Displacement, and Position sensors

Displacement Measurement

Measurement of displacement is the basis of measuring:

- Position
- Velocity
- Acceleration
- Stress
- Force
- Pressure
- Proximity
- Thickness
- ...

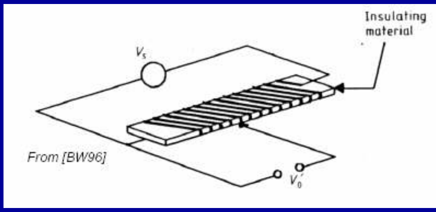
Displacement Sensors types

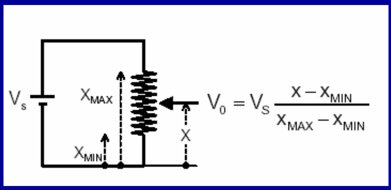
- Potentiometers displacement sensors
- Inductive displacement sensors
- Capacitive displacement sensors
- Eddy current displacement sensors
- Piezoelectric displacement sensors
- Ultrasonic displacement sensors
- Magnetostrictive displacement sensors
- Optical encoder displacement sensors
- Strain Gages displacement sensors
- ...

Potentiometers displacement sensors

Resistive displacement sensors

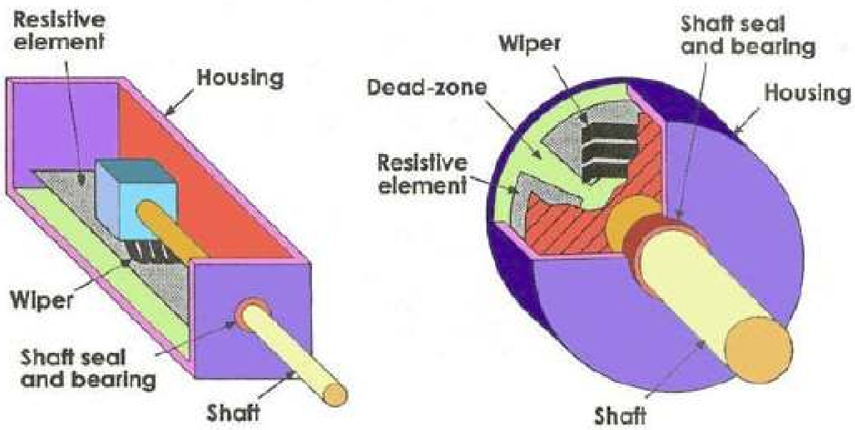
- An electrically conductive wiper that slides against a fixed resistive element.
- To measure displacement, apotentiometer is typically wired in a"voltage divider" configuration.
- A known voltage is applied to the resistor ends. The contact is attached to the moving object of interest
- The output voltage at the contact is proportional to the displacement.





Resistive displacement sensors

- Commonly termed **potentiometers** or "pots".



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Resistive displacement sensors

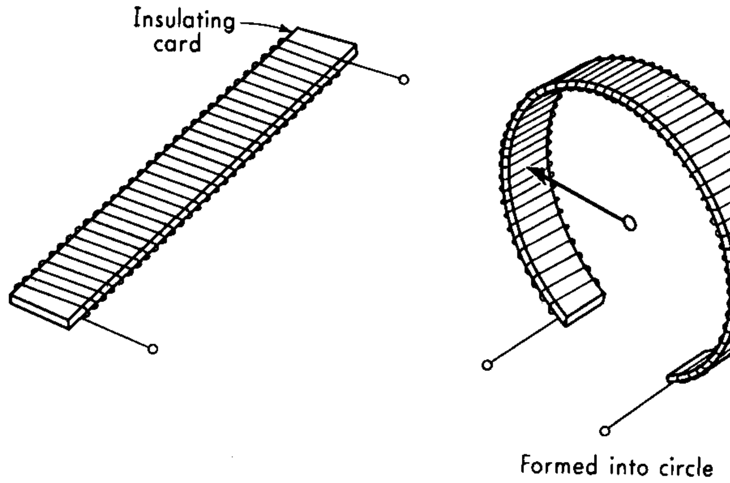
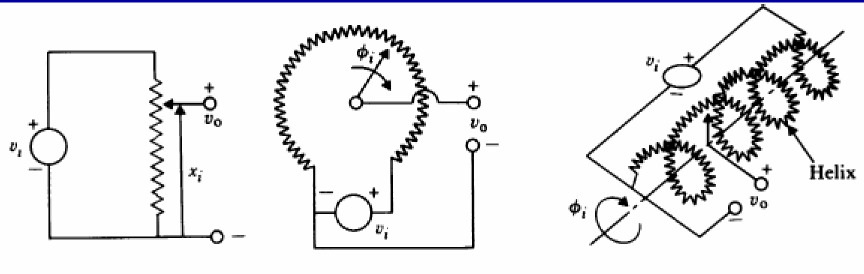


Figure 4.6 Construction of wirewound resistance elements.

Resistive displacement sensors

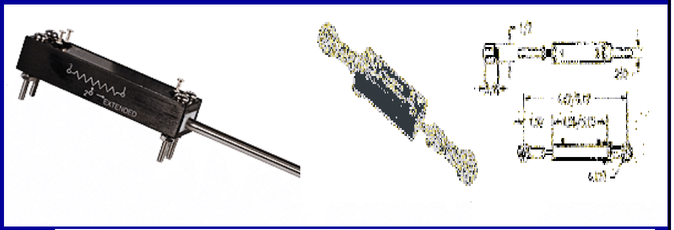
Three types of potentiometer devices for measuring displacement

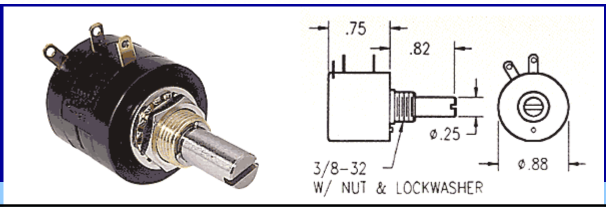


(a) Translational (b) Single-turn (c) Multi-turn

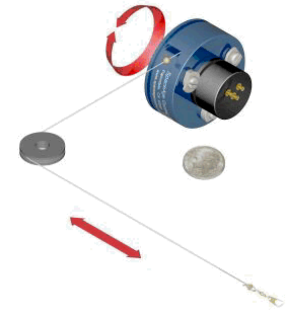
Potentiometer types

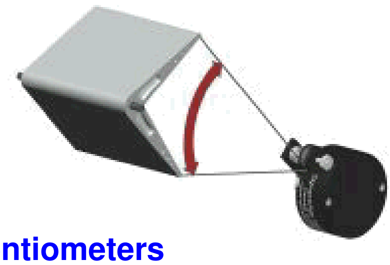
- Turn counting dial potentiometer
- Linear motion
- Multi turn Potentiometer



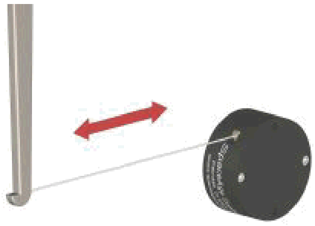


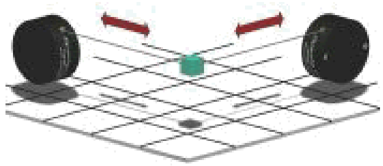
Resistive displacement sensors





String potentiometers





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Resistive displacement sensors

Advantages	Disadvantages
Easy to use	Limited bandwidth
Low cost	Frictional loading
High-amplitude output signal	Inertial loading
Proven technology	Wear
Passive	

http://bohr.physics.hku.hk/academic/courses/phys2234/06_Displacementvelocity.pdf

Resistive displacement sensors

	Conductive plastic	Wirewound	Hybrid
Resolution	Infinitesimal	Quantized	Infinitesimal
Power rating	Low	High	Low
Temperature stability	Poor	Excellent	Very good
Noise	Very low	Low, but degrades with time	Low
Life	$10^6 \sim 10^8$ cycles	$10^5 \sim 10^6$ cycles	$10^6 \sim 10^7$ cycles

