

Displacement, and Position sensors

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Displacement Measurement

Measurement of displacement is the basis of measuring:

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

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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
- ...

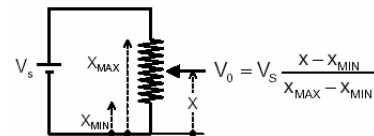
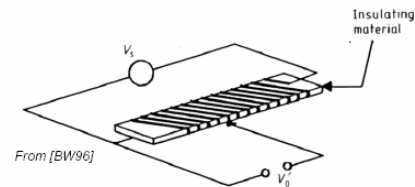
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Potentiometers displacement sensors

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Resistive displacement sensors

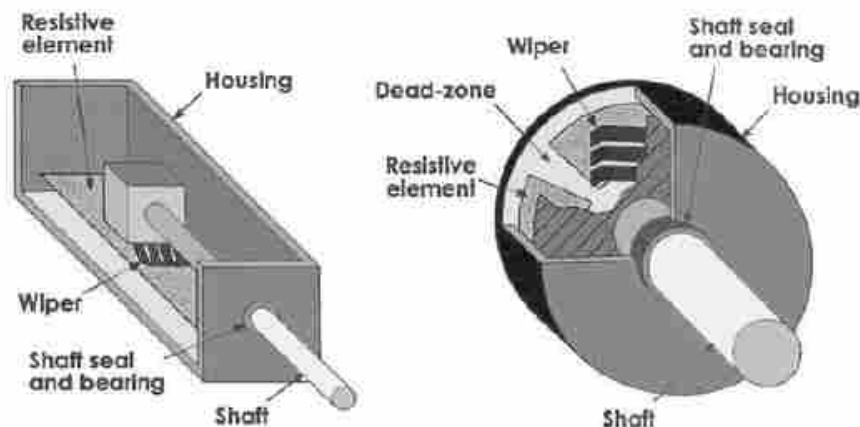
- An electrically conductive wiper that slides against a fixed resistive element.
- To measure displacement, a potentiometer is typically wired in a "voltage divider" configuration.
- A known voltage is applied to the resistor ends. The contact is attached to the moving object of interest
- The output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



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Resistive displacement sensors

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



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Resistive displacement sensors

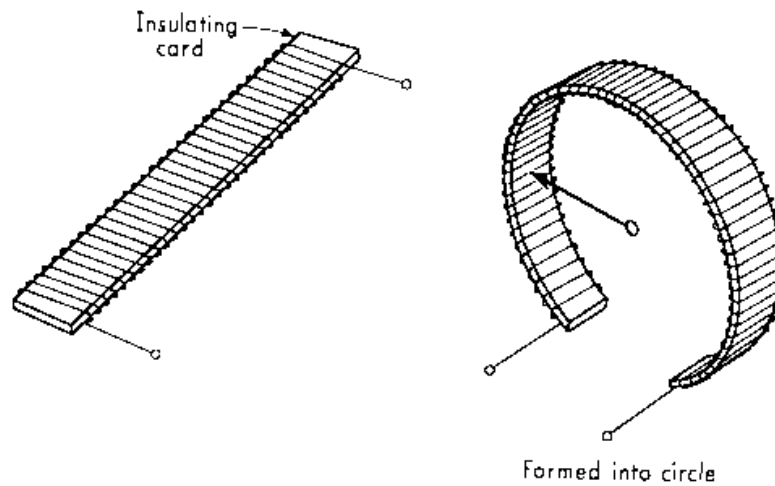
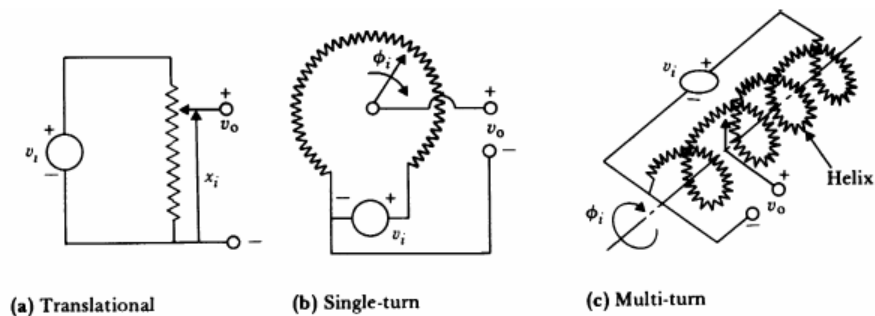


Figure 4.6 Construction of wirewound resistance elements.

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Resistive displacement sensors

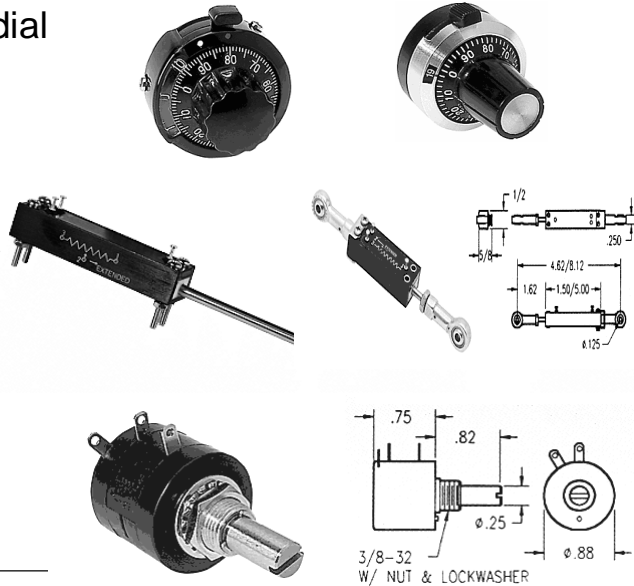
Three types of potentiometer devices for measuring displacement



