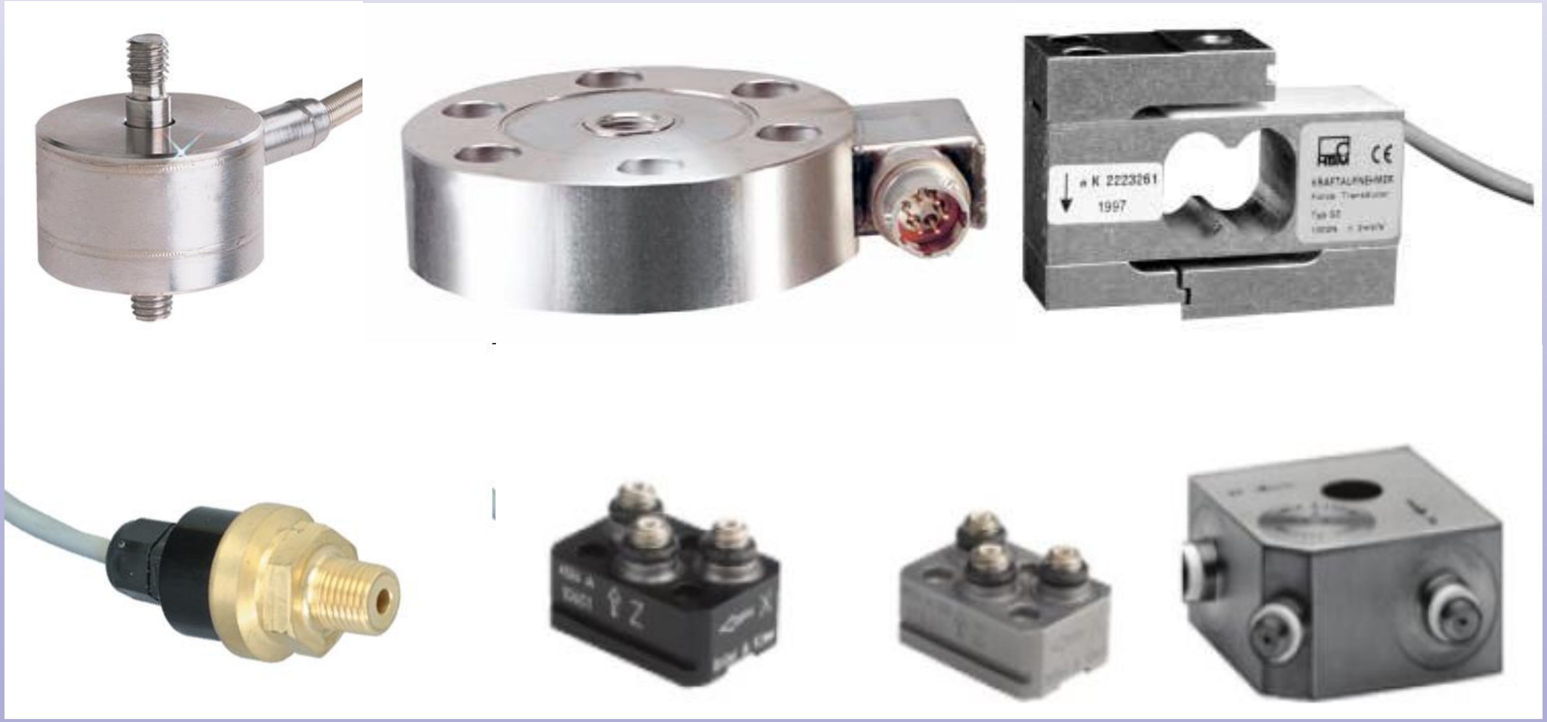
Force sensors
and other the same principle sensors
(torque sensors, pressure sensors, accelerometers)



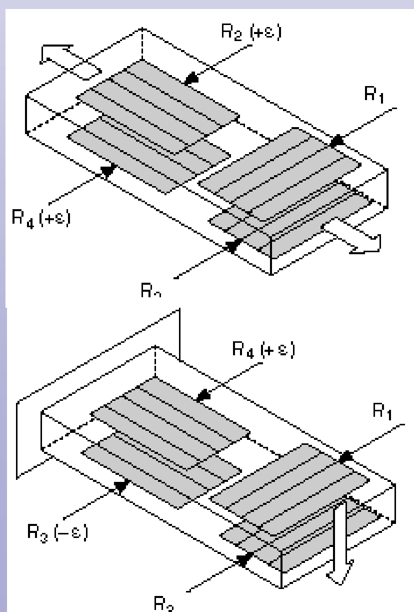
1. Force sensors

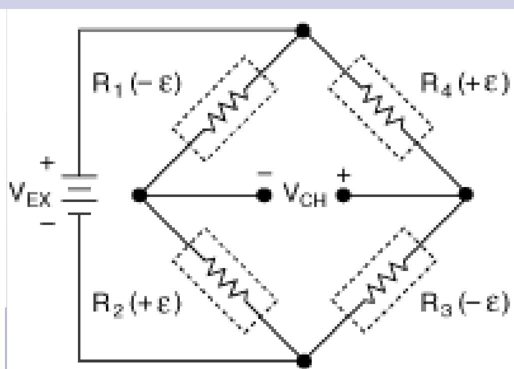
- **the force sensor function principle**
  - two possible principle
    - deformation of the measurement element
    - piezoelectric effect