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Choosing a potentiometer

- The important parameters are:
  - ✓Operating temprature
  - ✓Shock and vibration
  - ✓Humidity
  - ✓Contamination and seals

  - ✓Others:
    - ◆Life cycle
    - ◆Dither

Inductive displacement sensors

Inductive displacement sensors

Self-generating type

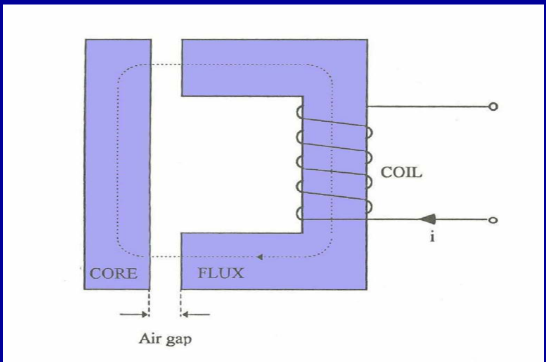
- ✓When there is a relative motion between aconductor and a magnetic field, a voltage isinduced in the conductor.

Passive type

- ✓Requires an external source of power.

Inductive displacement sensors

A basic inductive sensor consists of a magnetic circuit made from a ferromagnetic core with a coil wound on it.



The coil acts as a source of magnetomotive force that drives the flux through the magnetic circuit and the air gap. The presence of the air gap causes a large increase in circuit reluctance and a corresponding decrease in the flux. Hence, a small variation in the air gap results in a measurable change in inductance.

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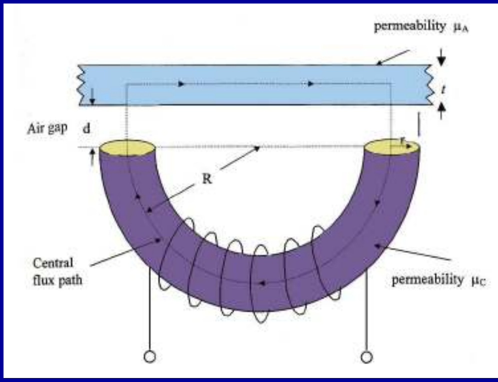
Inductive displacement sensors

Single-Coil Linear Variable-Reluctance Sensor



The reluctance of the coil is dependent on the single variable. The reluctance increases nonlinearly with increasing gap.

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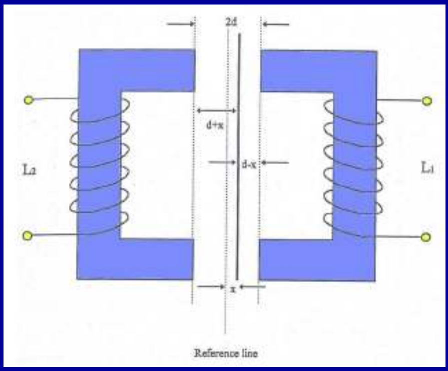
Inductive displacement sensors

Variable-Differential Reluctance Sensor



A variable-differential reluctance sensor consists of an armature moving between 2 identical cores separated by a fixed distance. The armature moves in the air gap in response to a mechanical input. This movement alters the reluctance of coils 1 and 2, thus altering their inductive properties. This arrangement overcomes the problem of nonlinearity inherent in single coil sensors.

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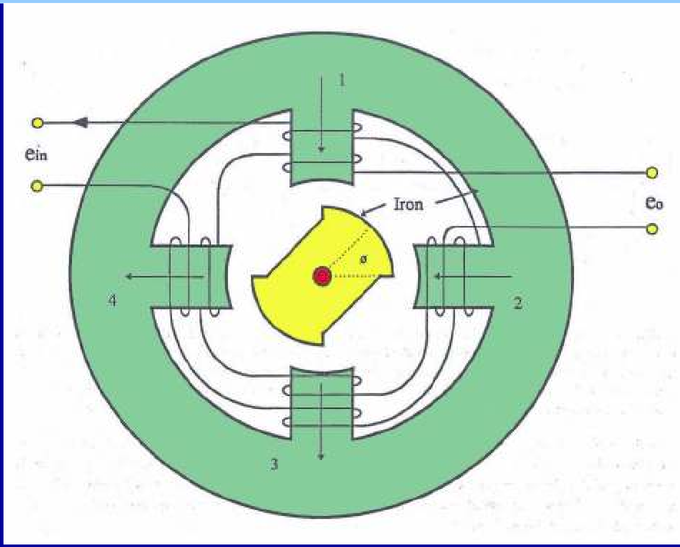
Inductive displacement sensors



Magnesyn

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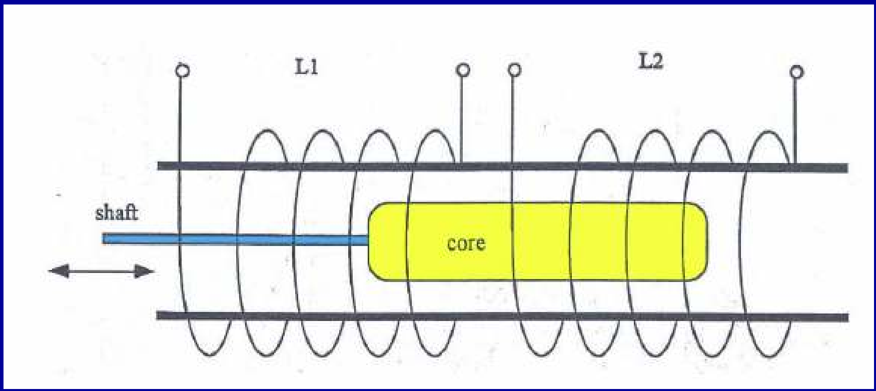
Inductive displacement sensors

Variable-Coupling Transducers



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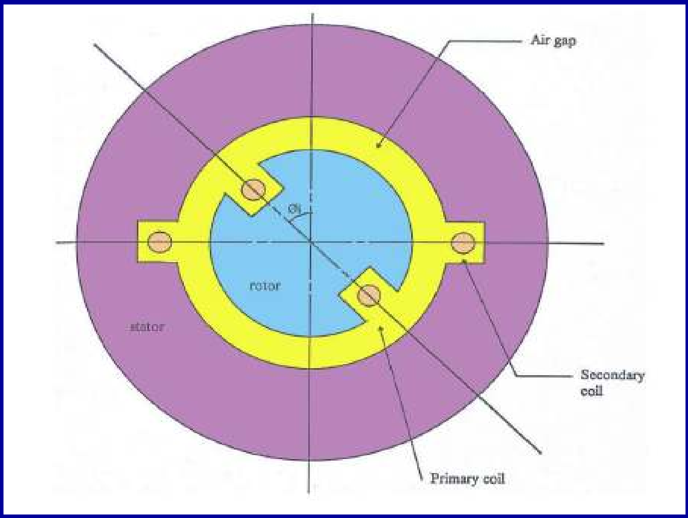
Inductive displacement sensors

