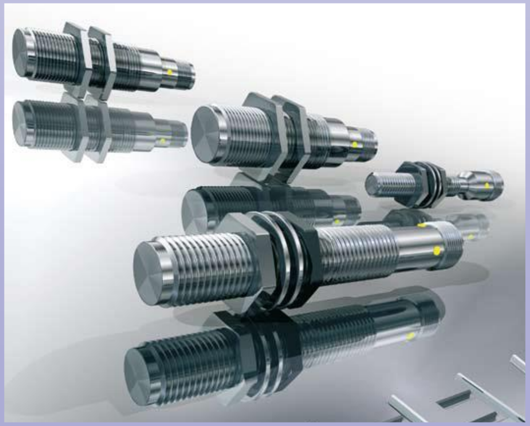
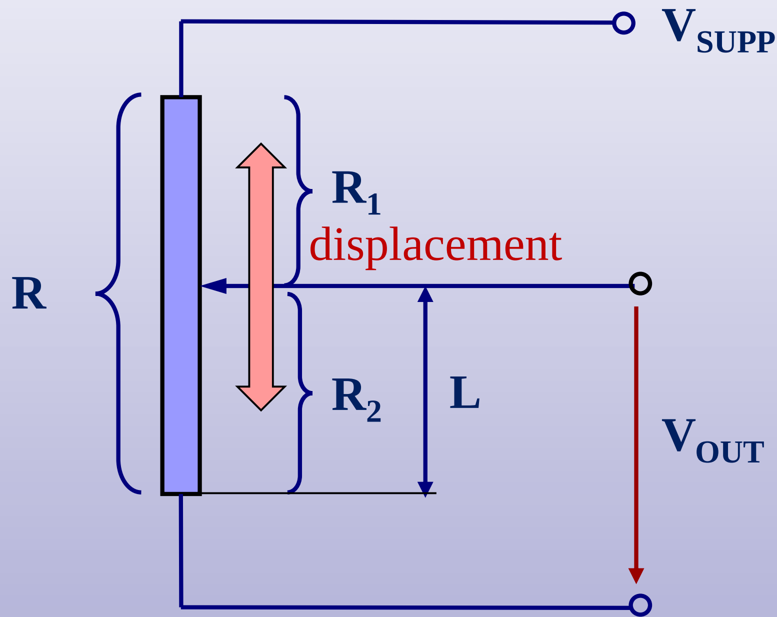
Sensors
for
displacement and rotation angle measurement

- Resistive sensors
- Inductive sensors
- Magnetostrictive sensors
- Capacitive sensors
- Optical sensors
- Incremental sensors



1. Resistive sensors

- **the sensor function principle**
  - displacement is converted to a change of resistance
  - principle of the voltage divider, ie potentiometer
  - output voltage $\mathbf{V_{OUT}}$ is directly proportional to the position of the slider **L**



Voltage divider

$$V_{OUT} = \frac{R_2}{R_1 + R_2} V_{SUPP}$$

$$V_{OUT} = \frac{R_2}{R} V_{SUPP}$$ where $R_2 = \rho \frac{L}{S}$

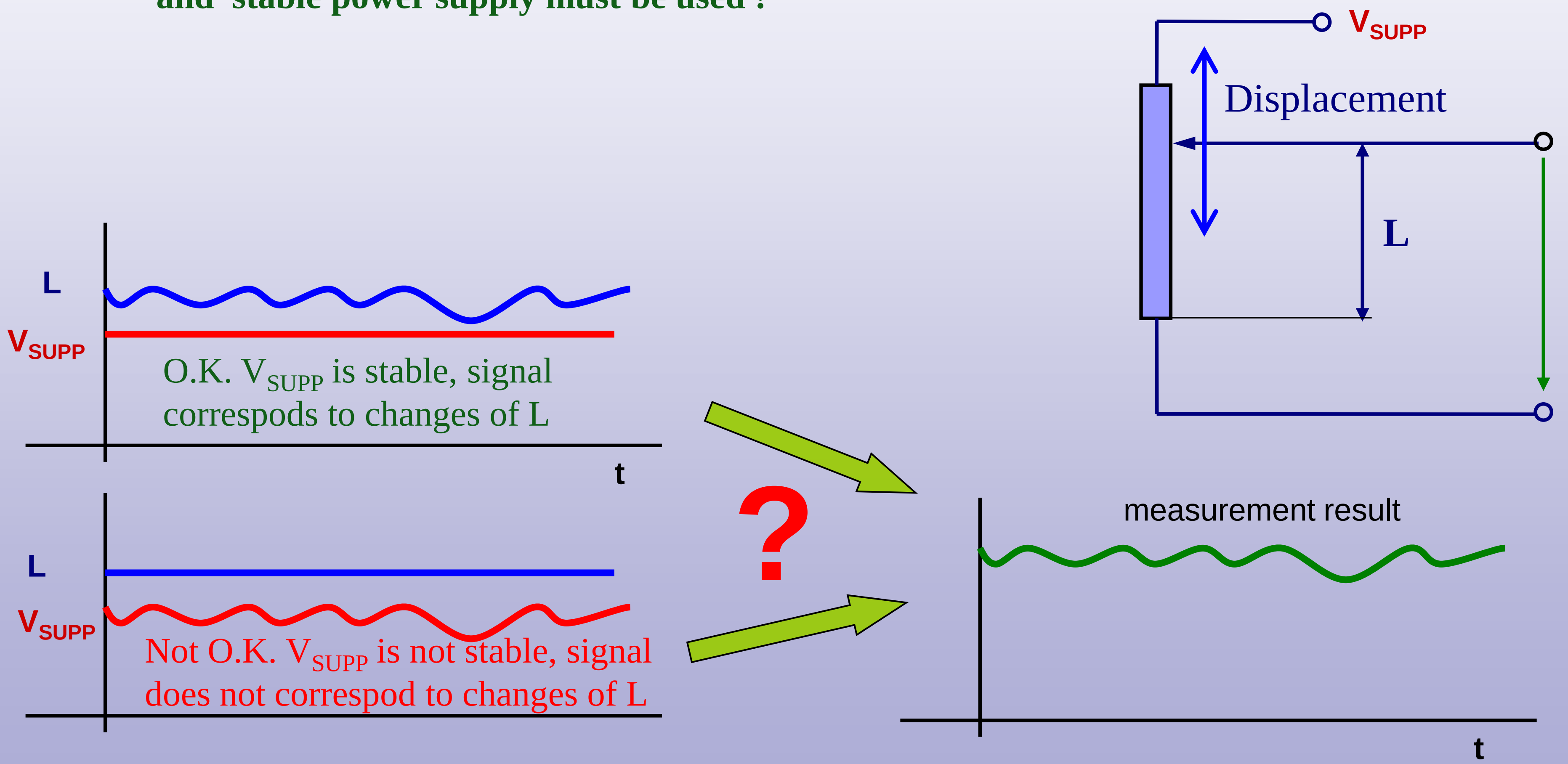
$$V_{OUT} = \frac{\frac{\rho}{S} V_{SUPP}}{R} L$$