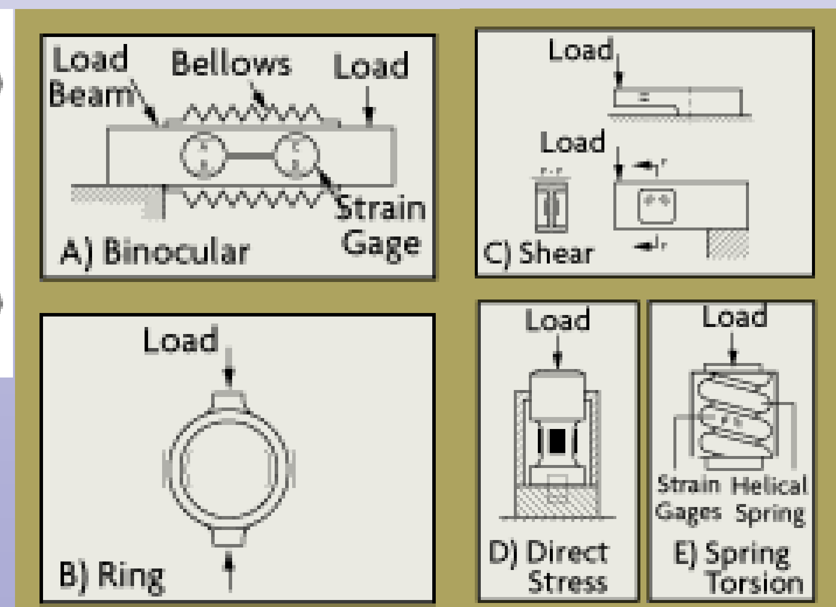
1. Force sensors

1.1. sensors with strain gauge measurement element

- **the sensor function principle**
  - the measurement element is deformed by the force F
  - **measured force is transformed to the measurement element elongation**
  - the measurement element elongation is measured by strain gauges
  - full bridge connection of strain gauges is used (temperature stability, greater sensitivity)
  - variable design of measurement elements can be used
    - the shape of the element affects the properties of the sensor



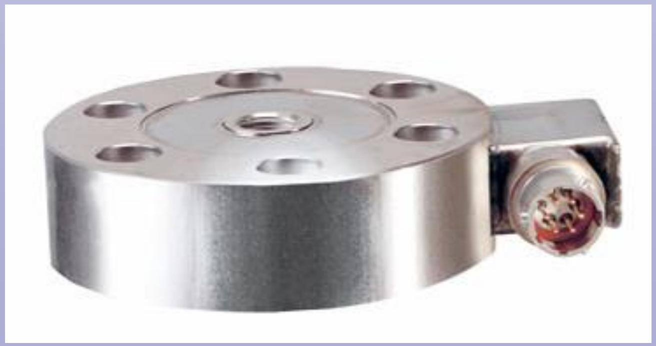




1. Force sensors

1.1. sensors with strain gauge measurement element

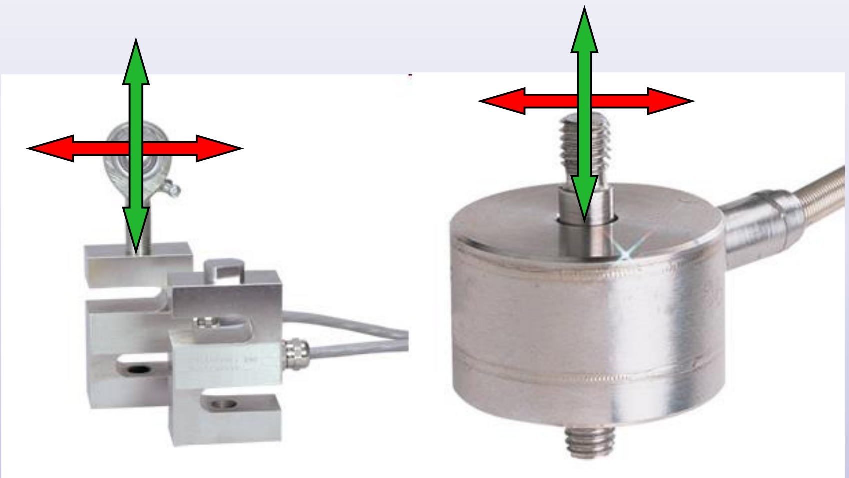
- **the sensor real design**
  - both directions force measurement (tensile and compressive)
    - flange design
    - with anchor bolts or holes
    - "S" shape
  - only compressive measurement
    - spherical canopy
- the shape of the sensor and the anchoring system determine the resistance of the sensor to parasitic lateral forces and torques



1. Force sensors

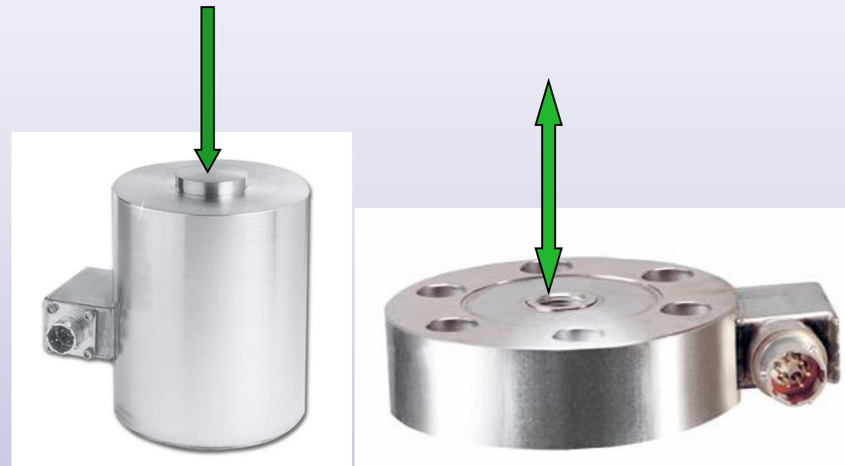
1.1. sensors with strain gauge measurement element