Induction Potentiometer



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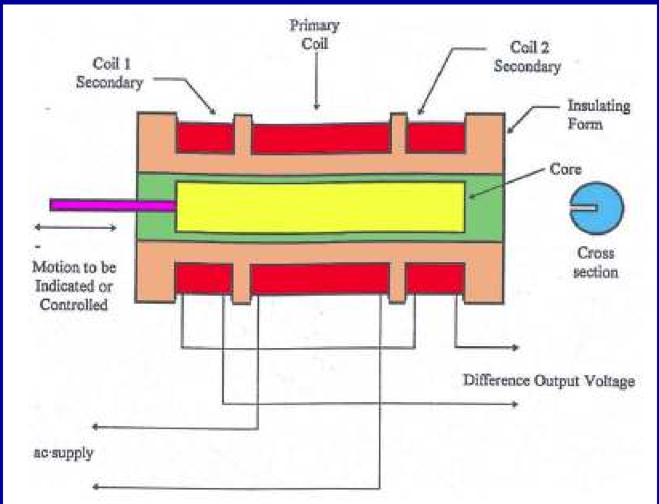
Inductive displacement sensors

Linear Variable-Differential Transformer (LVDT)



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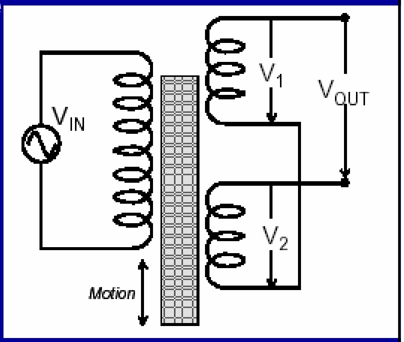
Inductive displacement sensors

Linear Variable Differential Transformer (LVDT)

Motion of a magnetic core changes the mutual inductance of two secondary coils relative to a primary coil



Primary coil voltage: $V_S \sin(\omega t)$

Secondary coil induced emf:

$V_1 = k_1 \sin(\omega t)$ and $V_2 = k_2 \sin(\omega t)$

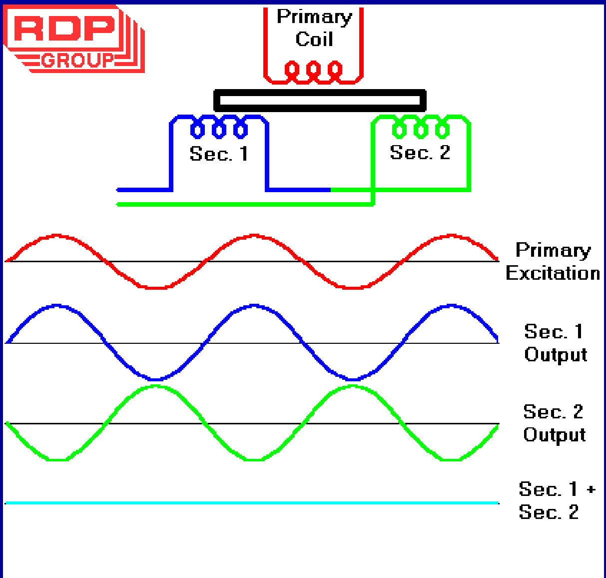
k_1 and k_2 depend on the amount of coupling between the primary and the secondary coils, which is proportional to the position of the coil.

When the coil is in the central position, $k_1 = k_2 \Rightarrow V_{OUT} = V_1 - V_2 = 0$

When the coil is is displaced x units, $k_1 \neq k_2 \Rightarrow V_{OUT} = (k_1 - k_2)\sin(\omega t)$

Positive or negative displacements are determined from the phase of V_{OUT}.

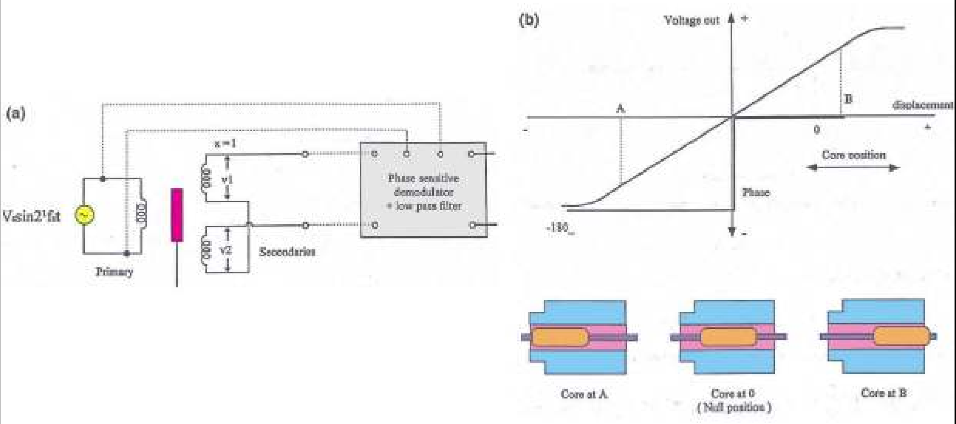
Inductive displacement sensors



http://www.rdpelectronics.com/displacement/lvdt/lvdt-principles.htm

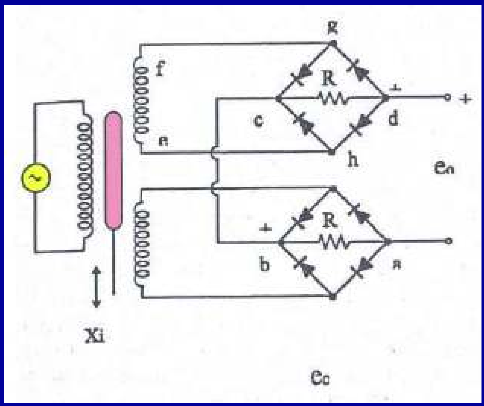
Inductive displacement sensors

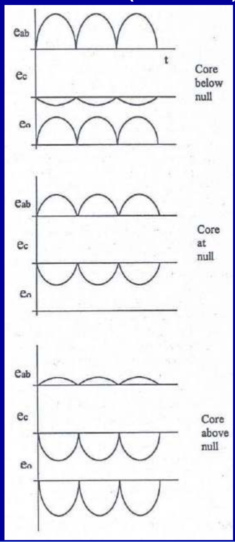
Linear Variable-Differential Transformer (LVDT)



Inductive displacement sensors

Linear Variable-Differential Transformer (LVDT)





Inductive displacement sensors

LVDT Characteristics

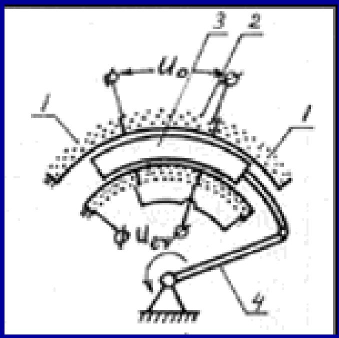
- ✓Typical LVDTs run at 3 to 15V, and freq. 60 to 20000Hz
- ✓LVDTs can measure from 75 mm down to 0.1 mm
- ✓Due to small variations in the windings, a small residual voltage appears at the output when the coil is in the central position

➢ **Advantages of the LVDT over other displacement sensors**

- ✓No mechanical wear ensures a long life Complete electrical isolation
- ✓DC versions with integrated oscillators are available

Inductive displacement sensors

Rotary voltage differential transformer



Uex = excitation voltage, Uo = output voltage,
1 = excitation coil, 2 = output coil, 3 = moving core or armature, 4 = sensing shaft.