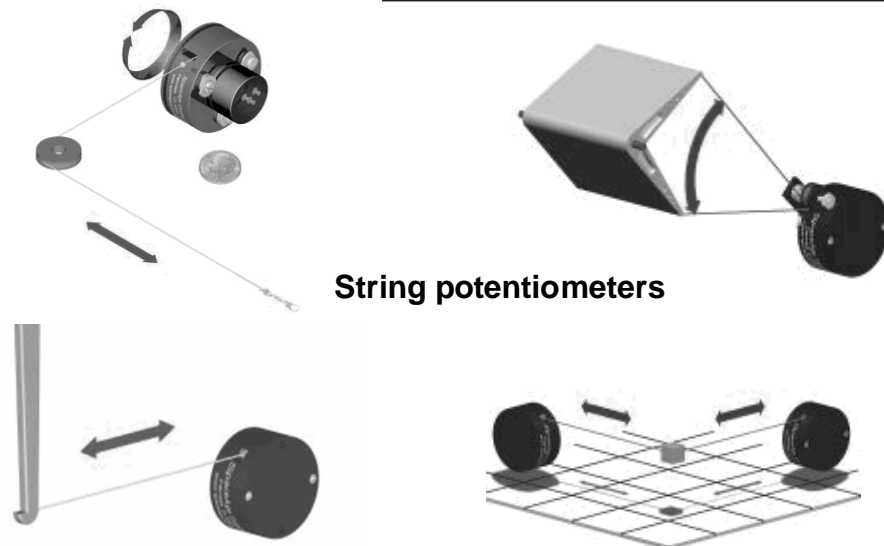
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Potentiometer types

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



Resistive displacement sensors



<http://zone.ni.com/devzone/conceptd.nsf/webmain/F015C145C6B8658586256CD20069531B>

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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

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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 temperature
- ✓ Shock and vibration
- ✓ Humidity
- ✓ Contamination and seals

✓ Others:

- ◆ Life cycle
- ◆ Dither

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Inductive displacement sensors

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Inductive displacement sensors

Self-generating type

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

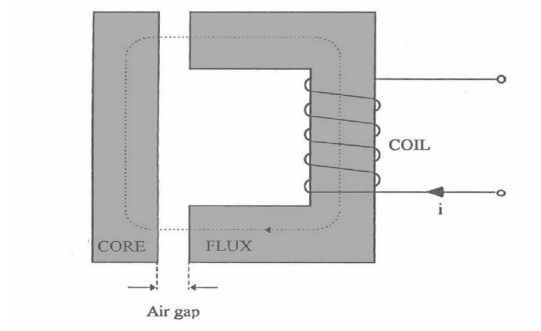
Passive type

- ✓ Requires an external source of power.

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Inductive displacement sensors

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



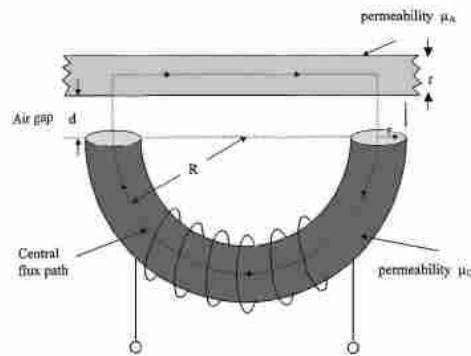
The coil acts as a source of magnetomotive force that drives the flux through the magnetic circuit and the air gap. The presence of the air gap causes a large increase in circuit reluctance and a corresponding decrease in the flux. Hence, a small variation in the air gap results in a measurable change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

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Inductive displacement sensors

Single-Coil Linear Variable-Reluctance Sensor



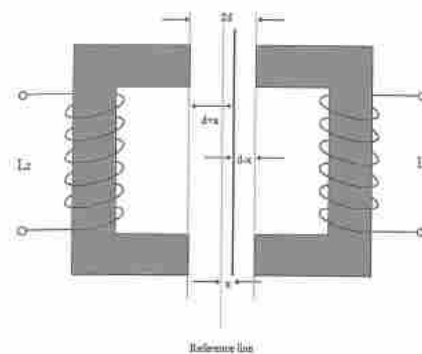
The reluctance of the coil is dependent on the single variable. The reluctance increases nonlinearly with increasing gap.

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Inductive displacement sensors

Variable-Differential Reluctance Sensor

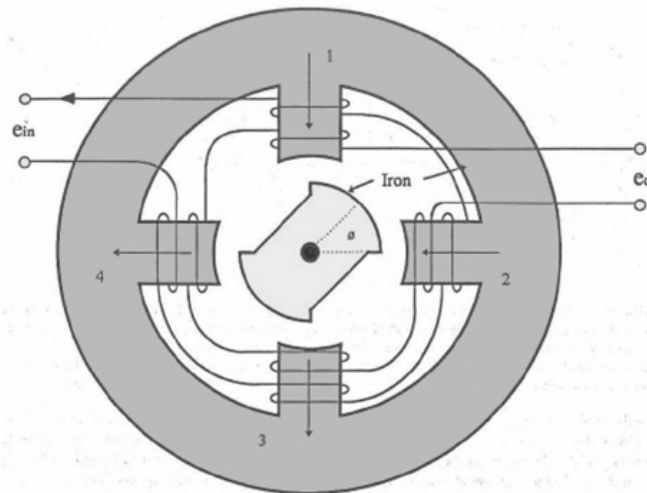


A variable-differential reluctance sensor consists of an armature moving between 2 identical cores separated by a fixed distance. The armature moves in the air gap in response to a mechanical input. This movement alters the reluctance of coils 1 and 2, thus altering their inductive properties. This arrangement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

