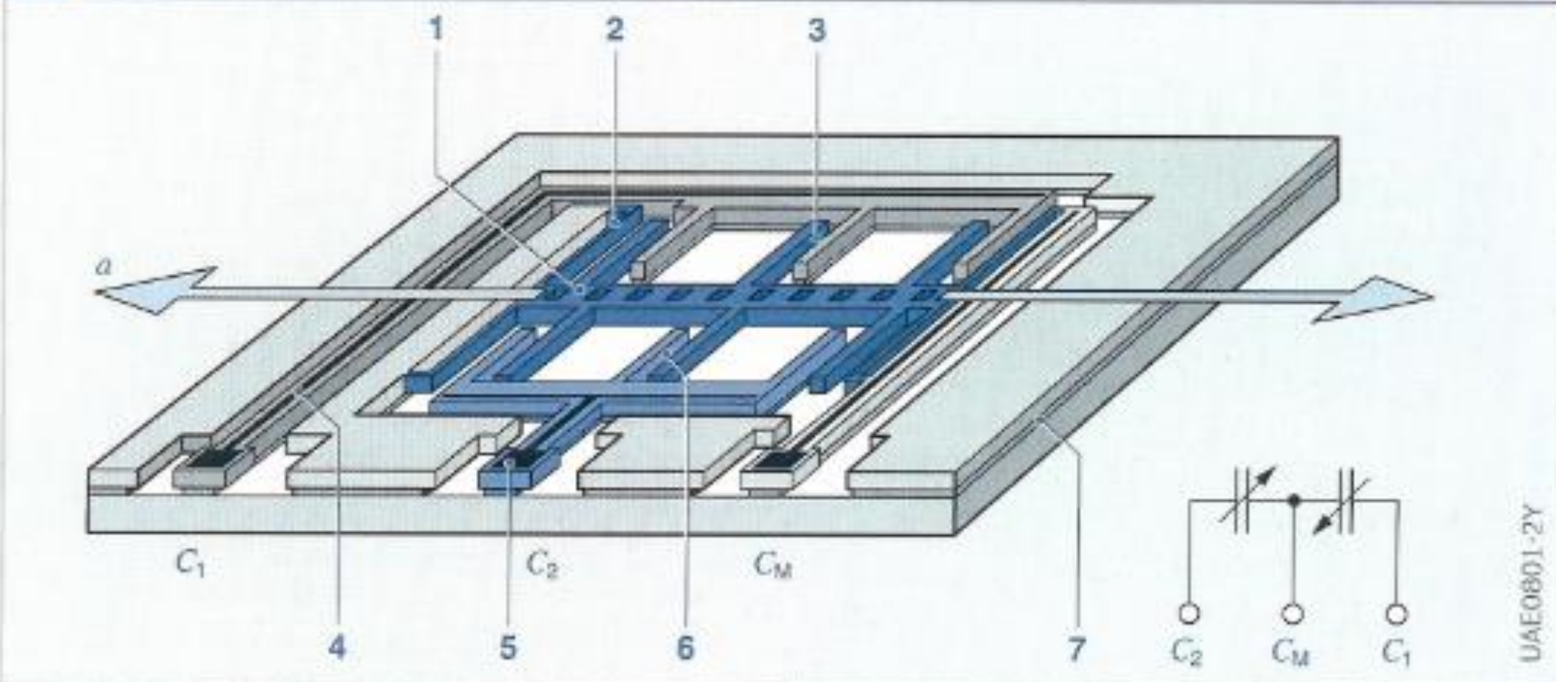


Fig. 2
1 Spring-mounted seismic mass with electrodes
2 Spring
3 Fixed electrodes with capacity C_1
4 Printed Al conductor track
5 Bond pad
6 Fixed electrodes with capacity C_2
7 Silicon oxide
a Acceleration in the sensing direction
C_M Measuring capacity