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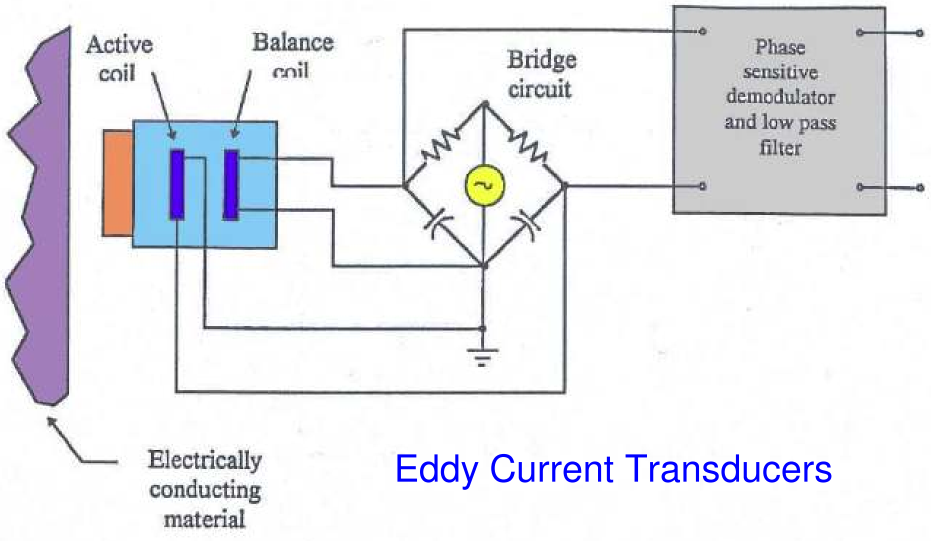
Eddy current displacement sensors

Inductive displacement sensors



Eddy Current Transducers

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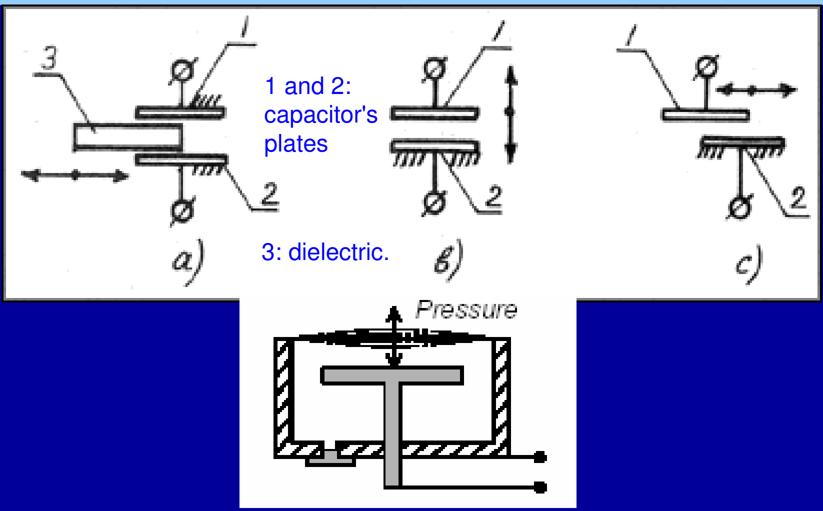
Capacitive displacement sensors

Capacitive displacement sensors



Capacitance will vary with variation in dielectric constant (a), gap between plates (b), and area of capacitor's plates (c).

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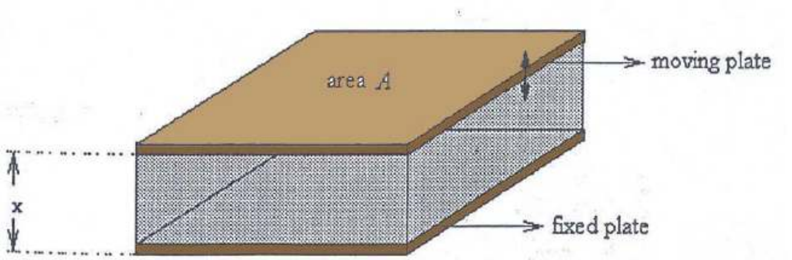
Capacitive displacement sensors



$$C(x) = \varepsilon A/x = \varepsilon_r \varepsilon_0 A/x$$

where ε = dielectric const. or permittivity
ε_r = relative dielectric const.
ε_0 = dielectric const. of vacuum
x = distance of the plates in m
A = effective area of the plates in m^2

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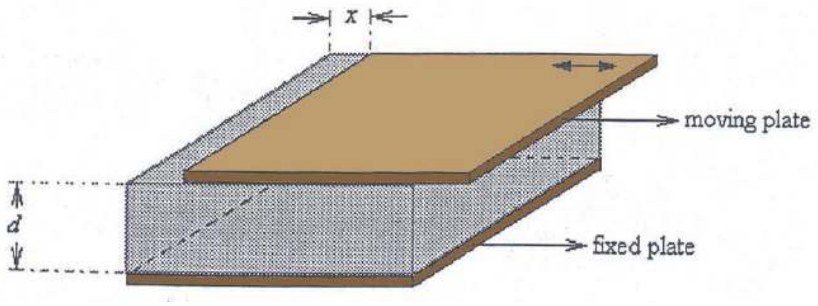
Capacitive displacement sensors



$$C = \varepsilon_r \varepsilon_0 (A-wx)/d$$

where w = width
wx = reduction in the area due to movement of the plate

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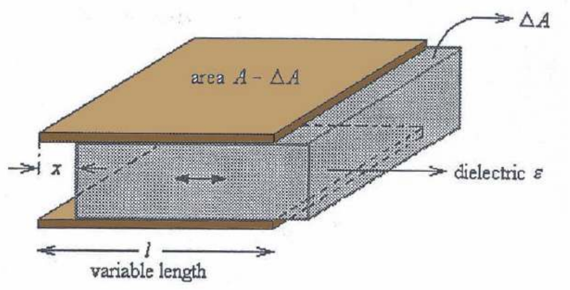
Capacitive displacement sensors

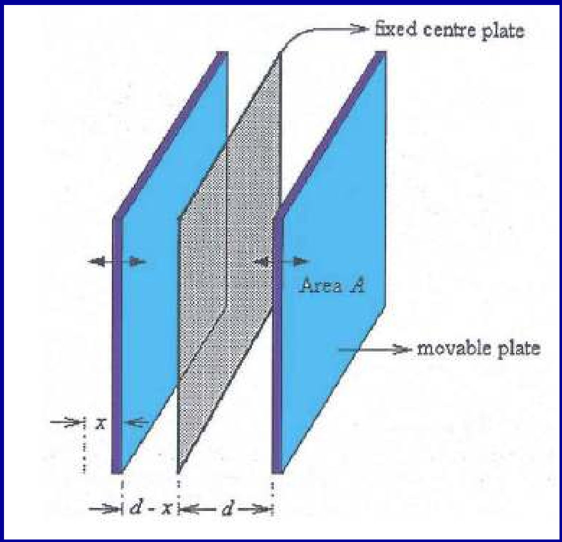


$$C = \varepsilon_0 w[\varepsilon_0 l\text{-}(\varepsilon_2\text{-}\varepsilon_1)x]$$

where ε_1 = relative permittivity of the dielectric material
ε_2 = permittivity of the displacing material (e.g., liquid)

Capacitive displacement sensors

Differential Capacitive Sensors



Capacitive displacement sensors

Notes

- displacement measurements for rotational or translational motions.
- Variable distance (d) sensors operate over a range of a few millimeters
- Cross-sensitivity to temperature and humidity if the dielectric is air, hence can be used for humidity and moisture sensing.
- Can easily be used at high and low temperatures.
- Capacitive sensors are also commonly used to measure pressure.
- "Condenser" microphones measure changes in air pressure of incoming sound waves

Piezoelectric displacement sensors

Piezoelectric displacement sensors

Piezoelectricity — the ability of certain materials to develop an electric charge that is proportional to a direct applied mechanical stress.

- The effect is reversible.
- Piezoelectric materials will deform (strain) proportionally to an applied electric field.
- The effect is of the order of nanometers.
- Applications - for example fine focusing of optical assemblies, etc.

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Piezoelectric displacement sensors

Applications of Piezoelectric effect

- Convert electrical energy to mechanical energy, vice versa.

Passive mode

- The transducer only receives signals.
- Obtain voltage from an external stress.
- Applications: microphones, vibrational sensor.