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Inductive displacement sensors



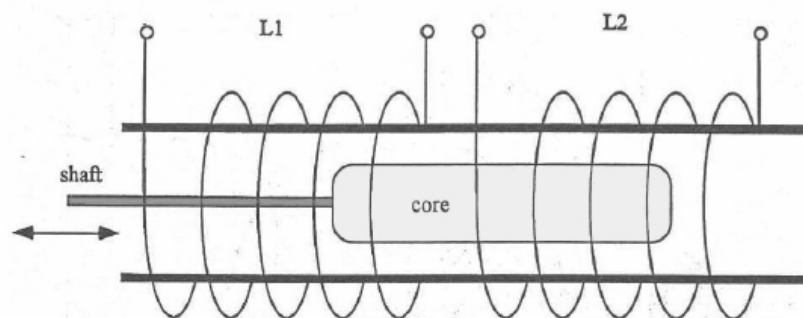
Magnesyn (angular displacement sensor)

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Inductive displacement sensors

Variable-Coupling Transducers

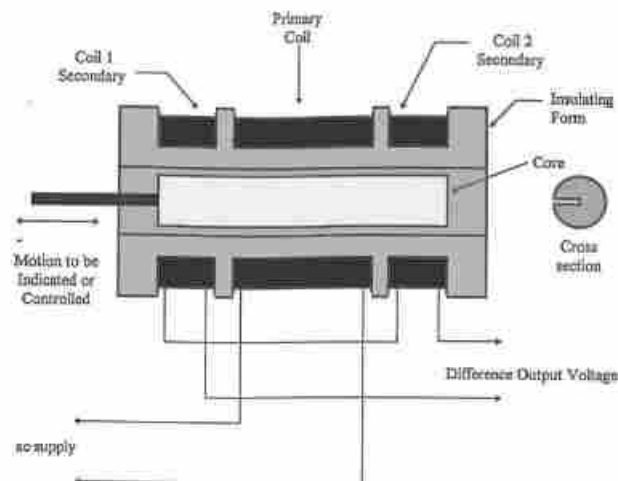


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Inductive displacement sensors

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:

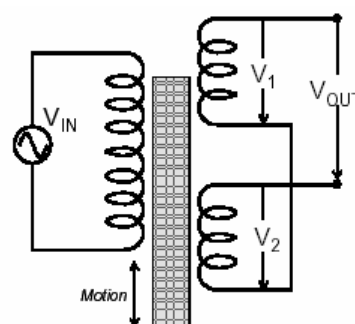
$$V_1 = k_1 \sin(\omega t) \text{ and } V_2 = k_2 \sin(\omega t)$$

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, $k_1 = k_2 \Rightarrow V_{OUT} = V_1 - V_2 = 0$

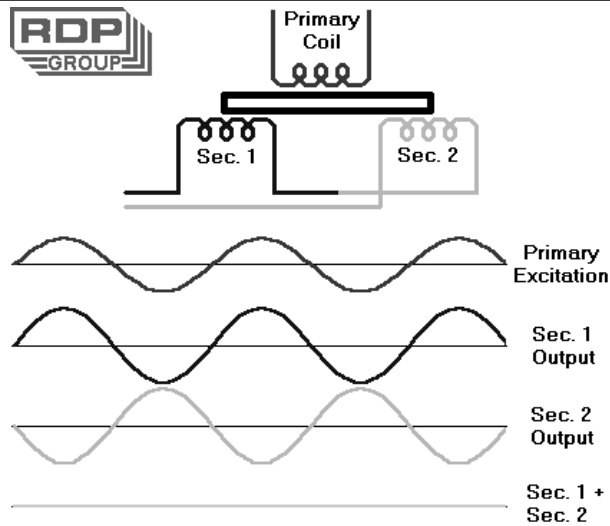
When the coil is displaced x units, $k_1 \neq k_2 \Rightarrow V_{OUT} = (k_1 - k_2) \sin(\omega t)$

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



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Inductive displacement sensors

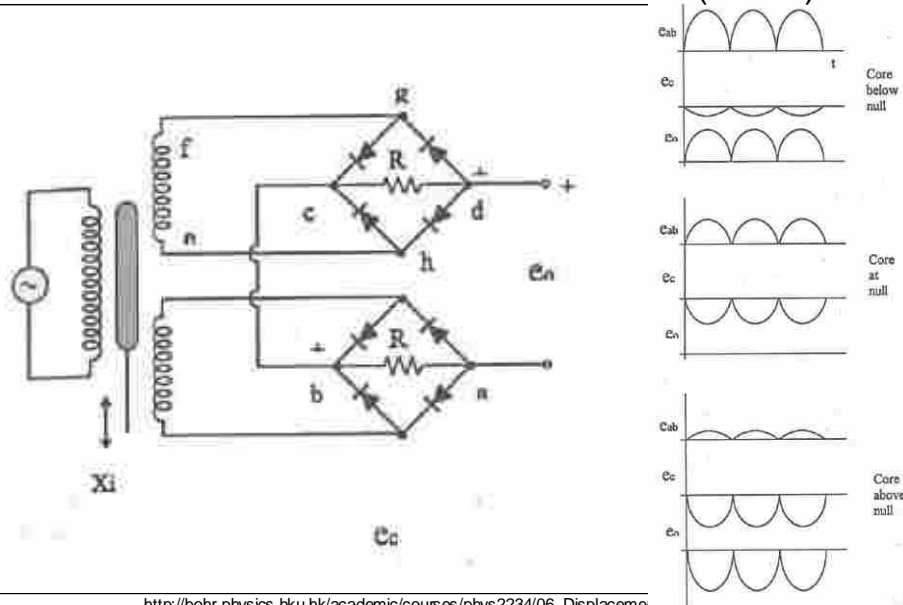


<http://www.rdpelectronics.com/displacement/lvdt/lvdt-principles.htm>

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Inductive displacement sensors