$$U_{OUT} = c * L$$

Caution: c is constant only if the supply voltage V_{SUPP} is constant !

1. Resistive sensors

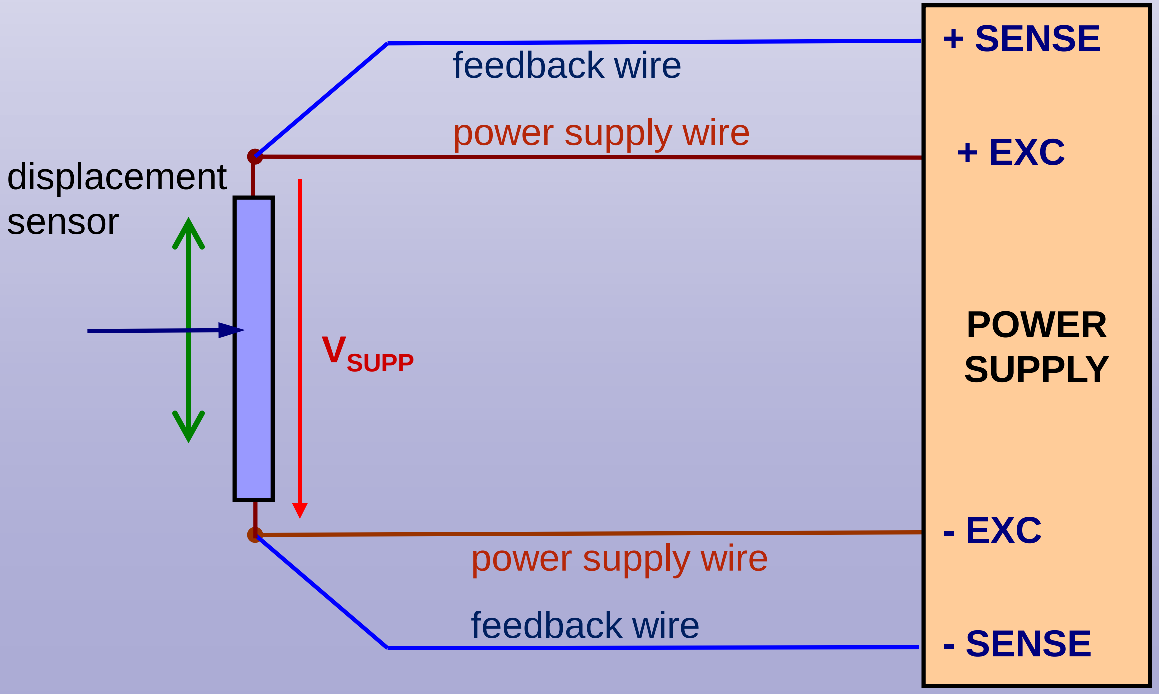
- **basic principles of connection and use**
  - **because the output voltage also depends on the supply voltage, an accurate and stable power supply must be used !**

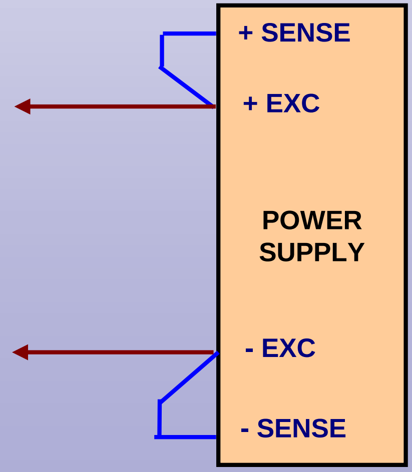


1. Resistive sensors

- **basic principles of connection and use**
  - power supplies for resistive sensors have SENSE feedback inputs
  - they are used to compensate for voltage drop on supply wires
  - feedback ensures accurate and stable sensor supply