Active mode

- The transducer changes its dimensions and sends an acoustic signal into a medium.
- Applications: ink jet printers, micropumps, medical ultrasonic imaging.

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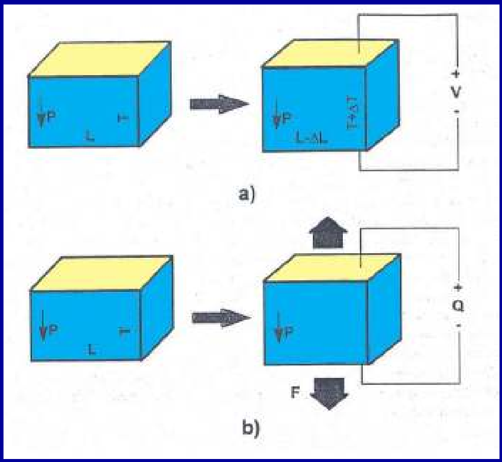
Piezoelectric displacement sensors



Direct and converse piezoelectric effect: (a) an electric field applied to the material changes its shape (b) a stress on the material yields a surface charge.

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Piezoelectric displacement sensors

Ferroelectrics — an important class of piezoelectric materials.

Single crystal

Quartz (SiO2), Lithium Niobate (LiNbO3) and Lithium Tantalate (LiTaO3).

Piezoelectric Ceramics

- Made up of mixed oxides containing corner-sharing octahedra of O^{2-} ions, which is the **Perovskite** family.
- General formula is ABO3. • E.g. BaTiO3.
- It is stable, has a wide temperature range of operation, and is easily fabricated.

Piezoelectric Polymers

- The electromechanical properties of piezoelectric polymers are significantly lower than those of piezoelectric ceramics.

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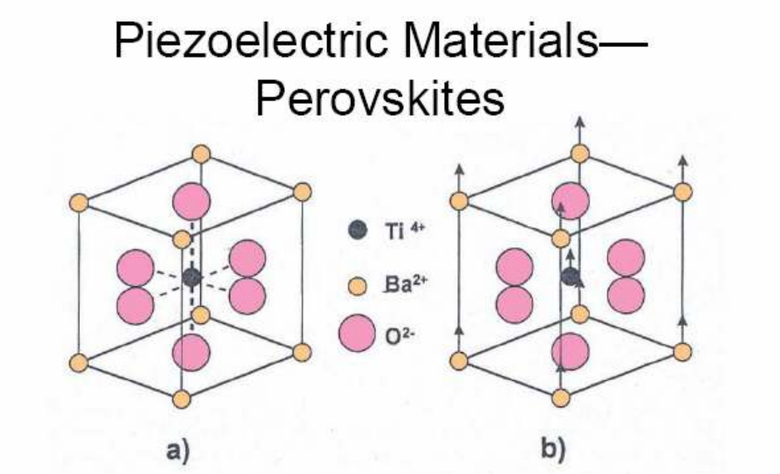
Piezoelectric displacement sensors



- The crystal structure of $GaTiO_3$: (a) above the Curie pt., the cell is cubic (b) below the Curie pt., the cell is tetragonal with Ba^{2+} and Ti^{4+} ions displaced relative to O^{2-} ions.

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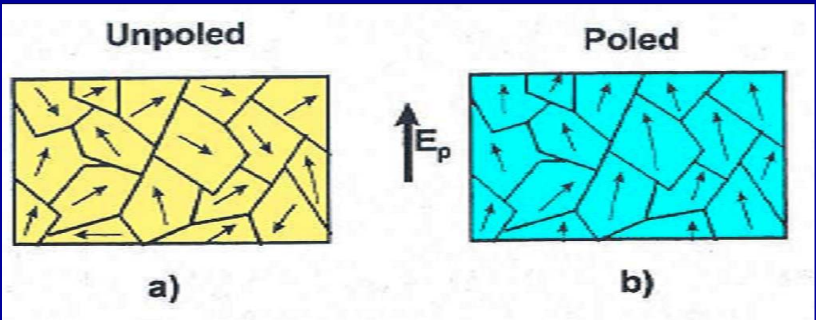
Piezoelectric displacement sensors

- To induce piezoelectric properties, **poling** procedure is often required.
- Poling is analogous to the magnetizing of a permanent magnet.



Polling process in piezoelectric ceramics: (a) in the absence of an electric field (b) in the electric field.

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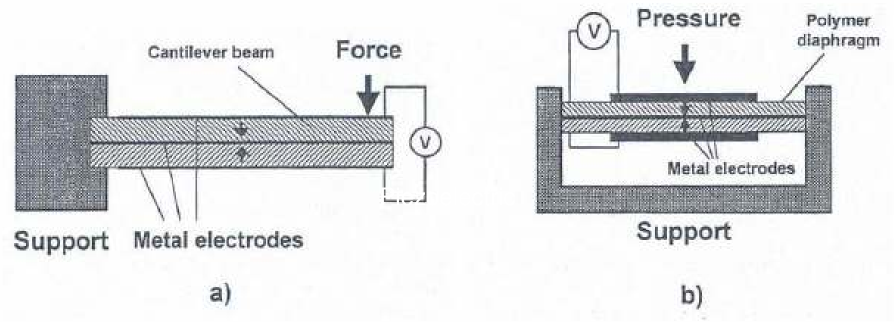
Piezoelectric displacement sensors



- (a) Displacement sensor based on piezoelectric ceramic (b) Pressure sensor based on piezoelectric polymer film. Arrows indicate the directions of ferroelectric polarization in the piezoelectric material.

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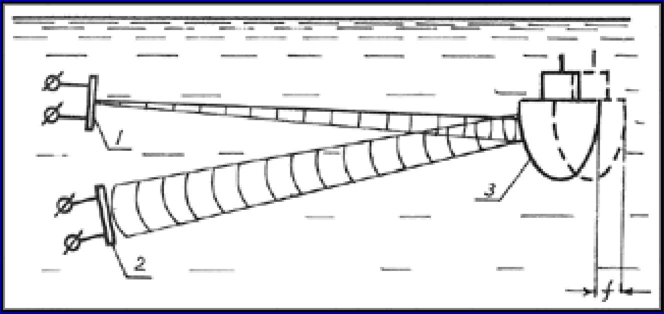
Ultrasonic displacement sensors

Ultrasonic displacement sensors



An ultrasonic transducer, used for the measurement of distance (primarily underwater), is provided with a piezoelectric element emitting pulses of acoustic energy directed to the target, which is a small area on the object. The signal reflected from the target travels back to the transducer, generating electrical pulses in the element. The time between transmitting and receiving the pulses is a measure of the distance between the transducer and the target. In this sonic radar, a separate or the same element can be used for generating and receiving the signals.

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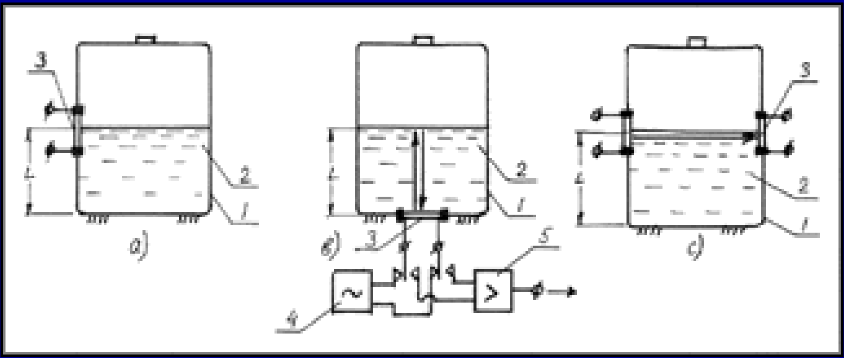
Ultrasonic displacement sensors



Ultrasound-level sensors, a, b, and c = level-sensing systems with one crystal at side (a), bottom (b), and two crystals at side (c) of tank; L = level, 1 = tank, 2 = liquid, 3 = piezoelectric crystal, 4 = pulse generator, 5 = pulse receiver.