3 Comb-like structure of the sensor measuring cell

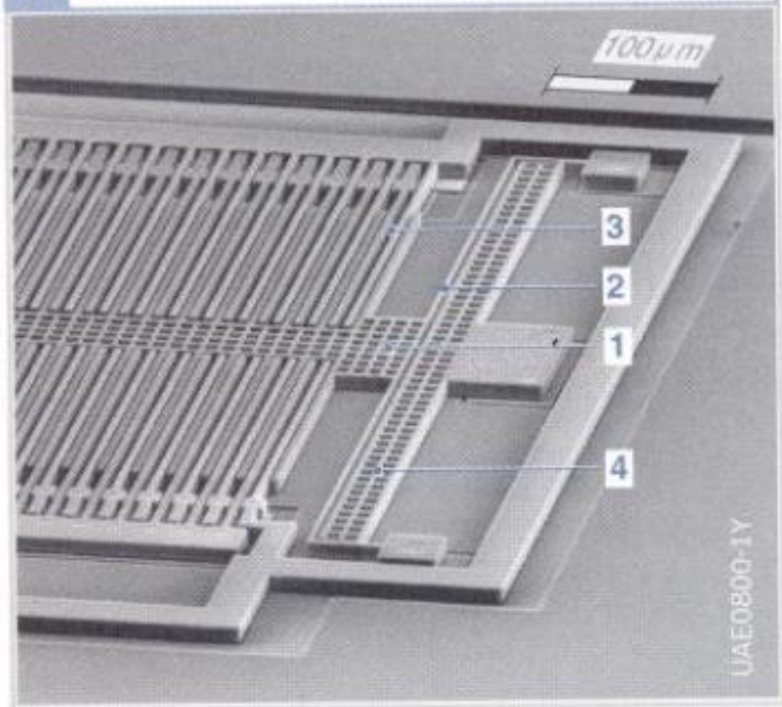
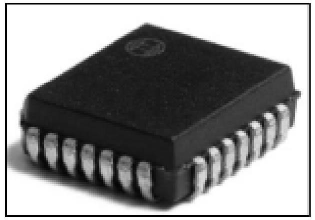


Fig. 3

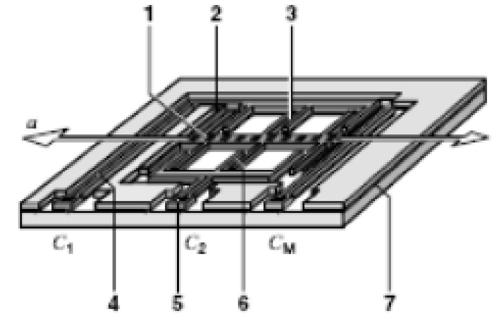
1 Spring-mounted seismic mass with electrode
2 Spring
3 Fixed electrodes
4 Anchor areas

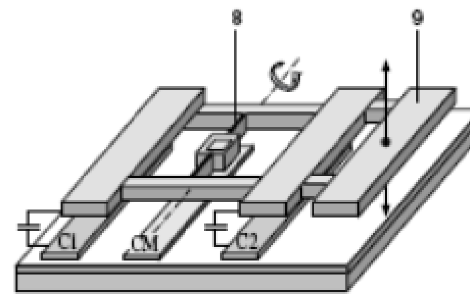
Surface micromechanical acceleration sensor