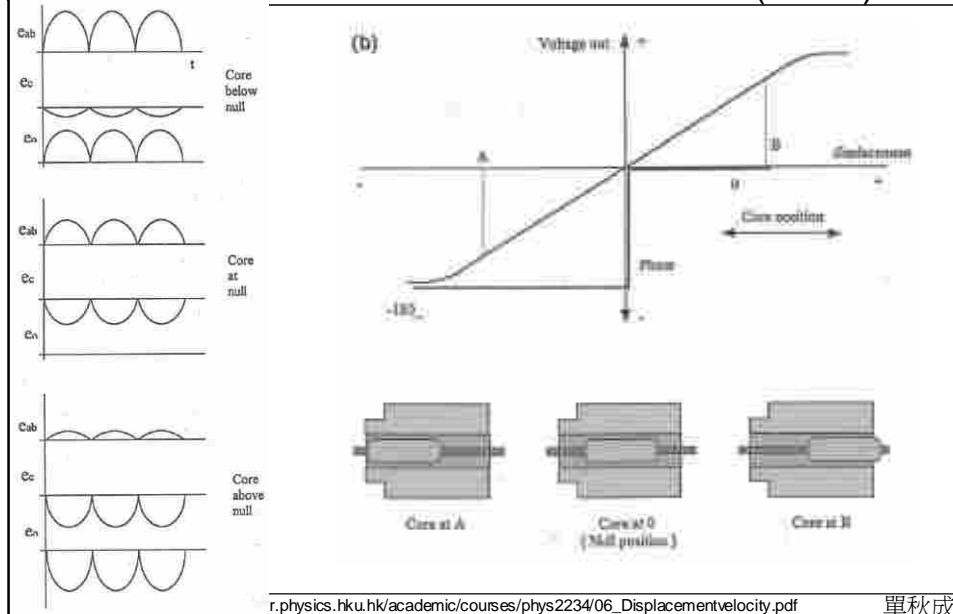
Linear Variable-Differential Transformer (LVDT)



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Inductive displacement sensors

Linear Variable-Differential Transformer (LVDT)



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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

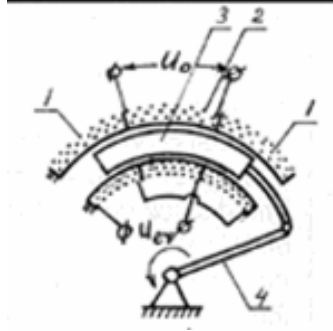
➤ Advantages of the LVDT over other displacement sensors

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

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Inductive displacement sensors

Rotary voltage differential transformer



U_{ex} = excitation voltage, U_o = output voltage,
1 = excitation coil, 2 = output coil, 3 = moving core
or armature, 4 = sensing shaft.

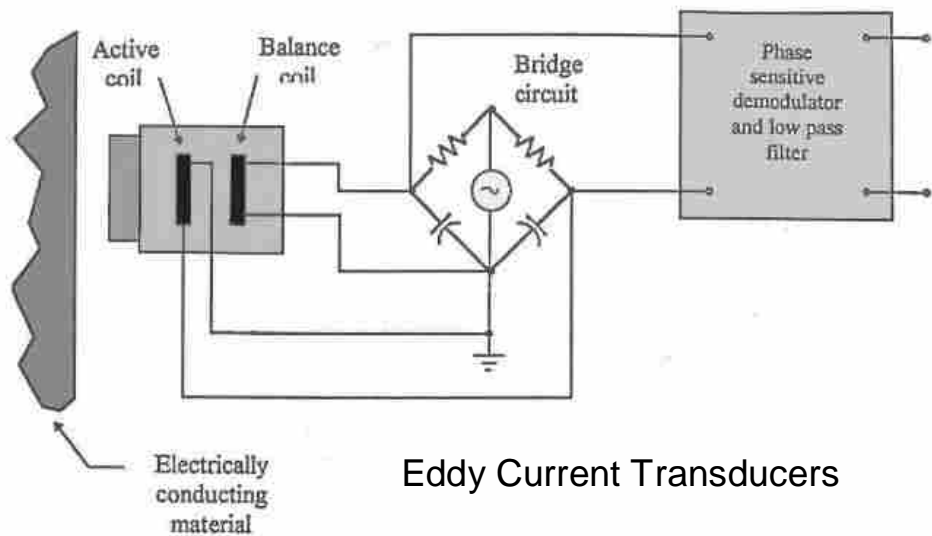
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Eddy current displacement sensors

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Inductive displacement sensors



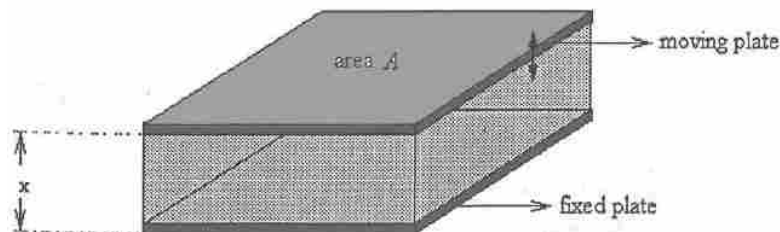
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Capacitive displacement sensors

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Capacitive displacement sensors



$$C(x) = \epsilon A/x = \epsilon_r \epsilon_0 A/x$$

where ϵ = dielectric const. or permittivity

ϵ_r = relative dielectric const.