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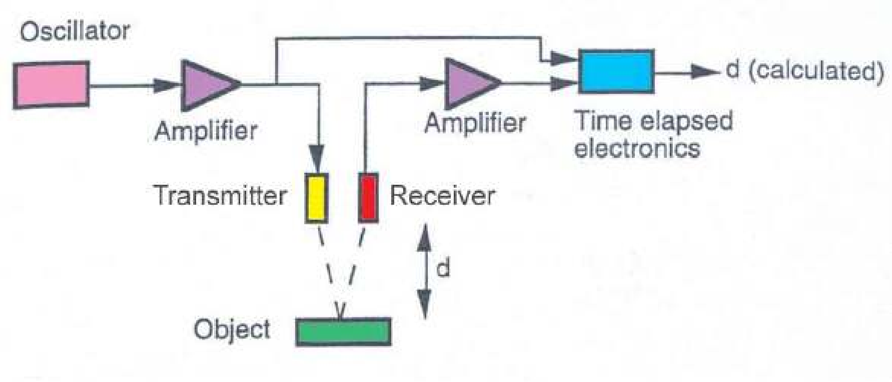
Ultrasonic displacement sensors

Principle of a pulse-echo ultrasound system for distance measurements.



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Ultrasonic displacement sensors

Time-of-Flight Ultrasonic Displacement Sensors

- With sound travels in velocity c and time t, the distance d is:

$$d = ct/2$$

- A plane wave propagates in x direction:

$$\Delta x = A\sin\omega(t - x/c)$$

- The velocity of sound depends on the medium in which it propagates. In a homogeneous and isotropic solid, the velocity depends on the density ρ and the modulus of elasticity E:

$$c = \sqrt{\frac{E}{\rho}}$$

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Ultrasonic displacement sensors

Ultrasound Transducers

- Convert electric energy to mechanical energy, vice versa.
- Common types of in-air transducers are:
  - Mechanical
  - Electromagnetic
  - Piezoelectric
  - Electrostatic
  - Magnetostrictive

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Ultrasonic displacement sensors

Principles of Time-of-Flight Systems

Method	Advantage	Disadvantage
Pulse echo method	Simple	Low signal-to-noise ratio
Phase angle method	Rather insensitive to disturbances	Cannot be used directly at distances longer than the wavelength of the ultrasound
Frequency modulation method	Robust against disturbances; multireflections detectable	Measurements on long and short distances can give the same result (compare with phase angle method)
Correlation method	Very robust against disturbances	Make relatively high demands on hardware and/or computations

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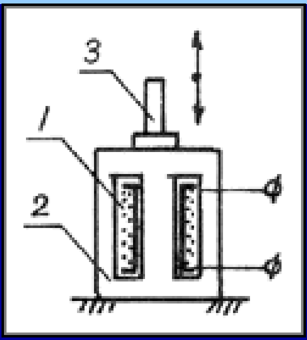
Magnetostrictive displacement sensors

Magetostrictive displacement sensors



Magnetoelastic or magnetorestrictive transducers.

1 = coil, 2 = magnetoelastic core,
3 = sensing shaft

In a magnetoelastic or magnetostrictive transducer, the change in the position of the sensing shaft creates stress in the stress-sensitive core. The permeability of the core material alters with stress, effecting the inductance of the winding wound around the core. The inductance is a function of the shaft's position.

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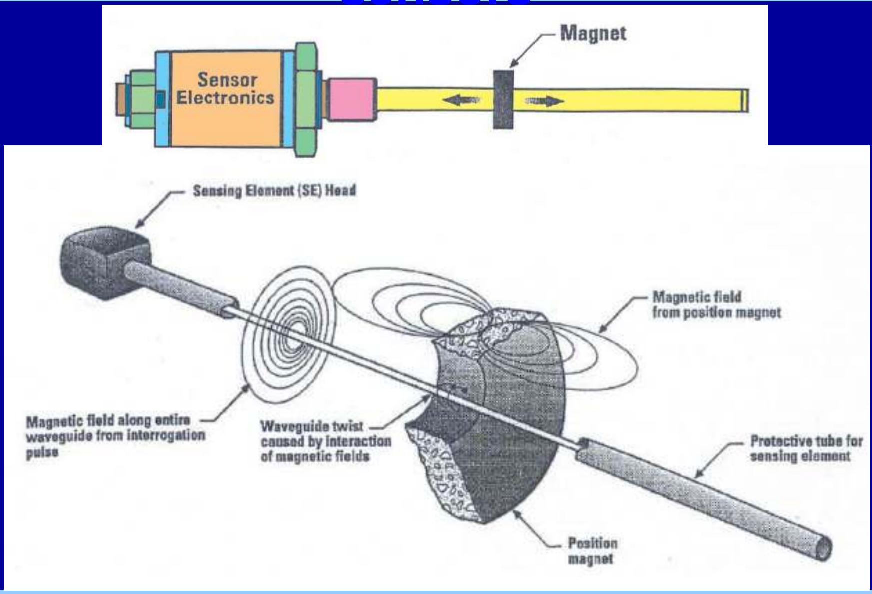
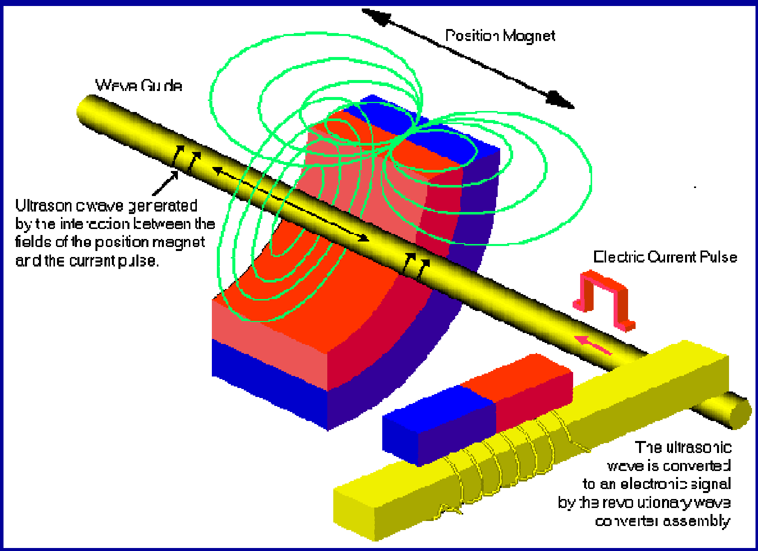
Magetostrictive displacement sensors



http://bohr.physics.hku.hk/academic/courses/phys2234/06_Displacementvelocity.pdf

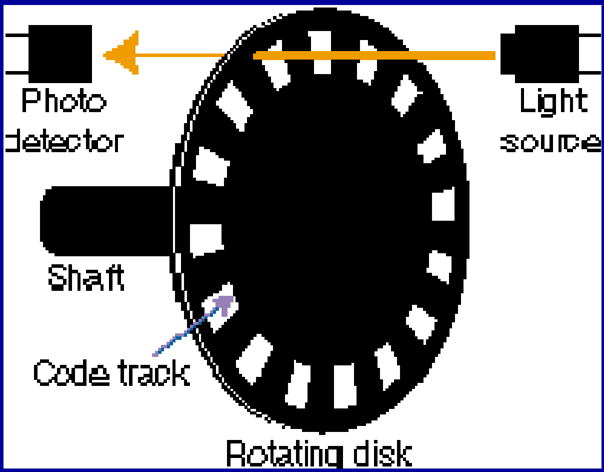
Magetostrictive displacement sensors



http://www.rdpelectronics.com/displacement/magneto/principle.htm

Optical encoder displacement sensors

Optical Encoders



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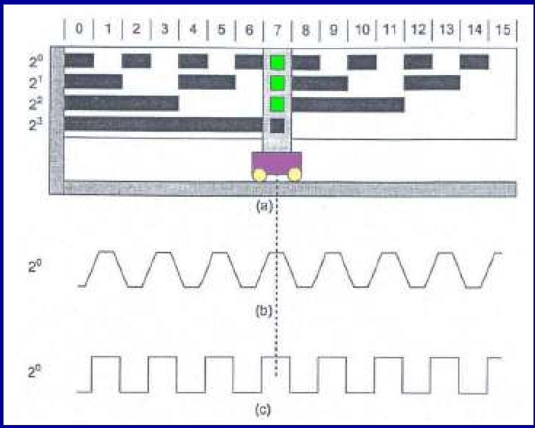
Optical Encoders