Measurement of ±35 g or ±50 g acceleration

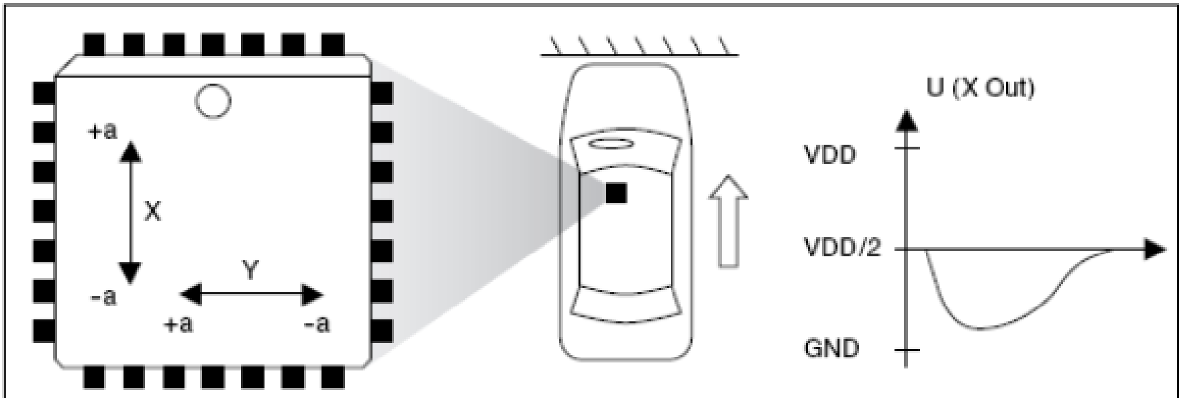


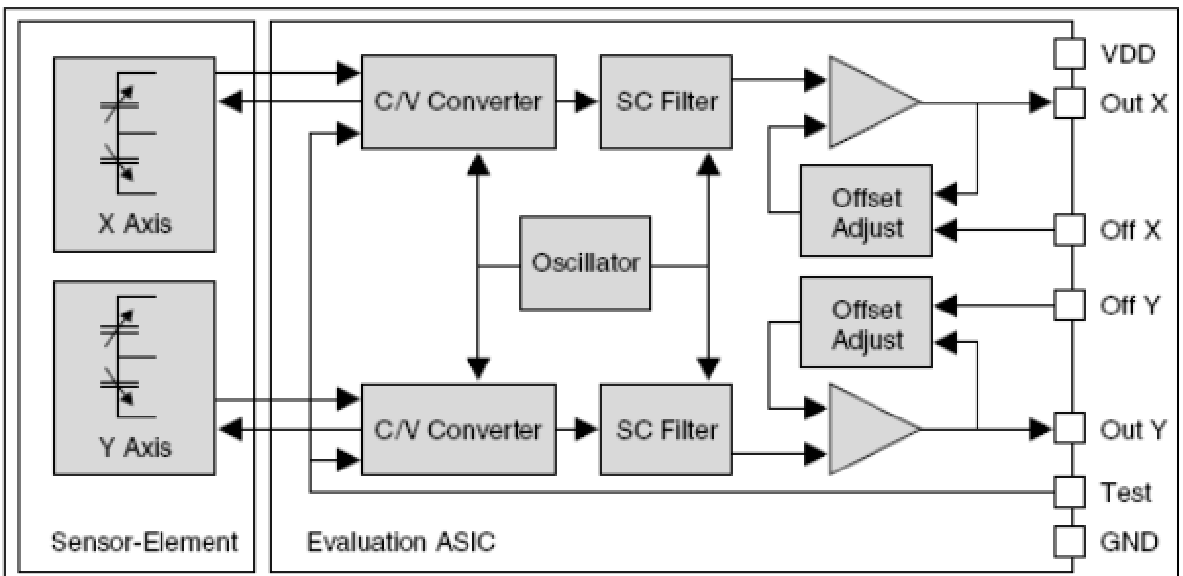
a	Acceleration (g_n = 9.81 m/s^2)
V_{DD}	Supply voltage
V_{off}	Offset voltage
S	Sensitivity
V_{out}	Output voltage
V_{out}	$=(V_{DD}/2)+(V_{off}+S\cdot a)\cdot(V_{DD}/5V)$





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)