ϵ_0 = dielectric const. of vacuum

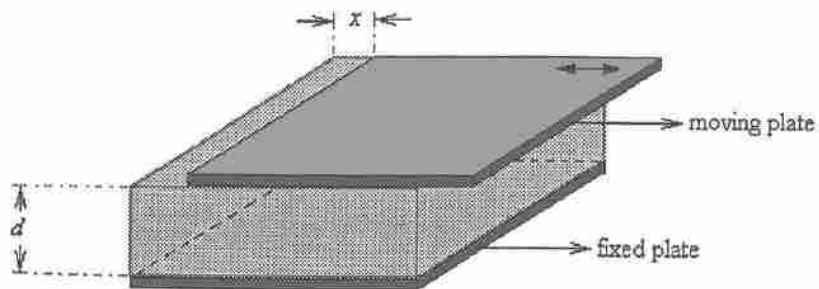
x = distance of the plates in m

A = effective area of the plates in m^2

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Capacitive displacement sensors



$$C = \epsilon_r \epsilon_0 (A - wx)/d$$

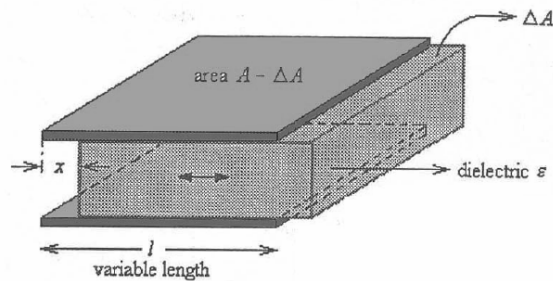
where w = width

wx = reduction in the area due to movement of the plate

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Capacitive displacement sensors



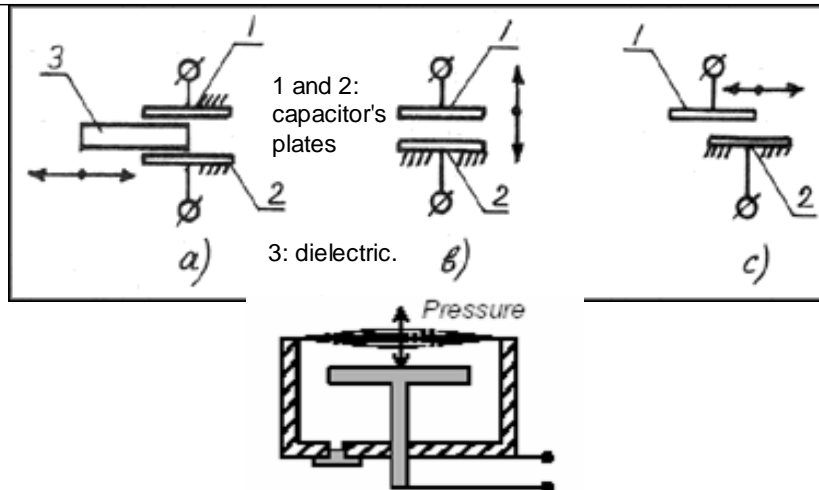
$$C = \epsilon_0 w [\epsilon_0 l - (\epsilon_2 - \epsilon_1) x]$$

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

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Capacitive displacement sensors



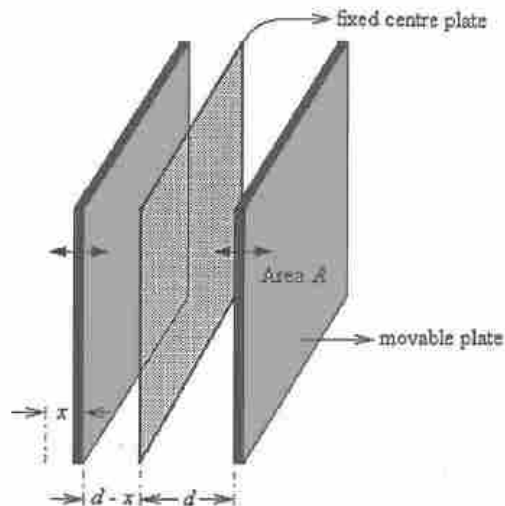
Capacitance will vary with variation in dielectric constant (a), gap between plates (b), and area of capacitor's plates (c).

<http://zone.ni.com/devzone/conceptd.nsf/webmain/7B94A3EBE32674128625684D007AA1DE>

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Capacitive displacement sensors

Differential Capacitive Sensors



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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

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Piezoelectric displacement sensors

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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.

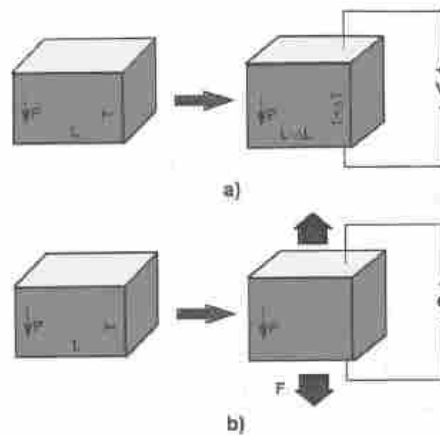
Active mode

- 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 (SiO_2), Lithium Niobate (LiNbO_3) and Lithium Tantalate (LiTaO_3).