- **the sensor real design**



the sensor signal is sensitive to parasitic lateral load - forces or torques

- measurement element „S“
- anchor bolts or holes



the sensor is insensitive to parasitic lateral load - forces or torques

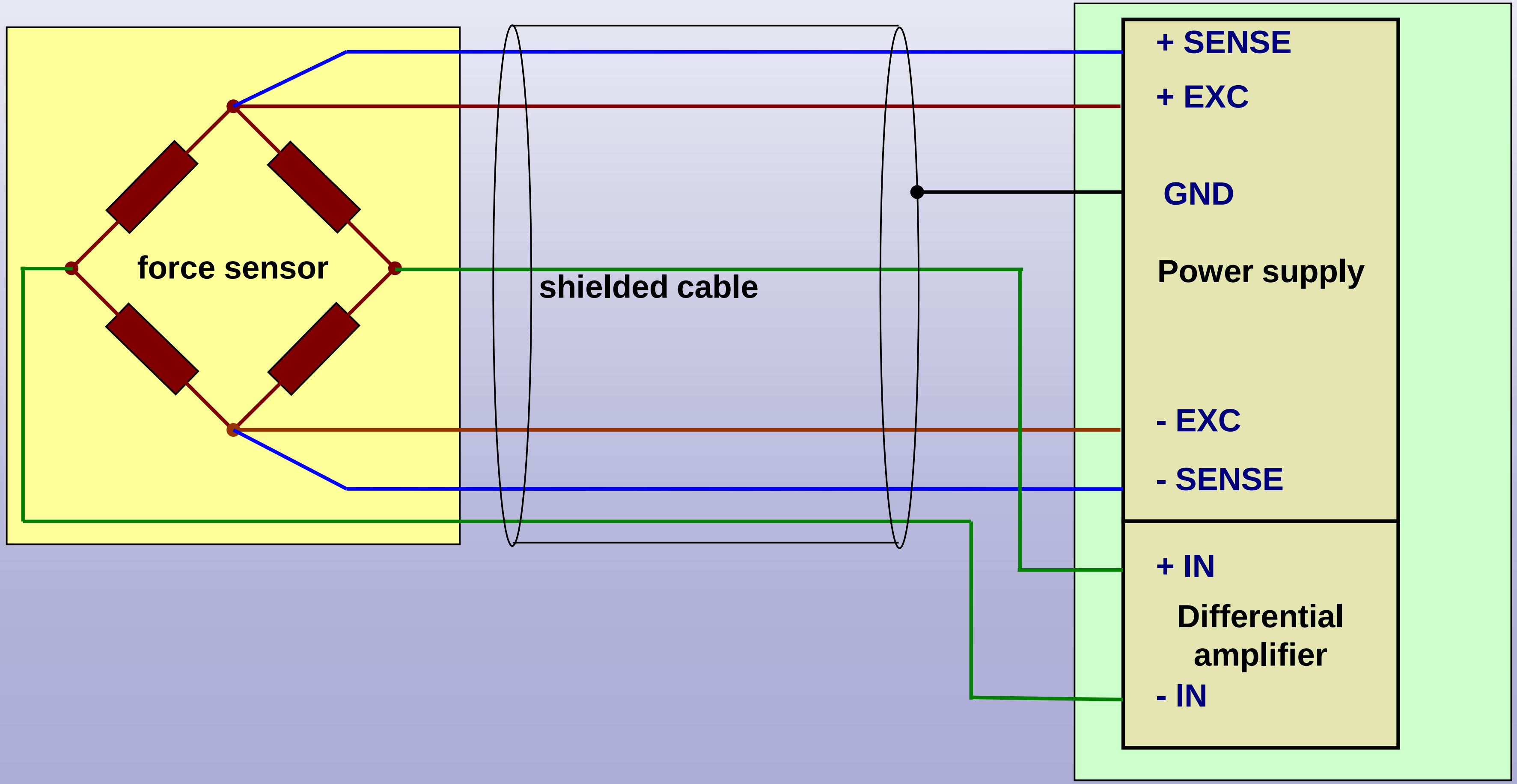
- spherical surface (only compressive force)
- flanged shape (a special ring-shaped measurement element is used inside)

- if a sensor sensitive to lateral forces is used, these forces must be eliminated by suitable mounting of the sensor
- otherwise
  - the output signal will not be correct, it will be affected by the lateral load
  - **the sensor can be mechanically overloaded and destroyed**

1. Force sensors

1.1. sensors with strain gauge measurement element

- **the sensor connection**
  - full strain gauge bridge mostly in six-wire connection
  - compensation of power supply voltage loss by feedback to SENSE inputs



1. Force sensors
1.1. sensors with strain gauge measurement element

- **basic properties**
  - range from 10N to MN
  - accuracy up to 0.03%
  - bidirectional or only pressure measurement

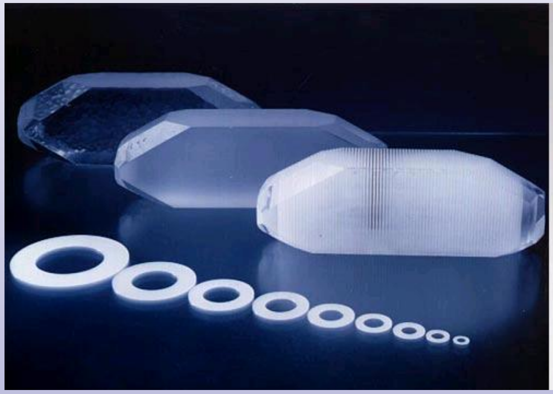
- **advantages**
  - suitable for tensile and compressive forces
  - high force range
  - **suitable for static or dynamic forces measurement**
  - many types, shapes, anchoring

- **disadvantages**
  - destruction during sensor overload
  - sensitivity to parasitic perpendicular forces or torques for any sensor shapes
  - relatively large dimensions
  - the measuring element deforms under load, the sensor reduces the rigidity of the structure where it is mounted

1. Force sensors

1.2. piesoelectric sensors

- **the sensor function principle**
  - piezoelectric effect (from Greek piezein - push)
    - it is the ability of a crystal to generate electrical voltage when it is deformed
    - only for crystals without center of symmetry
    - monocrystalline silicon is the best known piezoelectric substance