  - **feedback wires do not have to be used only if the supply wires have a short length**
  - if **in this case** the power supply has SENSE inputs, they must not remain unconnected!! **The SENSE inputs are connected to the power supply outputs on the power supply terminal board** (see picture on the right)**!!**





1. Resistive sensors

basic properties:

- linear or rotary angle measurement
- range from tens of mm to several meters, rotating up to 360°
- high accuracy up to 0.02%
- high speed up to 10 m/s and acceleration up to 200m/s2, rotation up to 10000 rpm
- lifetime up to 100 million cycles

advantages:

- simple design
- relatively low price
- wide selection of types, lengths, anchors
- return spring or free slider
- DC voltage supply
- output directly to el. voltage, trivial connection

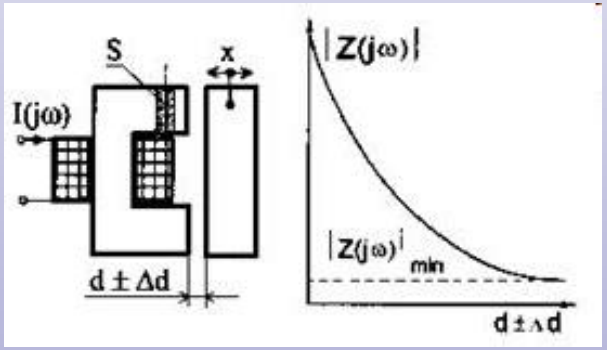
disadvantages:

- force is needed to drive the slider (slider friction) - the possibility of experiment influencing
- less resistance to environmental influences (vibrations, wetness and dirt)

2. Inductive sensors
2.1. sensors with closed magnetic circuit

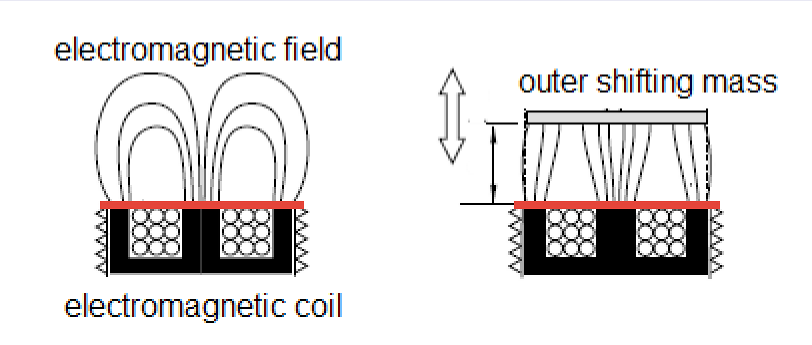
- **the sensor function principle**
  - the displacement is converted to a change in the size of the air gap ***d*** of the magnetic circuit, thus changing the inductance ***L***
  - the dependence is nonlinear
  - the relationships apply only to very small air gaps, ie they can only be used for very small displacements
  - needs special circuits for power supply (AC voltage) and signal evaluation

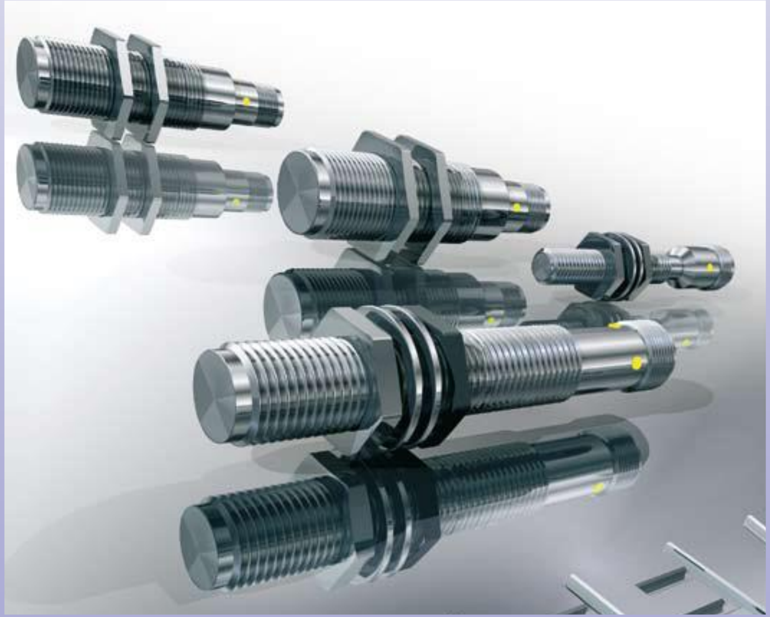
$$L = \frac{N^2}{2d} * \mu * S$$



2. Inductive sensors
2.1. sensors with closed magnetic circuit

- **the sensor real design**
  - the magnetic circuit is closed through the outer mass
  - **the outer mass must have magnetic properties, it must affect the magnetic field (eg iron)**
  - the distance of the mass from the front of the sensor is measured
  - all special circuits for power supply and signal evaluation are into the sensor body
    - the sensor output signal corresponds linearly to the distance
    - the sensor output is a standard 0-10V or 4-20mA signal