Piezoelectric Ceramics

- Made up of mixed oxides containing corner-sharing octahedra of O^{2-} ions, which is the **Perovskite** family.
- General formula is ABO_3 . • E.g. BaTiO_3 .
- It is stable, has a wide temperature range of operation, and is easily fabricated.

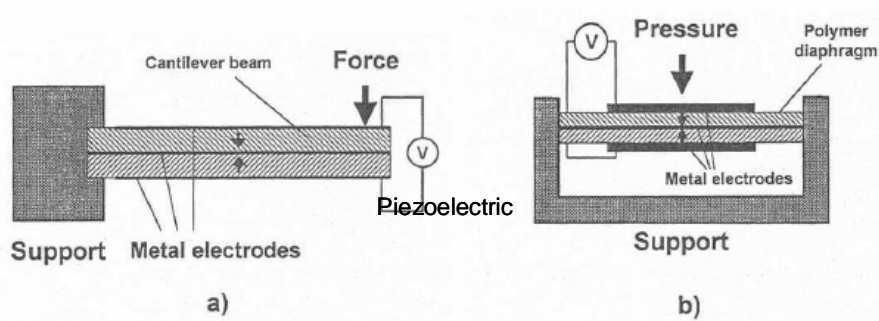
Piezoelectric Polymers

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

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Piezoelectric displacement sensors



- (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

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Ultrasonic displacement sensors

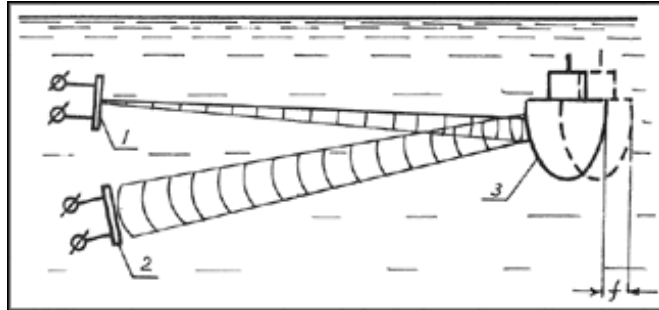
Ultrasound Transducers

- 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



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.

<http://zone.ni.com/devzone/conceptd.nsf/webmain/086A7733E65CCB028625684E00650AD2> 單秋成

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:

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

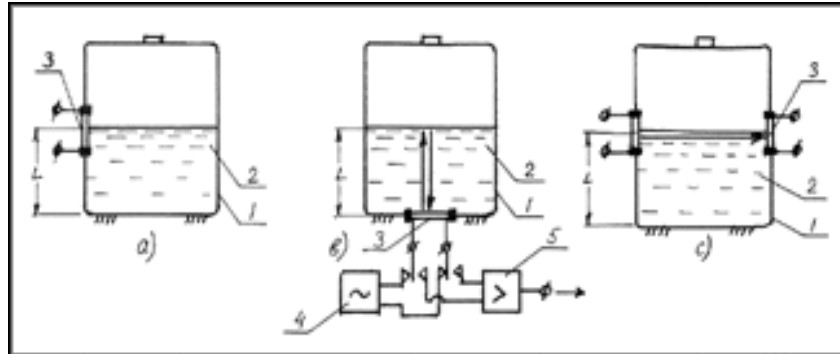
- The velocity of sound depends on the medium in which it propagates. In a homogeneous and isotropic solid, the velocity depends on the density ρ and the modulus of elasticity E :

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

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Ultrasonic displacement sensors



Ultrasound-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.

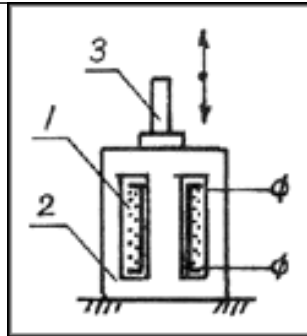
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Magnetostrictive displacement sensors

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Magetostrictive displacement sensors



Magnetoelastic or magnetostrictive transducers.

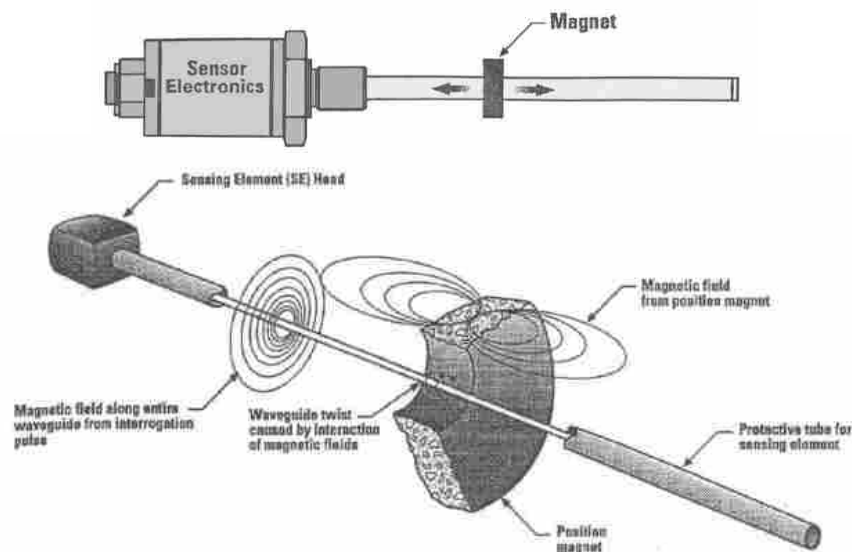
1 = coil, 2 = magnetoelastic core,
3 = sensing shaft