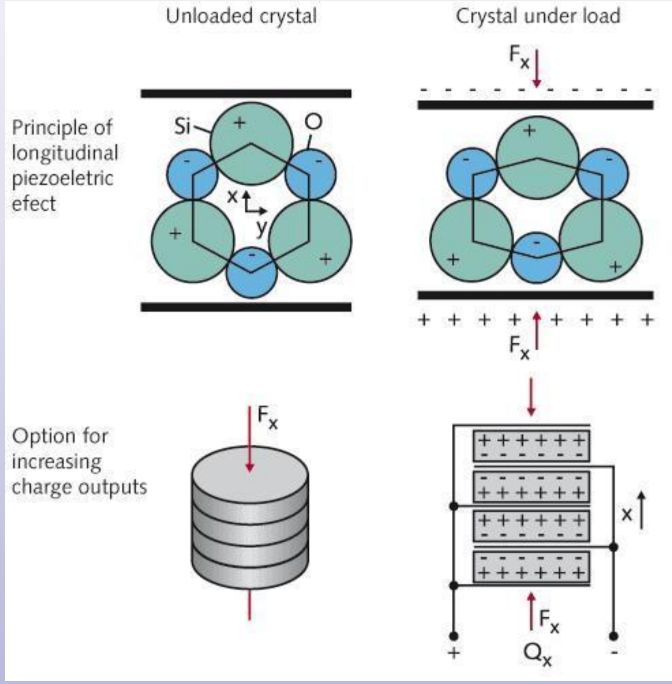


- big monocrystalline material is very expensive
- piezoceramics can be used instead of the big crystal
  - pressure and filler bonded small silicon crystals
  - various shapes
  - a much cheaper solution than a crystal cutout
  - currently the most used solution

1. Force sensors

1.2. piezoelectric sensors

- **the sensor function principle**



- silicon has positive charge
- oxygen has negative charge
- the electric field depends on the charge and its distance

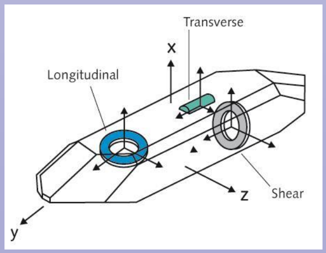
without loading

- one silicon is closer to the surface
- two oxygens are further away from the surface
- the total charge on the surface is 0

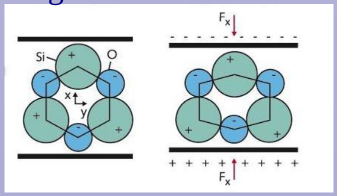
after loading

- the crystal lattice is deformed
- more oxygen are closer to the upper surface – the upper surface has negative charge
- more silicon are closer to the lower surface – the lower surface has positive charge

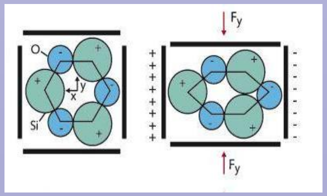
- the measurement element can be cut from the crystal in three ways for different deformations



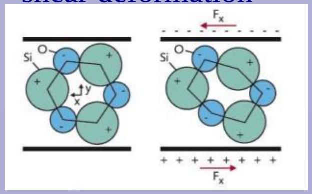
longitudinal deformation



transverse deformation

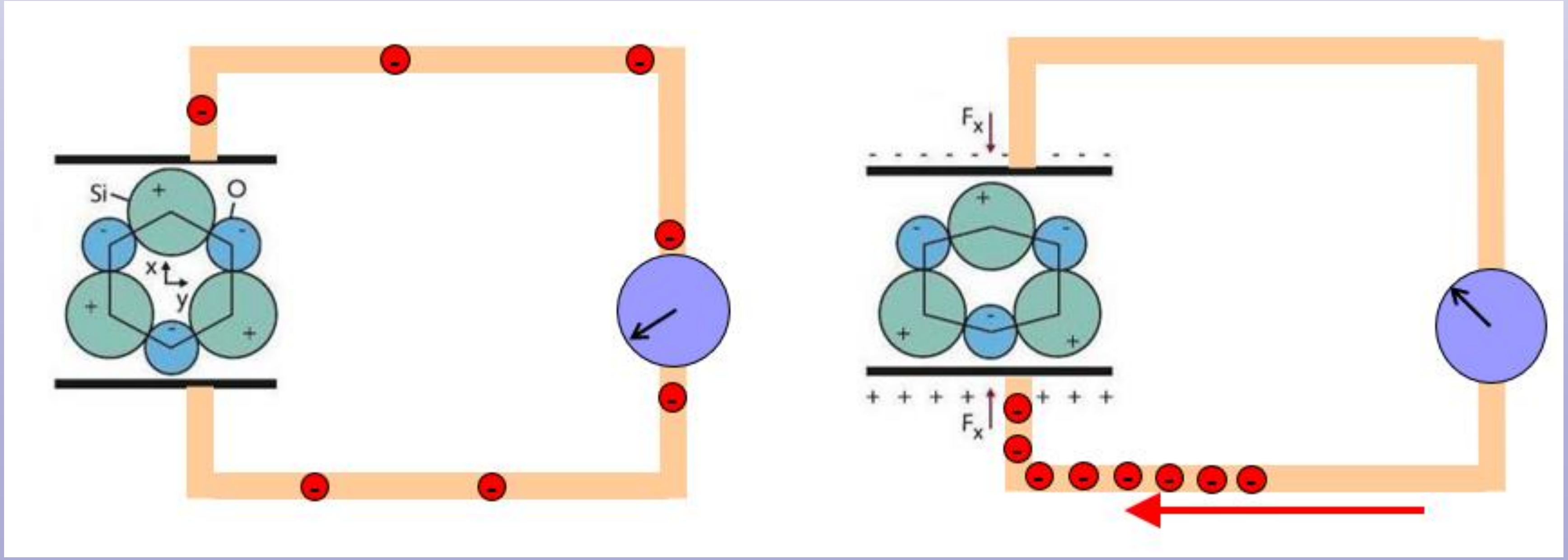


shear deformation



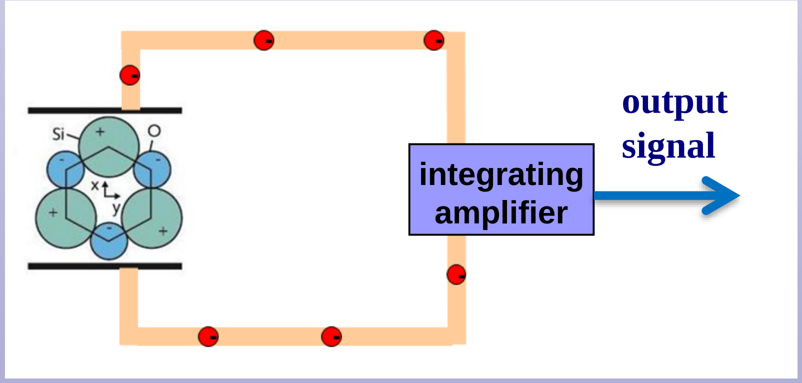
1. Force sensors
1.2. piesoelectric sensors