2. Inductive sensors

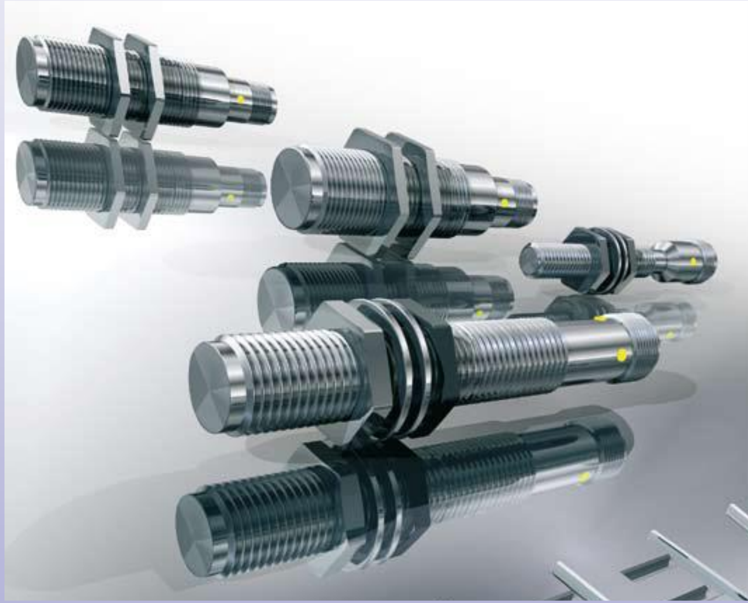
2.1. sensors with closed magnetic circuit

basic properties:

- linear distance measurement
- range from tenths of a millimeter to several millimeter (max. 20mm)
- accuracy about 1%

advantages:

- simple design
- relatively low price
- built-in electronics - unified output in optional format
- high resistance to external influences
- non-contact measurement, without touching fixed and moving parts, without friction
- virtually unlimited service life



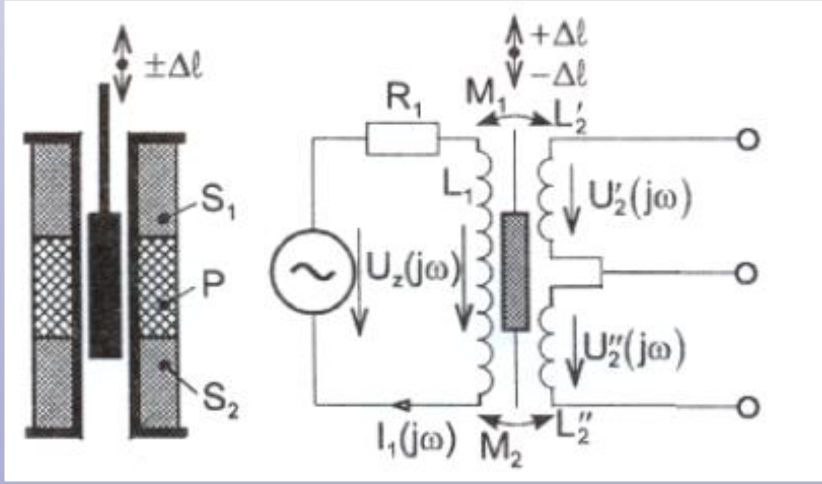
disadvantages:

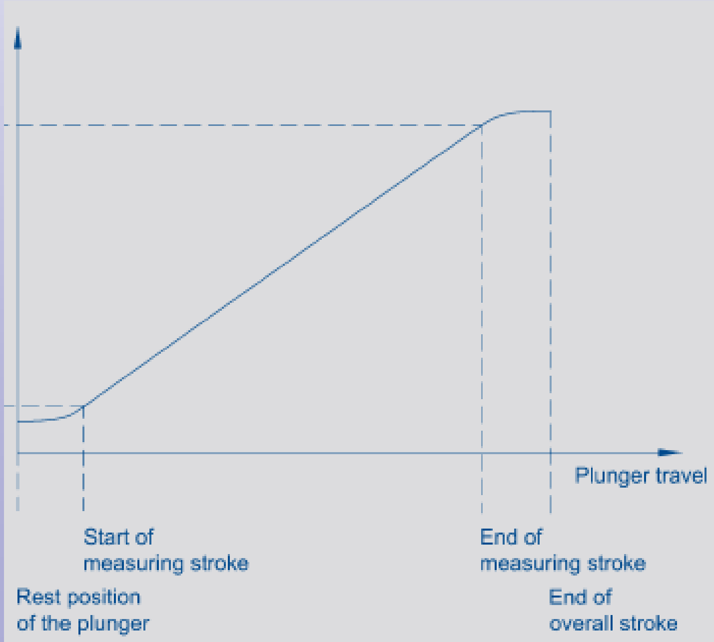
- only linear distance measurement for short distances
- sensor for a specific type of external mass (magnetic properties)
- limited temperature range (usually 0 - 80°C) due to built-in electronics
- frequency band is most often hundreds of Hz (it is limited due to AC power supply - Shannon's theorem)