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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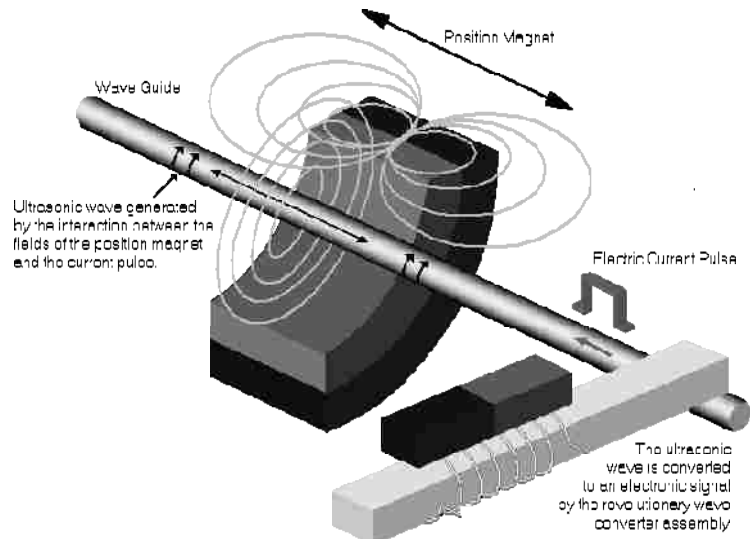
Magetostrictive displacement sensors



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Magetostriuctive displacement sensors



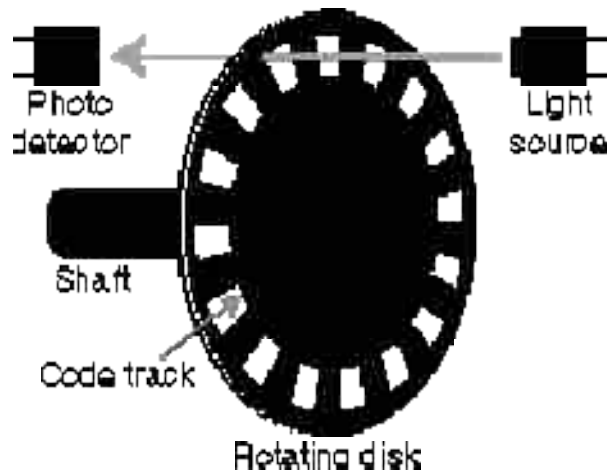
<http://www.rdpelectronics.com/displacement/magneto/principle.htm>

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Optical encoder displacement sensors

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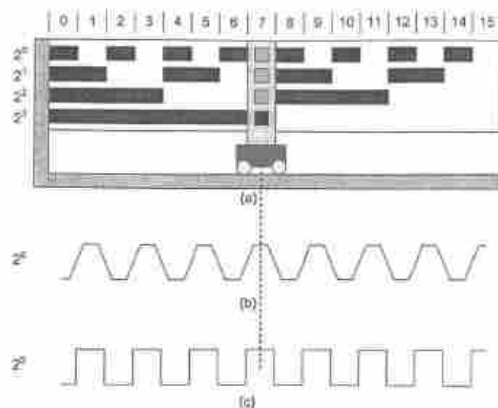
Optical Encoders



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Optical Encoders



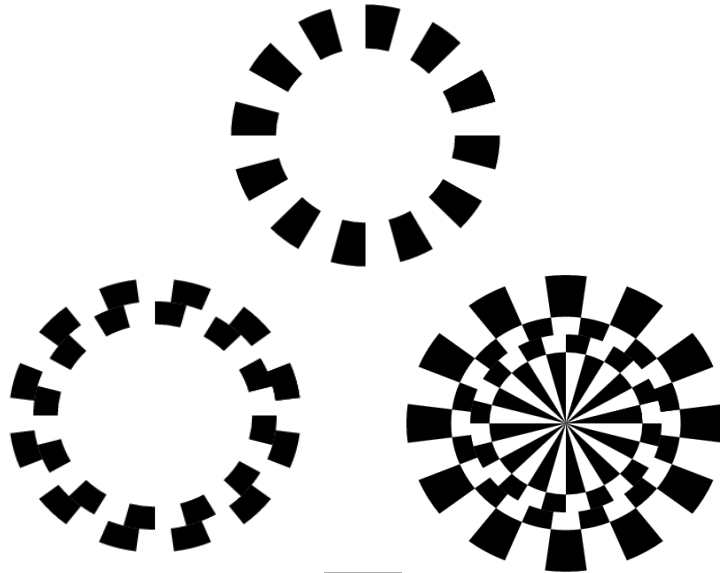
	2^3	2^2	2^1	2^0
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
:				

(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

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Optical Encoders



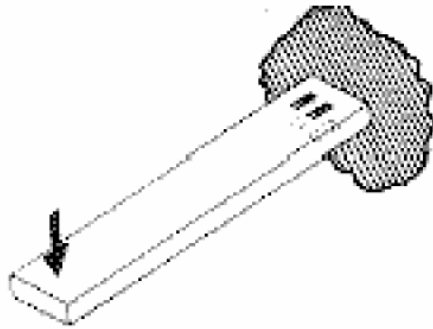
<http://www.swiss.ai.mit.edu/~pmitros/encoder/>

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Strain Gages displacement sensors

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Strain Gages displacement sensors



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

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Strain Gages displacement sensors