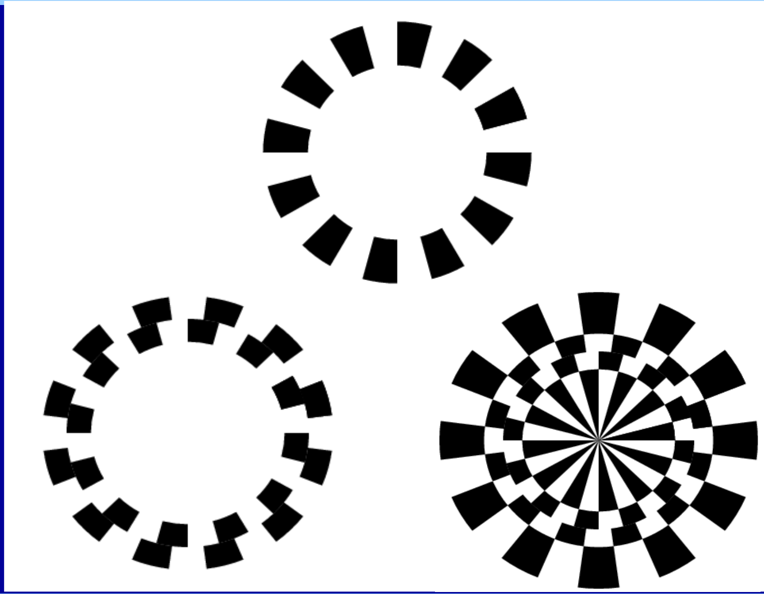


	2^3	2^2	2^1	2^0
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
:				

(a) Absolute encoders using a natural binary code of 4 digits (hence 4 tracks). (b) The output of the read head aperture. (c) The binary digit obtained after squaring the raw output signal.

http://bohr.physics.hku.hk/academic/courses/phys2234/06_Displacementvelocity.pdf

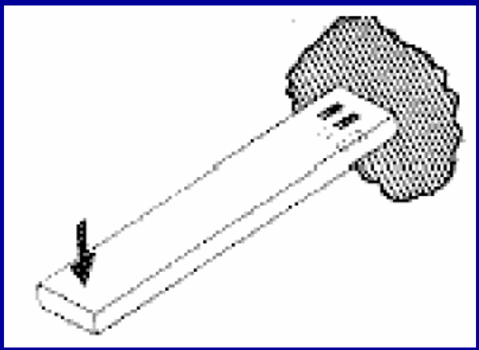
Optical Encoders



http://www.swiss.ai.mit.edu/~pmitros/encoder/

Strain Gages displacement sensors

Strain Gages displacement sensors



http://www.vishay.com/brands/measurements_group/guide/ta/sgbt/sgbt.pdf

Strain Gages displacement sensors

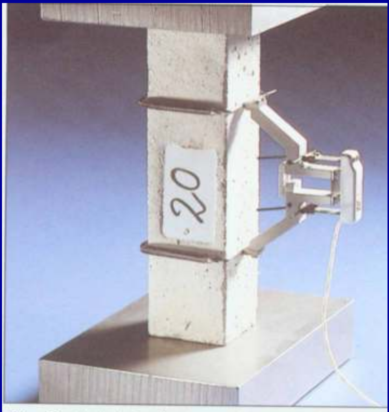


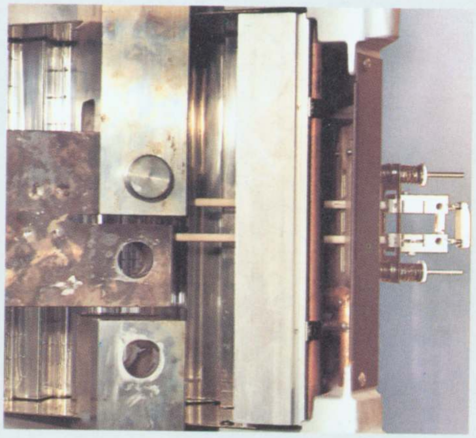
Fig. 2: Axial strain transducer DSA with gauge extension pieces

Schenck Hydropuls Standard Machine Series PSB catalogue

Strain Gages displacement sensors

Fig. 3: Diametral strain transducer DSQ

Fig. 8: High temperature strain transducer DSA-H



Schenck Hydropuls Standard Machine Series PSB catalogue

Proximity detectors

Proximity detectors

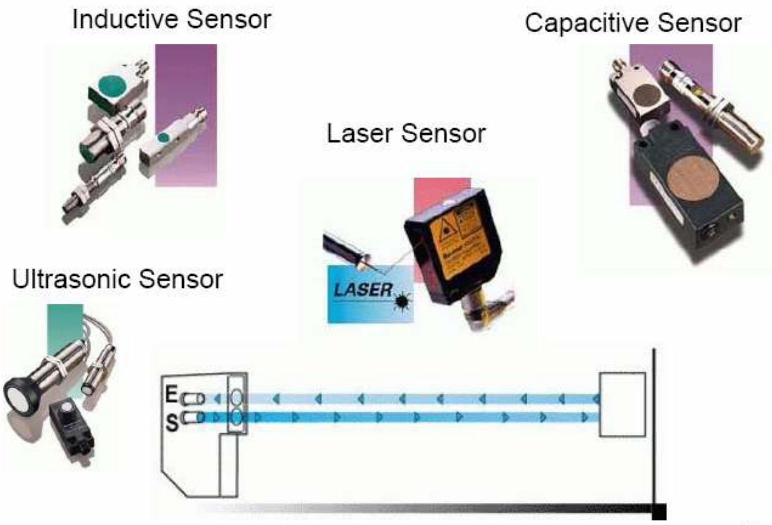
They sense the presence of nearby targets, usually without requiring any contact or wiring to the target or any particular target material properties.

Various principles are available for the proximity detection and measurement:

- Inductive
- Magnetic
- Optical
- Ultrasonic

http://bohr.physics.hku.hk/academic/courses/phys2234/06_Displacementvelocity.pdf

Proximity detectors



(http://www.clickautomation.com/products/index.php?func=list&cid=34)

80

http://bohr.physics.hku.hk/academic/courses/phys2234/06_Displacementvelocity.pdf

Proximity detectors

Applications

- Motion detection
  - Detection of rotating motion
- Motion control
  - Movement indication
- Process control
  - Automatic filling
- Sequence control
  - Verification and counting
- Liquid level detection
  - Tube high-low liquid level
- Material level control
  - Low level limit

http://bohr.physics.hku.hk/academic/courses/phys2234/06_Displacementvelocity.pdf

Thickness sensors

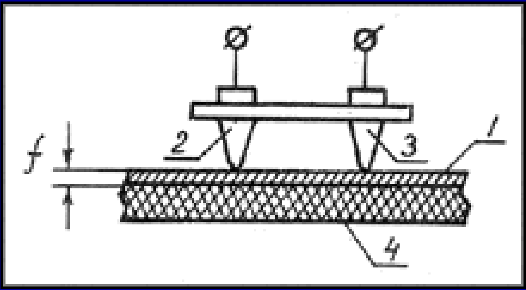
Thickness sensors

Various principles are available for the thickness measurement:

- **Resistive**
- Capacitive
- Displacement
- Inductive
- Standing-Wave Transducer

Resistive thickness transducer

For measuring the thickness or length of an electro-conductive body (often film) of known electroconductivity. The resistance between the electrodes is proportional to the measurand.