2. Inductive sensors

2.2. Linear Variable Differential Transformer - LVDT sensor

- **the sensor function principle**
  - the displacement is converted to a change of mutual inductance between primary and secondary coils ***M***
  - **one of the oldest displacement measurement principles**
  - the dependence is linear with the exception of the edge positions
  - simple, durable sensor without mechanical connection of fixed and moving parts
  - needs special circuits for power supply (AC voltage) and signal evaluation



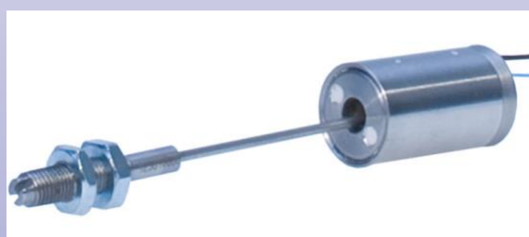


2. Inductive sensors

2.2. Linear Variable Differential Transformer - LVDT sensor

- **the sensor real design**
  - the iron core is slided into the "tube" with the coils
  - the core design options
    - free core - without contact of fixed and moving parts
    - the compact sensor - sprung or unsprung core
  - the sensor design option
    - separate sensor without electronics - very durable, but needs external electronics for AC power and signal evaluation
    - built-in electronics - limits the temperature range

free core



compact sensor, unsprung core

compact sensor, sprung core

modul of external electronics

2. Inductive sensors

2.2. Linear Variable Differential Transformer - LVDT sensor

basic properties

- range from 1 mm to 1 m
- accuracy up to 0.1%
- high speed up to 10 m/s and very high acceleration up to 2500m/s2
- return spring or free slider
- lifetime up to 10 million cycles for compact sensor with sprung core, unlimited lifetime with free core

advantages:

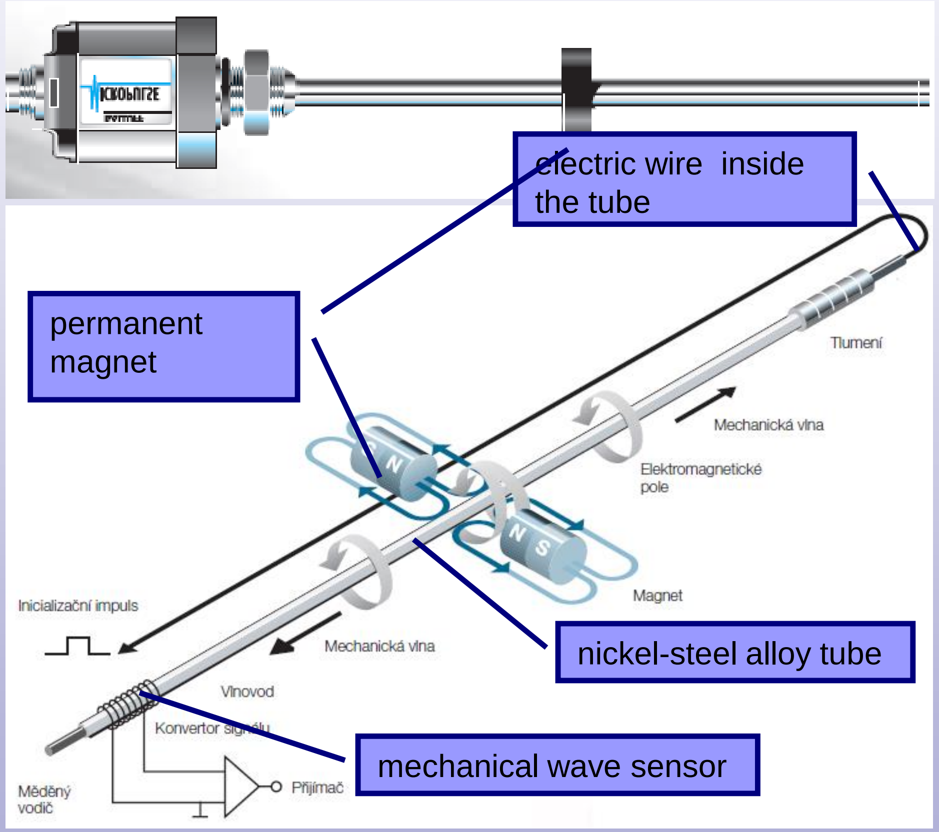
- simple and durable design
- wide selection of types, lengths, anchors
- non-contact movement, without friction for the free core type
- the sensor without bulit-in electronics is the best sensor for extreme ambient conditions
    - vibrations, wetness, underwater use, dirt, mud,….
    - high temperature range

disadvantages:

- only for linear movement measurement
- nonlinear dependence at the end positions
- AC voltage supply (usually 4,8kHz), AC output signal
    - electronics for power supply and signal processing is needed (external or bulit-in)

3. Magnetostrictive sensors

- **the sensor function principle**
  - the displacement is converted to measure the propagation time of a mechanical wave in a special material
  - a circular magnetic field around the inside wire is created by a current pulse in it
  - elastic deformation of the tube occurs at the point where this field intersects with the field of the outer permanent magnet (this is called the magnetostrictive phenomenon)
  - elastic deformation of the tube proceeds as a mechanical wave to the its end at a speed of 2830 m / s (speed is given by the alloy)
  - the sensor at the end of the tube detects the wave and the time delay between the current pulse and the arrival of the wave is measured