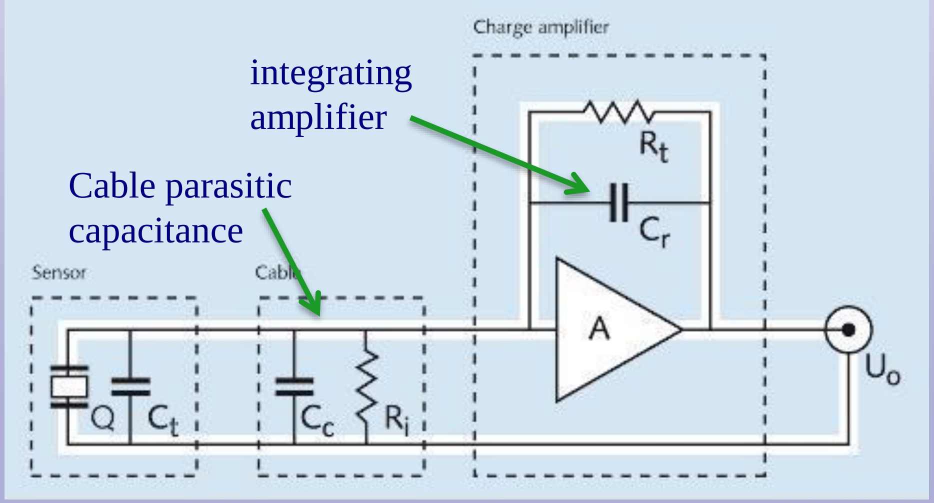
- **the crystal electrical imbalance evaluation principle**
  - the surfaces of the crystal are connected by the conductor
  - positive charge on the surface pulls free electrons in the conductor
  - the movement of the electrons in the conductor is the electrical current that can be measured
  - after balancing the charge, the motion of the electrons is stopped - the electric current is stopped too
  - **piezoelectric sensor measures only changes of the force, does not measure static force value!!!!**



1. Force sensors
1.2. piesoelectric sensors

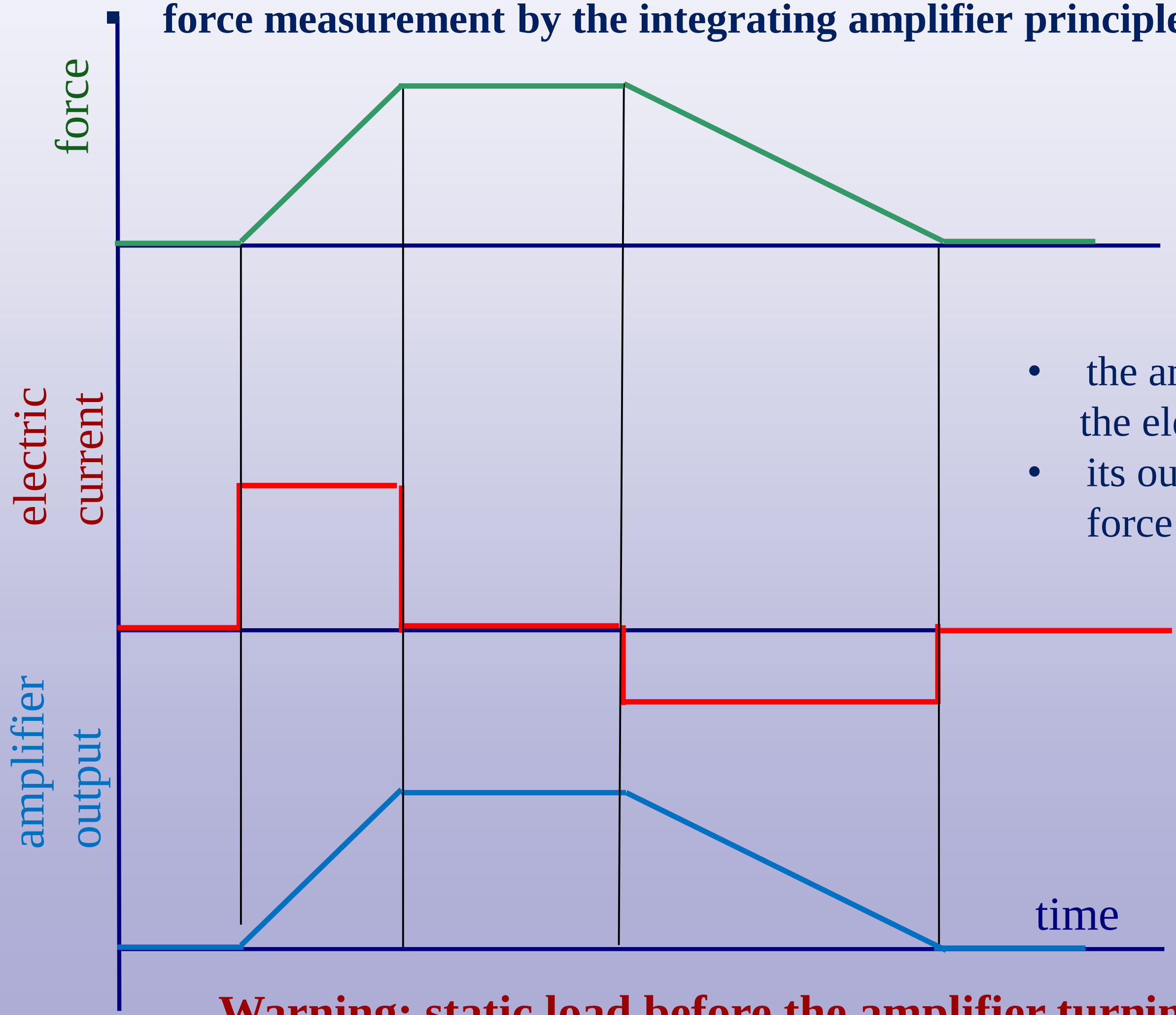
- **the crystal electrical imbalance evaluation principle**
  - a so-called CHARGE AMPLIFIER is used to evaluate the motion of electrons
  - it is basically an integrating amplifier that integrates the input electric current
  - a very small electric current can be measured
  - the amplifier has a feedback capacity and is therefore sensitive to the input capacitance
  - the input capacity is affected by the parasitic capacitance of the connecting cable
    - need to use a special cable (usually part of the sensor)
    - very limited cable length - standard approx. 3 meters
    - best to use everything (sensor, cable, amplifier) from one manufacturer





1. Force sensors
1.2. piezoelectric sensors

- **force measurement by the integrating amplifier principle**



- the amplifier integrates the electrical current from the sensor
- its output signal corresponds to the input force

Warning: static load before the amplifier turning on is not measured!!!!