Resistive thickness or length transducer, f = thickness, 1 = electroconductive film, 2 and 3 = electrodes, 4 = non-electroconductive substrate.

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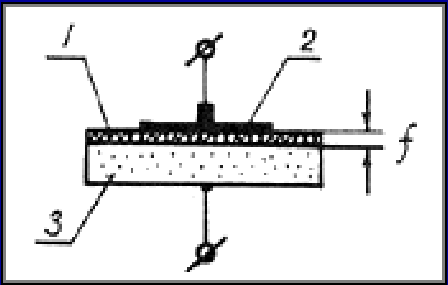
Capacitive thickness transducer

The capacitance is a measure of the thickness that is formed by two flat electrodes. One of them is applied to the surface of the layer and the other one is the base.



Capacitive thickness transducer, f = thickness, 1 = thin insulating layer, 2 = surface electrode, 3 = electroconductive base.

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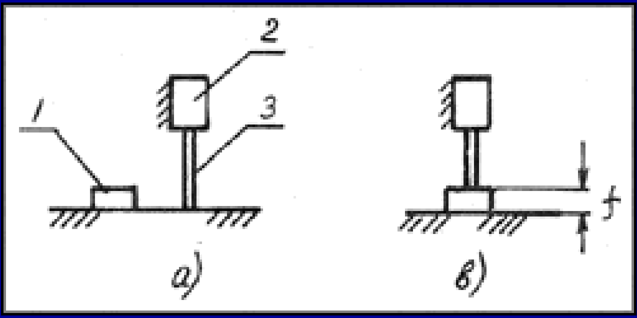
Displacement thickness transducer



f = thickness, 1 = object, 2 = displacement transducer, 3 = sensing shaft,

(a) Reference surface; (b) making thickness measurement.

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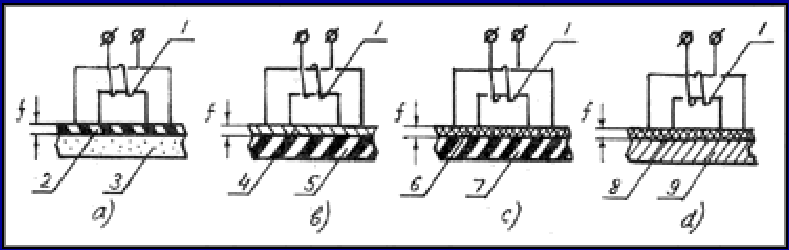
Inductive thickness transducer



a through d = inductive thickness transducer at different combinations of test pieces and bases; f = thickness, 1 = coil, 2 = ferromagnetic test piece, 3 = nonmagnetic base, 4 = nonmagnetic test piece, 5 = magnetic base, 6 = nonmagnetic and nonconductive test piece, 7 = magnetic base, 8 = nonmagnetic and nonconductive test piece, 9 = nonmagnetic but electroconductive base.

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Inductive thickness transducer

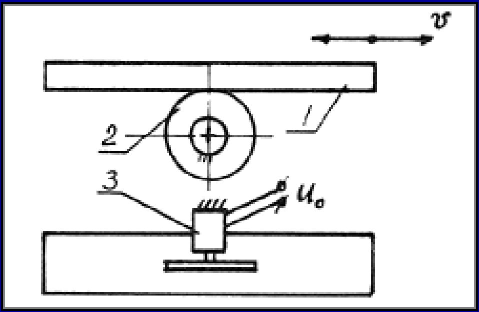
An inductive thickness transducer contains a coil whose magnetic circuit's reluctance is varied by all of the following:

- The thickness of the ferromagnetic test piece attached to the nonmagnetic base
- The thickness of the nonmagnetic but conductive test piece attached to the magnetic base
- The thickness of the nonmagnetic and non- conductive test piece attached to the magnetic base
- The thickness of the nonmagnetic and non- conductive test piece attached to the non-magnetic but electro- conductive base

http://zone.ni.com/devzone/conceptd.nsf/webmain/D8712D903B6AC3CA8625684F005CCD37

Standing-Wave Transducer

A source of ultrasonic energy excites vibrations at the surface of a test piece whose thickness is to be measured. In the presence of standing waves, the power absorption from the source is increased. The lowest noted frequency of the excitation, corresponding to the maximum absorption, is used for calculating the thickness, which is inversely proportional to this frequency.



1 = test piece, 2 = source of ultrasonic energy, 3 = substrate.

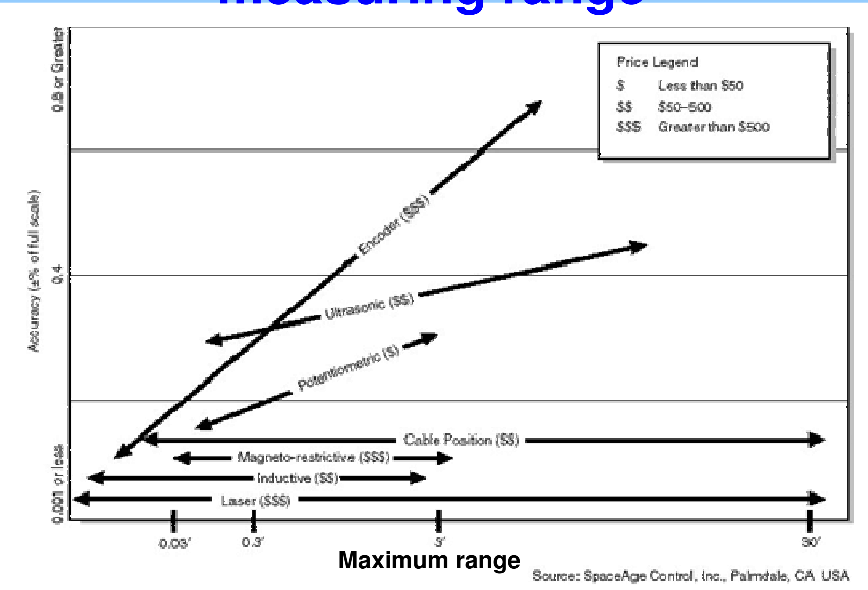
http://zone.ni.com/devzone/conceptd.nsf/webmain/72380565937FB5E28625684F005E8B38

How to choose among different sensors

Guide to decision

Parameter	Choices			
Contact	Contact	Noncontact		
Motion Type	Linear	Rotary		
Dimensions	One Dimensional	Multidimensional		
Measurement Type	Absolute	Incremental	Threshold (Proximity)	
Range	< 1"	1" - 30"	> 30"	
Size/Weight	Size Restriction____	Weight Restriction____		
Environment	Humidity	Vibration	Corrosion	Temperature
Installation/Mounting	Removable	Installation	Time Limit______	
Accuracy	Linearity	Resolution	Repeatability	Hysteresis
Lifetime	Cycles_____	Hours of Continuous Operation___		
Cost	< $50	$50 - $500	> $500	
Output	Voltage	Current	Digital	Visual
Freq. Response	< 5 Hz	5 - 50 Hz	> 50 Hz	

Relative cost, accuracy and measuring range



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END