  - the time delay is directly proportional to the distance of the permanent magnet from the sensor at the end of the tube
  - **the position of the permanent magnet relative to the end of the tube is thus measured**

3. Magnetostrictive sensors

- **the sensor real design**
  - the fixed sensor body around which a permanent magnet is moved
  - the permanenet magnet options
    - ring around the tube
    - magnet on one side of the sensor
  - the sensor design option
    - separate permanent magnet without mechanical contact between it and sensor body (maximum distance between the magnet and the sensor is limited)
    - the permanent magnet is fixed to the slider on the sensor body
  - the sensor contains integrated electronics
  - **modern replacement of LVDT sensors**

3. Magnetostrictive sensors

basic properties

- only linear measurement
- range from tens of mm to units of meters
- high accuracy up to 0.02%
- built-in electronics, standard output 0-10V or 4-20mA or digital output

advantages:

- unlimited lifetime with free magnet
- non-contact measurement, without friction for the free magnet type
- the best sensor for extreme ambient conditions – wetness, underwater use, dirt, mud,….

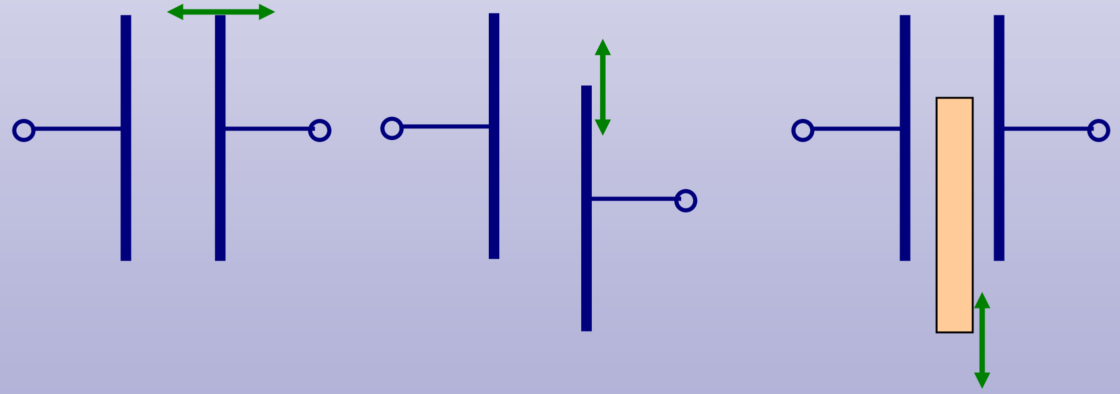
disadvantages:

- the sensor works discontinuously
  pulse - time delay measurement, pulse - time delay measurement, ……
- therefore it cannot be used for high speeds
- temperature range limited by built-in electronics

4. Capacitive sensors

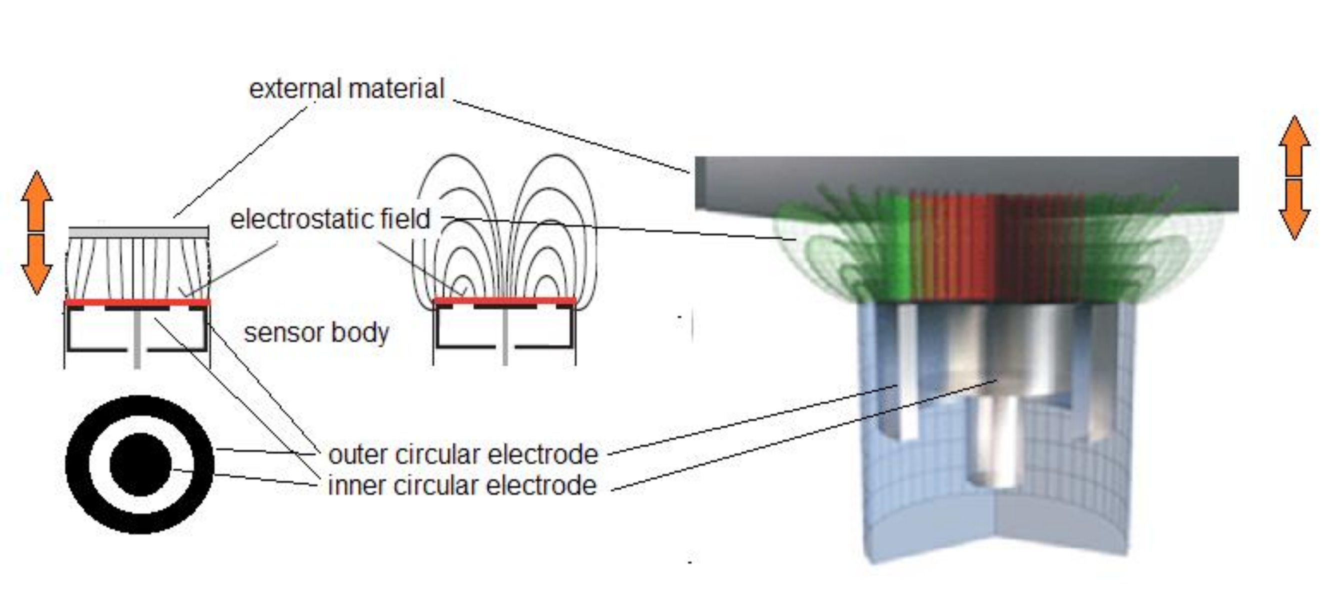
- **the sensor function principle**
  - the displacement is converted to a change of capacity ***C***
  - capacity change can be achieved:
    - by changing the distance of the plates - nonlinear dependence
    - by changing the permittivity of space - linear dependence
    - by changing the area of the electrodes - linear dependence, mostly for the rotation angle sensor