1. Force sensors

1.2. piesoelectric sensors

- **the sensor real design**
  - piezoceramic ring in a metal case
  - **the sensor only measures compressive forces, the crystal can only be compressed, not stretched**

  - "pre-pressed" piezo sensor is used to measure compressive and tensile force
    - piezo sensor is "pre-pressed" between two plates by a screw to its mid-range
    - when the tensile force is measured, the screw is elongated, the sensor is released from the pressure, but remains in pressure at all times

1. Force sensors
1.2. piesoelectric sensors

- **basic properties**
  - range from 10N to MN
  - accuracy up to 0.1%
  - only pressure measurement or special pre-pressed assembly for both direction measurement

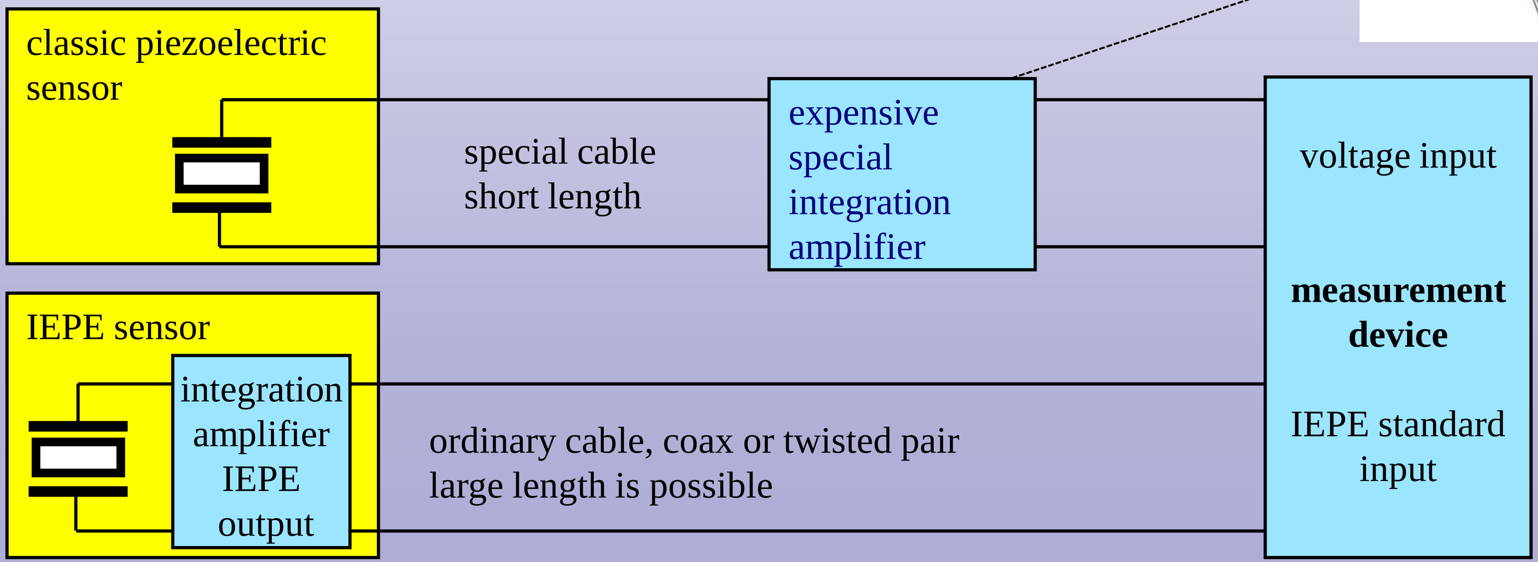
- **advantages**
  - minimum dimensions even for large forces
  - overload without destroying the sensor
  - suitable for high frequency of the input force (quick changes)

- **disadvantages**
  - only for compressive force (the crystal can be only compressed, not stretched)
  - only for dynamic measurement (static sensor loading before the amplifier turning on is not measured)
  - special integration amplifier and special connecting cable must be used
  - expensive solutions

- **the last two disadvantages are eliminated by the new modern solution - IEPE sensors!**

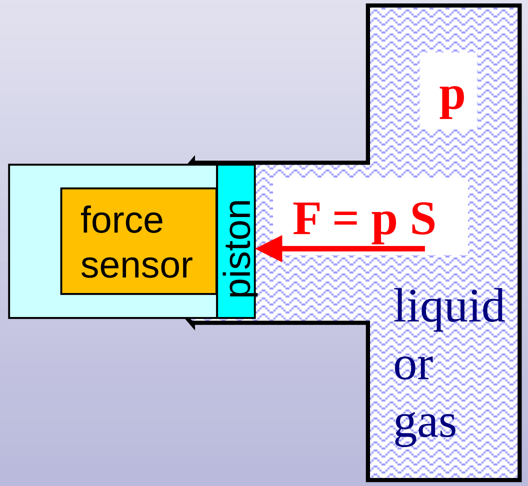
1. Force sensors
1.2. piesoelectric sensors

- **IEPE sensors**
  - **I**ntegrated **E**lectronics **P**iezo-**E**lectric
    - the integration amplifier and electronics is built directly into the sensor housing
    - no special cable and expensive integration amplifier are needed
    - the output signal is a standardized IEPE output
      - an ordinary two-wire cable (coaxial or twisted pair) is used
      - large cable length is possible (up to hundreds of meters)
      - modern measuring devices have an input for the IEPE standard



2. Pressure sensors

- **the sensor function principle**
  - **the pressure is transformed into the force**
  - a piston with known surface and a force sensor are used
  - strain gauge or piezoelectric or IEPE force sensors can be used
  - the sensor properties are determined by the type of force sensor used



2. Pressure sensors

- **the sensor real design and basic properties**
  - sensor without electronics
    - full bridge force sensor or classic piezoelectric sensor
  - built-in electronics
    - amplifier for full bridge sensor or IEPE electronics for piezoelectric sensor
    - standard output signal
  - all in one design
    - instead of mechanical pressure gauges, battery power
  - many different connection systems - fittings
  - various resistance to the measured medium - air, liquids, acids, ...