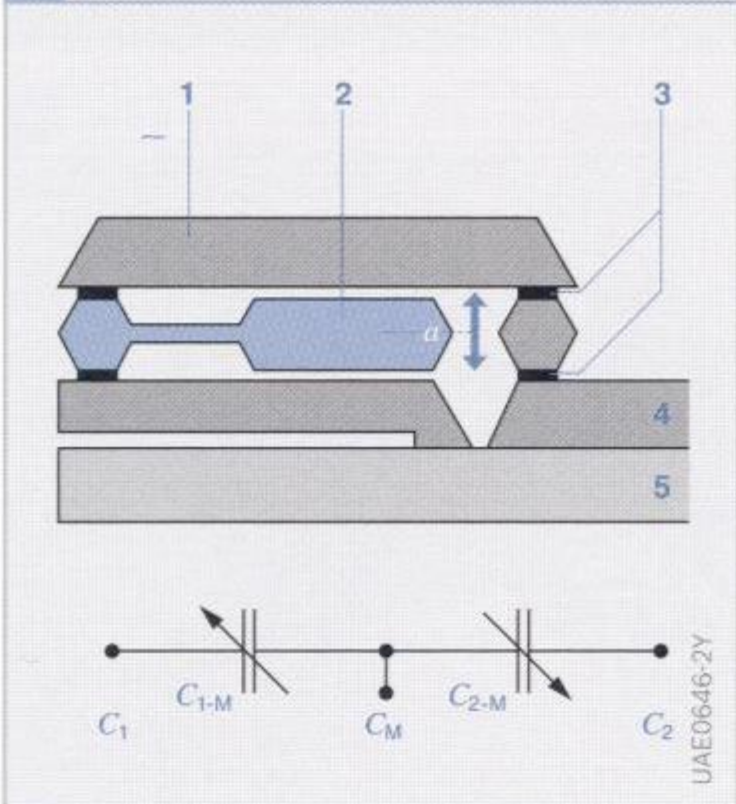


Fig. 1

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

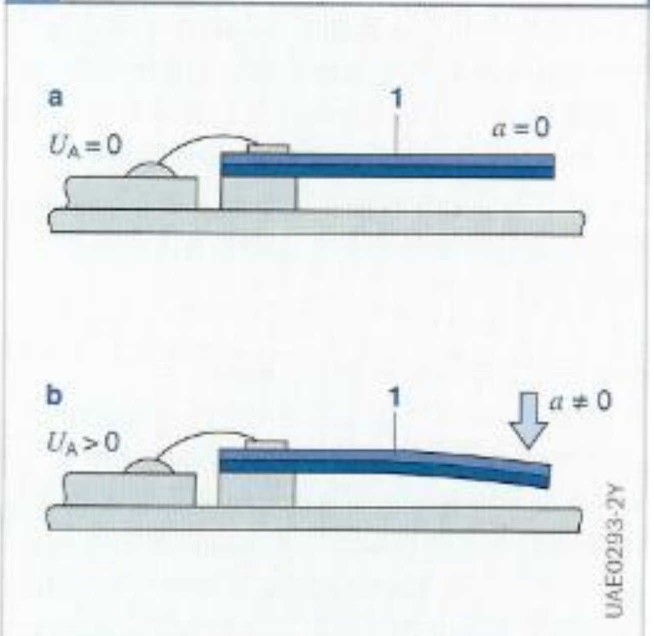


Fig. 1

a Not under acceleration

b Under acceleration a

1 Piezoceramic bimorphous spring element

U_A Measurement voltage

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