$$C = \varepsilon_0 * \varepsilon_r * \frac{S}{d}$$



4. Capacitive sensors

- **the sensor real design**
  - „open capacitor" - both ring-shaped electrodes are in the body of the sensor
  - the electrostatic field is affected by an external material that must be electrically conductive
  - the capacitor capacity is changed by changing the distance of the external material, it is evaluated by the built-in electronics



4. Capacitive sensors

basic properties

- only linear measurement
- non-contact measurement – unlimited lifetime
- very small range up to 20 mm
- accuracy up to 0.5%

advantages:

- simple and durable design, low price
- non-contact measurement without friction
- unlimited lifetime
- good resistance to environmental influences (wetness and dirt)
- built-in electronics – standard output signal

disadvantages:

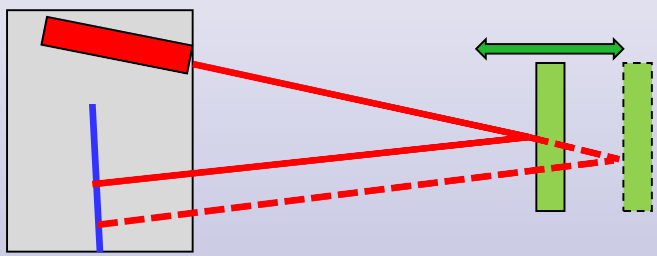
- only linear distance measurement for short distances
- sensor for a specific type of external mass (electric conductive)
- limited temperature range (usually 0 - 80°C) due to built-in electronics
- frequency band is most often hundreds of Hz (it is limited due to AC power supply - Shannon's theorem)

5. Optical (laser) sensors

- **two different function principles**

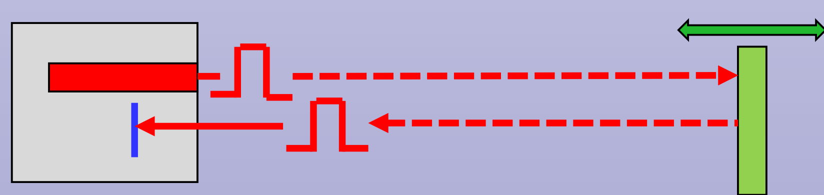
1. triangulation principle

- the sensor emits a laser beam at a certain angle, the beam is reflected from the measured object back to the CCD receiver in the sensor
- the position of the beam on the CCD sensor corresponds to the distance of the object from the sensor



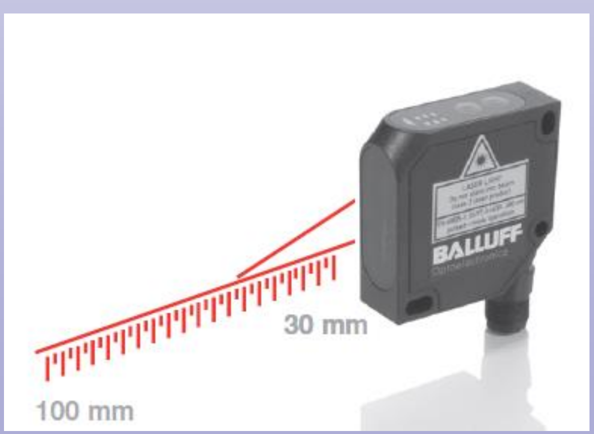
2. measuring the time between the transmitted pulse and the pulse reflected back

- the speed of light is a known constant
- requires very accurate timing



5. Optical (laser) sensors

- **the sensor real design**
  - compact sensor for distance measurement
  - always with built-in electronics
  - triangulation sensor is used to measure shorter distances (this is limited by the angle of the transmitted beam and the resolution of the CCD element
  - time sensors are used for long distances measurement (short distances are limited by the accuracy of time measurement due to the high speed of light)



5. Optical (laser) sensors

basic properties

- only linear measurement
- accuracy up to 0.2%
- triangulation principle
  - range from mm to higher hundreds of mm
  - the measurement speed is limited by the speed of the CCD element
- time-measuring sensors
  - range from of lower hundreds of mm to tens of m

advantages:

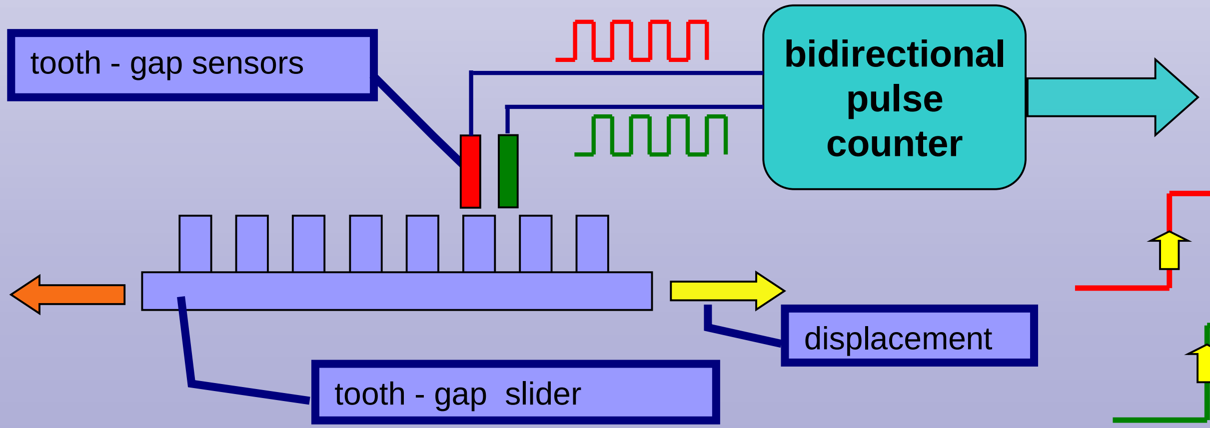
- non-contact measurement – unlimited lifetime
- integrated electronics – standard output signal

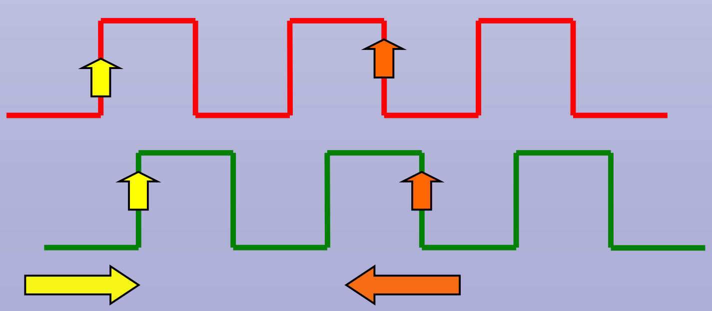
disadvantages:

- the sensor works discontinuously
- temperature range limited by built-in electronics
- less resistance to environmental influences (vibrations, wetness and dirt)
- defined requirements for the surface quality of the object for good beam reflection
- high price (depends on accuracy and speed)

6. Incremental sensors

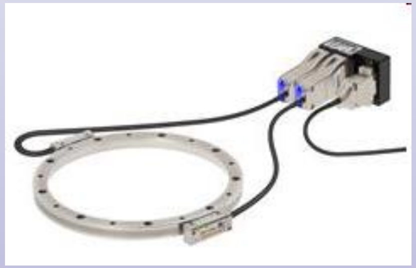
- **the sensor function principle**
  - displacement is converted to a sequence of impulses
  - two tooth - gap sensors (optical or magnetic principle)
  - two 90° offset signals
  - the bidirectional counter (up/down counter)
    - the displacement value is determined by number of impulses
    - the displacement direction is determined by order of rising edges





6. Incremental sensors

- **the sensor real design**
  - stationary scanning head and separate moving tooth - gap slider or disk
    - tooth - gap slider, disk
      - made from low temperature dilating material
      - tape with magnetic recording "mass - gap"
      - tape with optical recording "mass - gap" - laser generated lines
      - it can also be really "mechanical matter - gap" - slider or disk with holes (eg in an old type of mouse with a moving ball)



  - compact sensor
    - usually only rotary design
    - scanning head and tooth - gap disk in one body

6. Incremental sensors

basic properties

- linear or rotary angle measurement
- linear range from tens of mm up to 10 m
- fully 360 degrees for rotary angle measurement
- accuracy up to 1μm
- frequent use in machine tools

benefits:

- non-contact measurement – unlimited lifetime
- integrated electronics – digital or analogue output signal
- long displacements measurement

disadvantages:

- **unspecified position value after switching on !!!**
  - the sensor measures only the position increments - the number of pulses during moving, the static starting position is not known
  - after switching on, the slider must first move to the "mechanical" zero where the sensor counter is reset
- high price (depends on accuracy and speed)

Exam questions

- Resistive sensors
  - the sensor function principle (p. 2)
  - basic properties, advantages, disadvantages (p. 5)
- Inductive sensors with closed magnetic circuit
  - the sensor function principle, the sensor real design (p. 6, 7)
  - basic properties, advantages, disadvantages (p. 8)
- Linear Variable Differential Transformer - LVDT sensor
  - the sensor function principle, the sensor real design (p. 9, 10)
  - basic properties, advantages, disadvantages (p. 11)
- Magnetostrictive sensors
  - the sensor function principle, the sensor real design (p. 12, 13)
  - basic properties, advantages, disadvantages (p. 14)
- Capacitive sensors
  - the sensor function principle, the sensor real design (p. 15, 16)
  - basic properties, advantages, disadvantages (p. 17)
- Optical laser sensors
  - two sensor function principle, the sensor real design (p. 18, 19)
  - basic properties, advantages, disadvantages (p. 20)
- Incremental sensors
  - the sensor function principle, the sensor real design (p. 21, 22)
  - basic properties, advantages, disadvantages (p. 23)