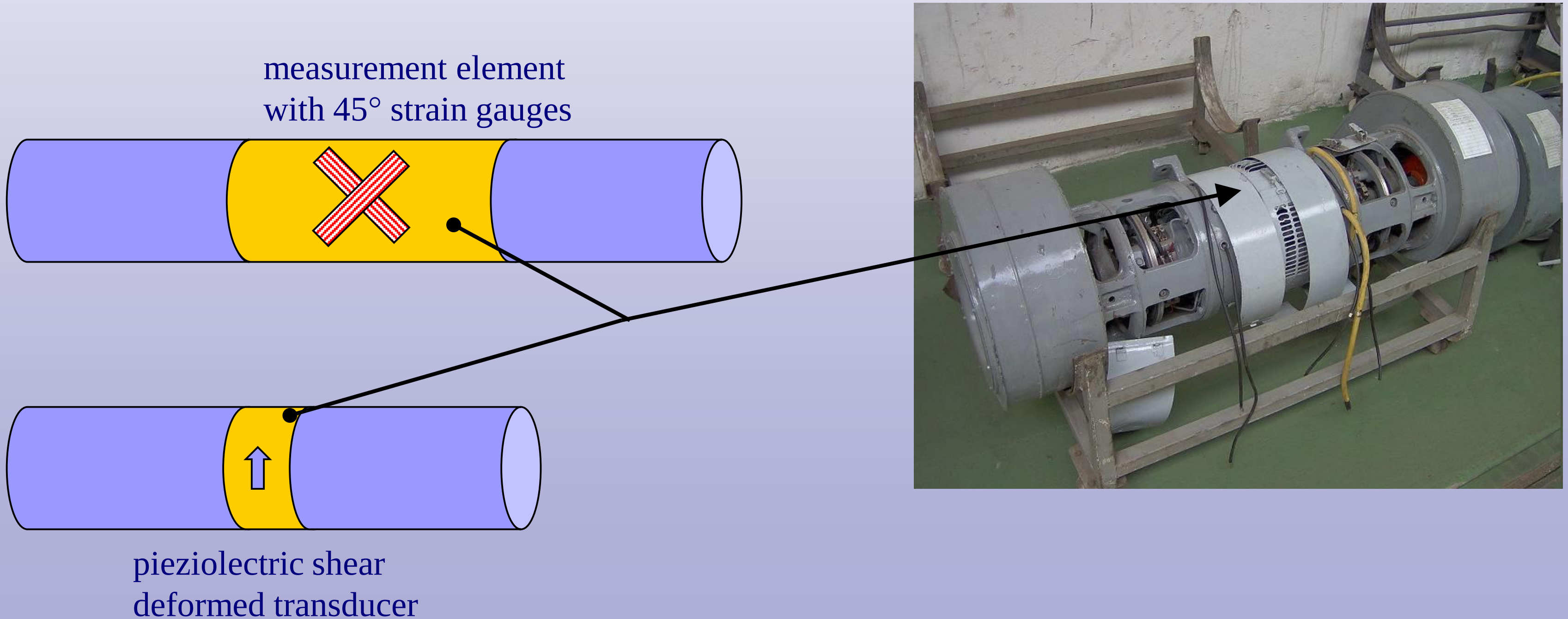
  - sensor measurement properties, advantages and disadvantages are determined by the type of force sensor and use or non-use of the built-in electronics





3. Torque sensors

- **the sensor function principle**
  - **the torque is transformed into a torsional deformation of the measurement element**
  - torsional deformation is measured by strain gauges or a piezoelectric transducer
  - measurement of torsional deformation
    - strain gauges are glued at an angle of 45°
    - piezoelectric sensor with shear deformation



3. Torque sensors

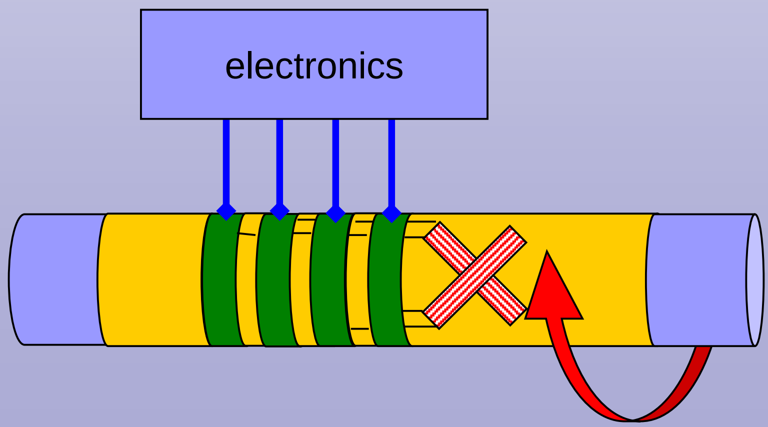
- **the sensor real design and basic properties**
  two basic design
- **non-rotating design for static torque measurement** (eg tightening torque)
  - sensor without electronics
    - full bridge force sensor or classic piezoelectric sensor
  - sensor with built-in electronics
    - amplifier for full bridge sensor or IEPE electronics for piezoelectric sensor
    - standard output signal