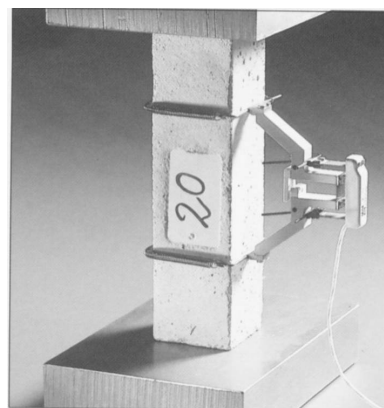
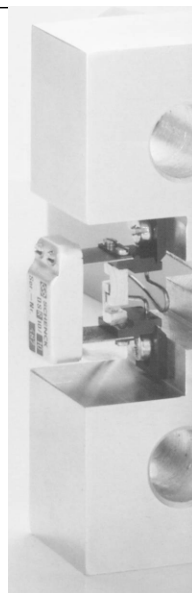
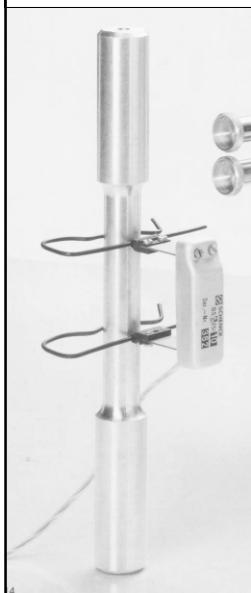


Fig. 2: Axial strain transducer DSA with gauge extension pieces

Schenck Hydropuls Standard Machine Series PSB catalogue

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Strain Gages displacement sensors

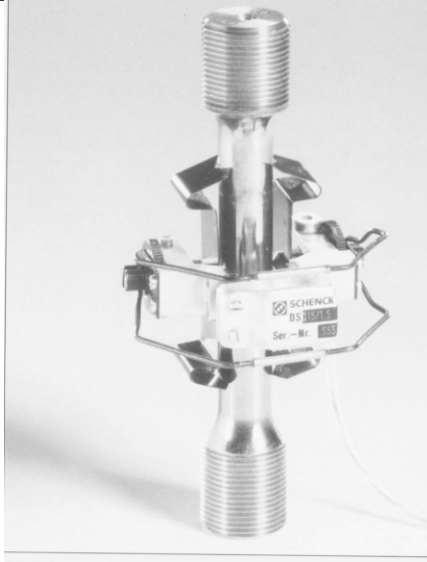
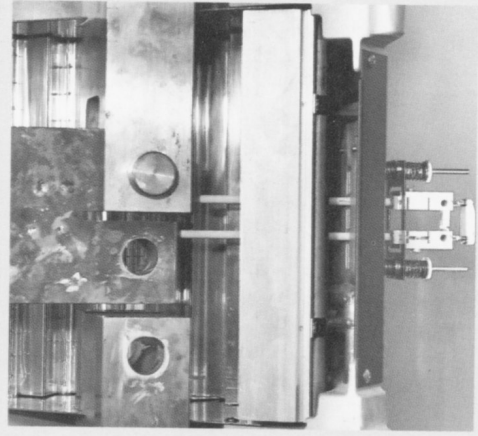


Fig. 3: Diametral strain transducer DSQ

Fig. 8: High temperature strain transducer DSA-H



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Proximity detectors

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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:

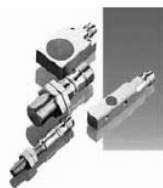
- Inductive
- Magnetic
- Optical
- Ultrasonic

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Proximity detectors

Inductive Sensor



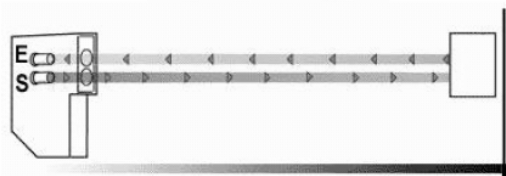
Capacitive Sensor



Laser Sensor



Ultrasonic Sensor



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

80

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

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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

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How to choose among different sensors

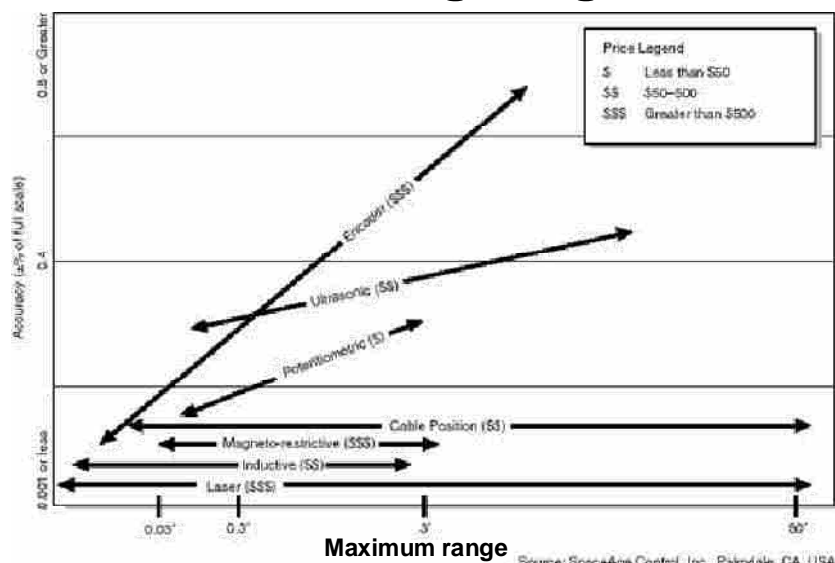
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Guide to decision

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	
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Relative cost, accuracy and measuring range



<http://zone.ni.com/devzone/conceptd.nsf/webmain/5E45F01A9456E5C386256A9B0060230F>

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