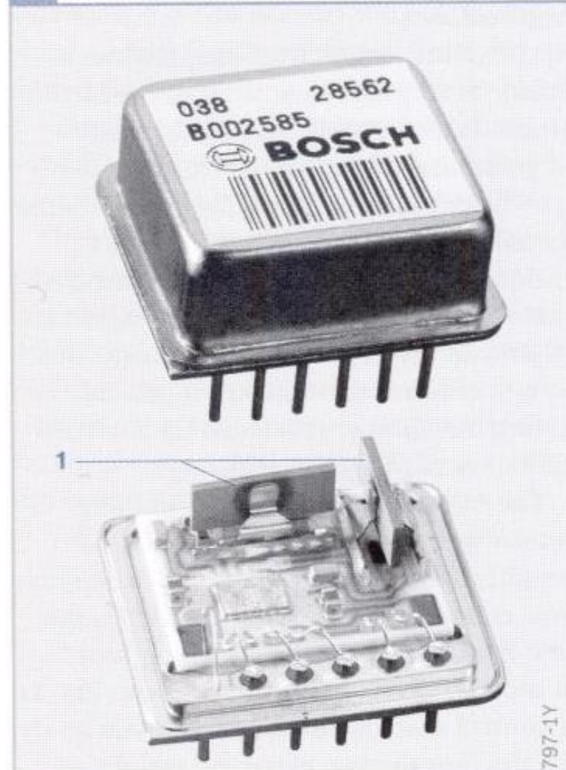


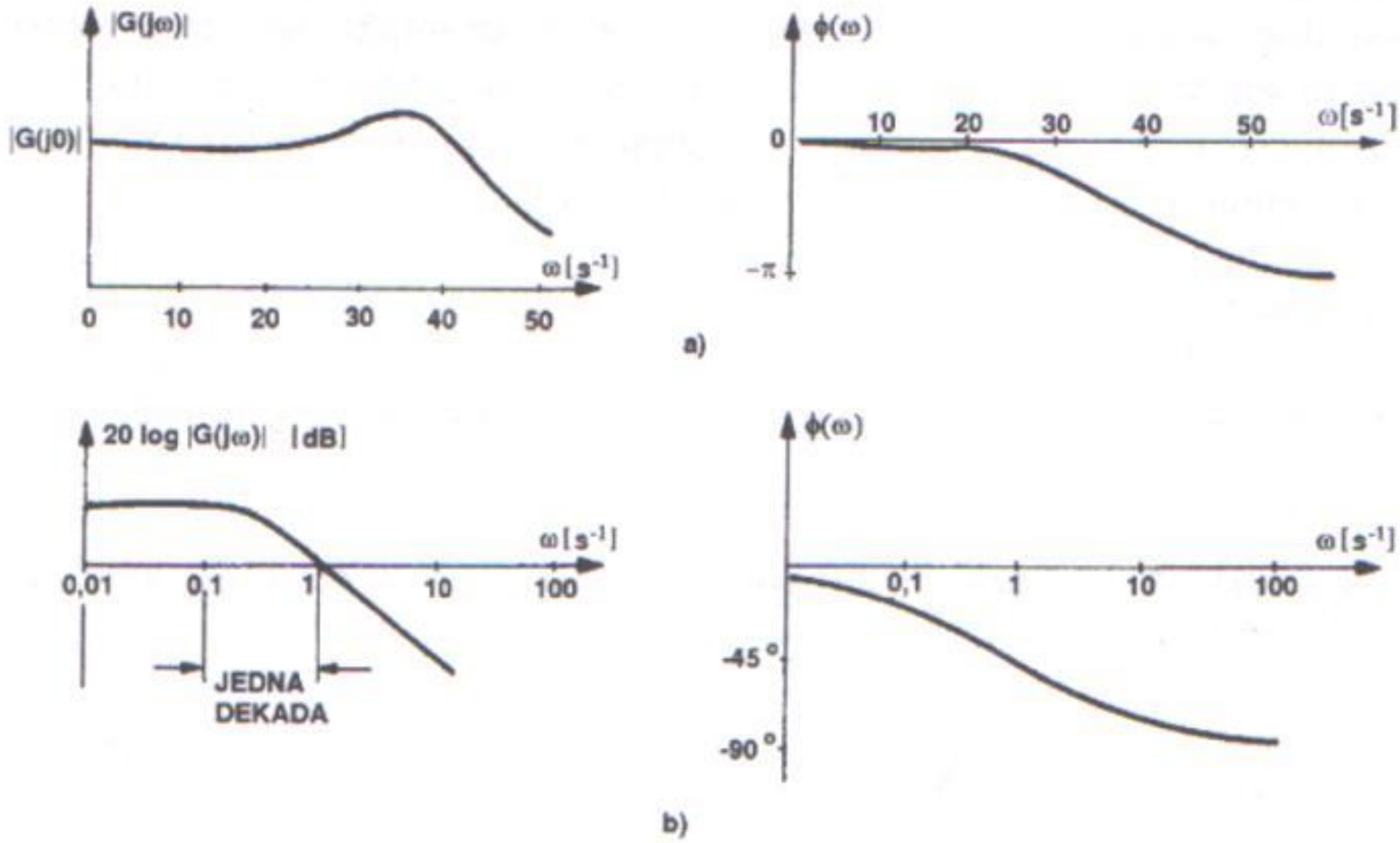
Fig. 2

1 Spring element

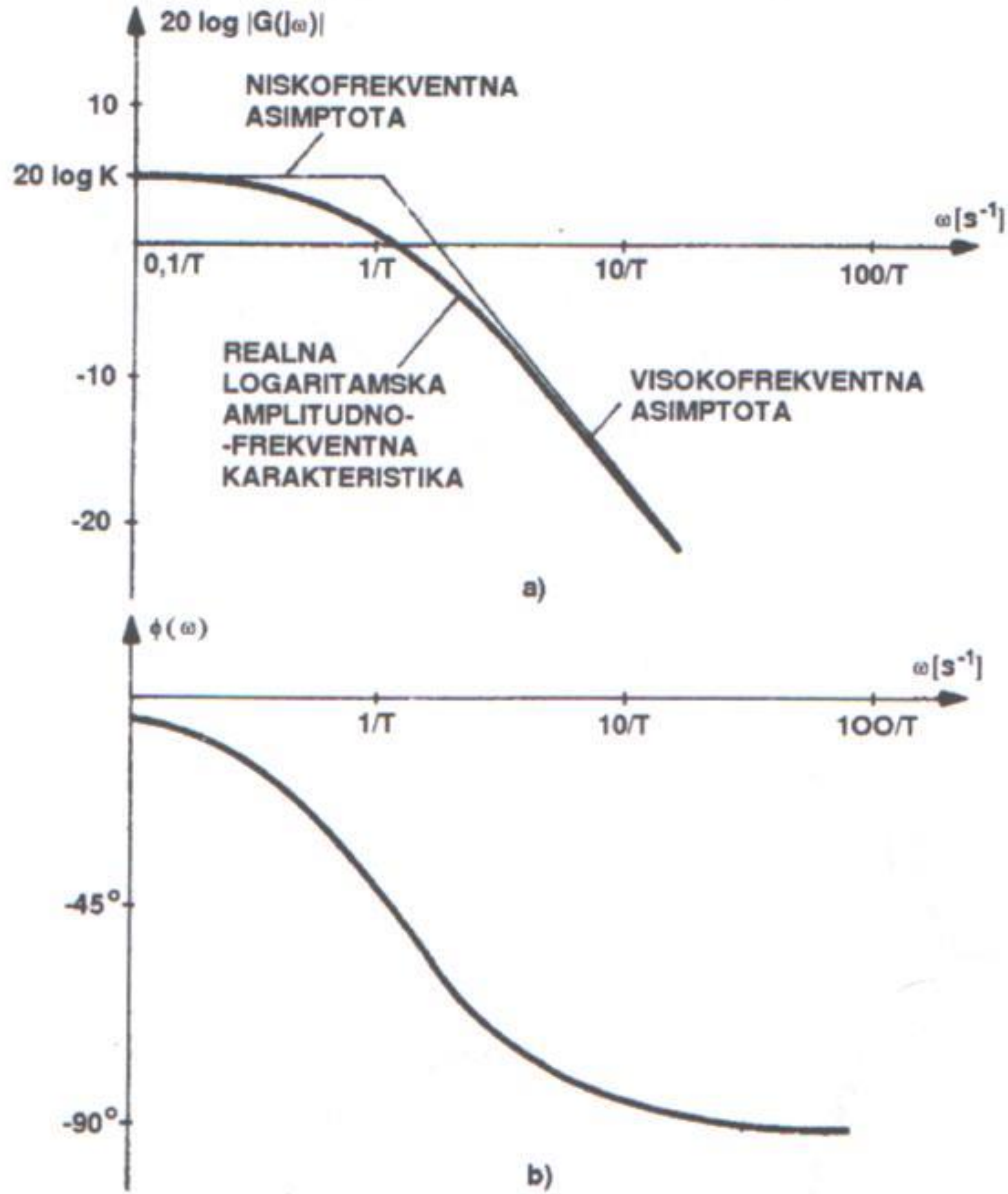
- Pijezo-oscilatorni elementi ne zahtevaju dodatnu seizmičku masu.
- Njihova masa je prikladna za lako analiziranje signala.

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

Динамичке карактеристике у фрквенцијској области:



Slika 8.12. Frekventne karakteristike senzora: a) sa linearnom razmerom na apscisi, b) Bodeov prikaz


20 log |G(jω)|
10
20 log K
-10
-20
NISKOFREKVENTNA
ASIMPTOTA
ω[s⁻¹]
0,1/T
1/T
10/T
100/T
REALNA
LOGARITAMSKA
AMPLITUDNO-
-FREKVENTNA
KARAKTERISTIKA
VISOKOFREKVENTNA
ASIMPTOTA
a)
ϕ(ω)
ω[s⁻¹]
1/T
10/T
100/T
-45°
-90°
b)