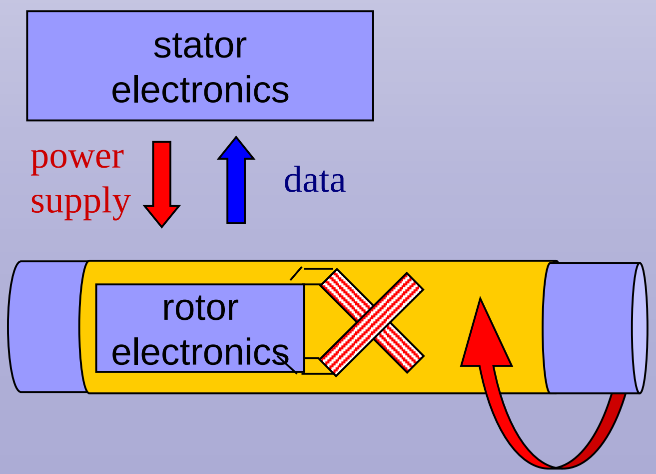
  - many different mounting variants - flanged, hexagon, square,…
  - all in one design (eg torque wrench with display)

  - sensor measurement properties, advantages and disadvantages are determined by the type of sensor and use or non-use of the built-in electronics

3. Torque sensors

- **the sensor real design and basic properties**
- **rotary design for rotating shafts**
  - problem with signal output from the rotating shaft
    - conductive rings and contacts - older variant
      - only a strain gauge measurement system is possible
      - only for lower speeds, up to approx. 4000 rpm
    - wifi - modern system
      - electronics on rotating part
      - is powered contactless (same principle as contactless mobile phone charger)
      - the signal is digitized and transmitted as a data stream by wifi transmission
      - a strain gauge or piezo sensor is possible
      - high speed, up to approx. 24000 rpm



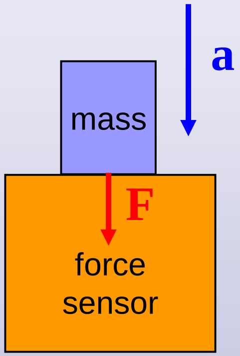


3. Torque sensors

- **the sensor real design and basic properties**
- **rotary design for rotating shafts**
  - compact sensor
    - many different mounting variants - flanged, hexagon, square,…
  - separate stator and rotor part
    - a flanged design is usual
    - the prescribed distances between the stator and the rotor must be observed
  - non-contact sensors usually have a second output too - pulse rotation speed output
    - n-pulses per revolution is in the output signal
    - their number expresses the angle of rotation
    - their frequency is proportional to the speed

4. Accelerometers

- **the sensor function principle**
  - **the acceleration is transformed into a force**
  - a mass of known size and a force transducer are used

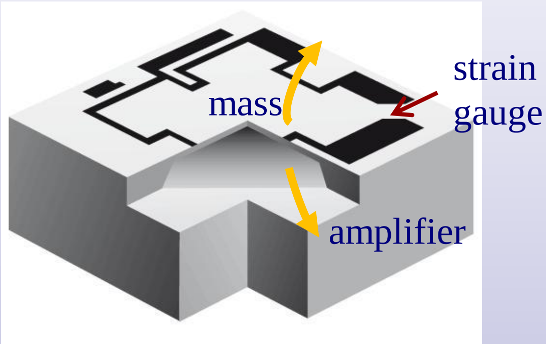


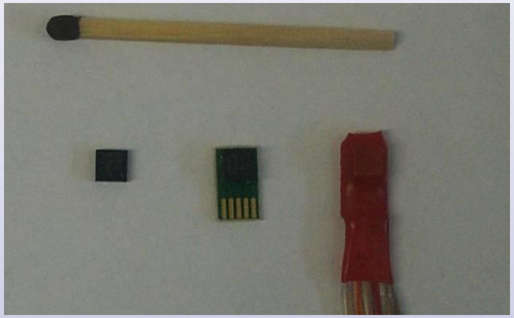
F = m a

- force sensor
  - strain gauge - old solution, large dimensions and weight of the sensor
  - todays solution
    - **i-MEMS accelerometers** – semiconductor strain gauges + amplifier in one chip
    - **piezoelectric,** usually IEPE

4. Accelerometers

- **i-MEMS accelerometers = „all in one“ solution**
- **the sensor real design and basic properties**
    - mass, semiconductor strain gauges and amplifier are in one electronical chip
    - everything made by integrated circuit manufacturing technology





- **basic properties:**
- measurement **of static acceleration - gravity**
- acceleration range **0 - 70g**
- frequency range **0 – 1500Hz**
- one, two, or three axis sensors
- **advantages:**
    - very small dimensions, very small weight, very small price (mass production of chips)
- **disadvantages:**
    - low range of accelerations and frequencies

- use in everyday life - rotating the phone screen according to its position

8.3.2. piezoelectric accelerometers

- **piezoelectric accelerometers**
- **the sensor real design and basic properties**
    - mass and small piezoelectric transducer are used

- **basic properties:**
- **does not measure static acceleration** – gravity
- acceleration range **0 - 50000g**
- frequency range **0.5 – 30000Hz**
- one, two, or three axis sensors
- today usually with bulit-in electronics, ie. IEPE standard

- **advantages:**
    - very high acceleration and very high frequency range
- **disadvantages:**
    - higher price
    - a special integration amplifier for sensors without IEPE is required

Exam questions

- Force sensors with strain gauge measurement element
  - the sensor function principle (p. 3)
  - basic properties, advantages, disadvantages (p. 7)
- Piesoelectric force sensors
  - the sensor function principle (p. 8, 9)
  - the crystal electrical imbalance evaluation principle (p. 10, 11, 12)
  - basic properties, advantages, disadvantages (p. 14)
- Pressure sensors
  - the sensor function principle (p. 16)
  - basic properties, advantages, disadvantages (p. 17)
- Torgue sensors
  - the sensor function principle, the sensor real design (p. 18)
  - non-rotating sensor for static torque measurement, real design and basic properties (p. 19)
  - sensor for rotating shafts, real design and basic properties (p. 20, 21)
- Accelerometers
  - the sensor function principle, the sensor real design (p. 22)
  - i-MEMS accelerometers, basic properties, advantages, disadvantages (p. 23)
  - piezoelectric accelerometers, basic properties, advantages, disadvantages (p. 24)