Measurement (Motion Measurement-2)

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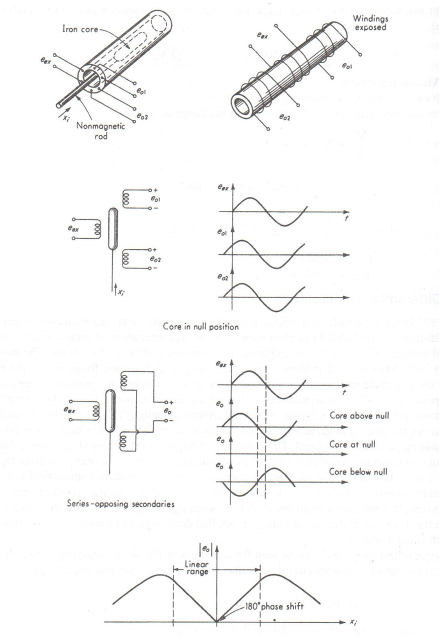
Differential Transformers

- Voltage is induced in two identical secondary coils, of the same frequency as excitation (or input)
- The amplitude of induced voltage however varies with the position of the iron core
- The secondary coils are connected in series opposition
- Motion from null position, causes larger inductance for one coil and smaller inductance for the other coil
- Output e_o is out of phase with excitation
- The amplitude e_o is nearly linear over a considerable range on either side of null position
- 180^o phase shift is obtained upon passing through null position

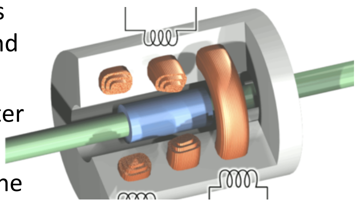
Differential Transformers



(a)
Fig. 4.17 *(a) Differential transformer.*

Linear variable differential transformer (LVDT)

- The linear variable differential transformer has three solenoidal coils placed end-to-end around a tube
- The center coil is the primary, and the two outer coils are the top and bottom secondaries
- A cylindrical ferromagnetic core, attached to the object whose position is to be measured, slides along the axis of the tube
- An alternating current drives the primary and causes a voltage to be induced in each secondary proportional to the length of the core linking to the secondary. The frequency is usually in the range 1 to 10 kHz.

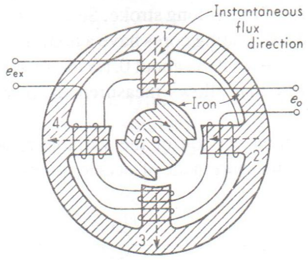


LVDT

- As the core moves, the primary's linkage to the two secondary coils changes and causes the induced voltages to change
- The coils are connected so that the output voltage is the difference (hence "differential") between the top secondary voltage and the bottom secondary voltage
- When the core is in its central position, equidistant between the two secondaries, equal voltages are induced in the two secondary coils, but the two signals cancel, so the output voltage is theoretically zero
- In practice minor variations in the way in which the primary is coupled to each secondary means that a small voltage is output when the core is central.

https://en.wikipedia.org/wiki/Linear_variable_differential_transformer

Microsyn

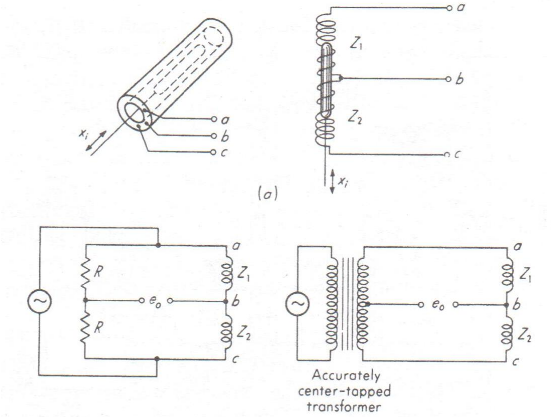


- Based on variable reluctance idea
- Used for measuring rotary motion
- Employed in sensitive gyroscopic instruments
- Motion of shaft induces voltage in coils 1 and 3 (aiding each other) and coils 2 and 4 (which aid each other but oppose 1 and 3)
- Thus a net output voltage is obtained
- Typical values: Sensitivity of 0.2-0.5 V/deg; Non-linearity about 0.5% of full scale; Resolution ~ 0.01 deg

Variable-inductance pickup

- Similar to LVDT – but only two inductance coils
- Inductance coils form two legs of a bridge
- Movable coil provides the mechanical input
- When core at null position, inductance of two coils are equal
- Core motion changes the coil inductances – increasing one and decreasing the other
- Causing bridge unbalance; thus output voltage

Variable-inductance pickup



Two possible methods of exciting transducer and forming bridge circuit

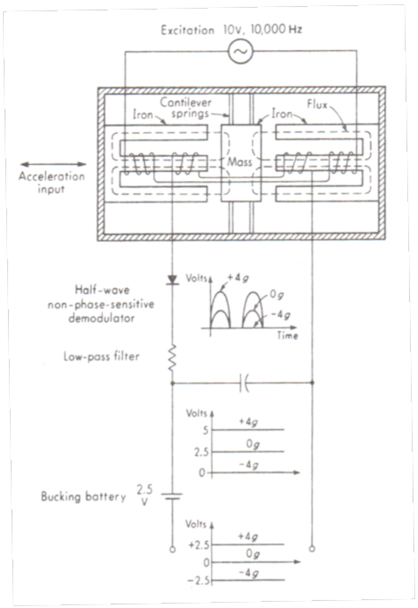
(b)

Variable-inductance pickup

- To get high sensitivity, high excitation voltage is needed
- High voltage however causes higher power loss due to heating
- Center-tapped transformer circuit is used to solve this problem
- Typical range – 2.5-5000 mm; resolution – infinitesimal; non-linearity – 0.02-1% of full-scale; sensitivity – 0.2-1.5 V/mm
- Rotary versions also available

Variable-reluctance accelerometer

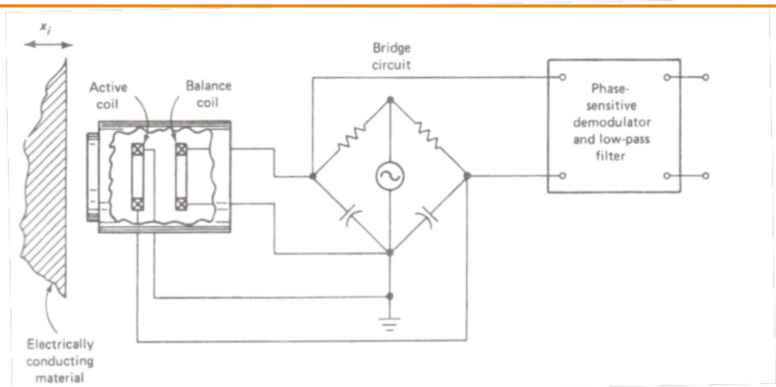
- Here measurement of motion is used to measure acceleration
- Springs supporting the mass deflect in proportion to acceleration



Eddy-current non-contacting transducer

- Here the probe consists of two coils: active (influenced by presence of a conducting target) and second/balance (serves to complete the bridge circuit – also provides temperature compensation)
- When a conducting material is kept close to the active coil so as to be influenced by its presence (or absence) or by being any closer or away, magnetic flux is induced in the active coil and is passed through the conductor producing eddy currents
- The density of this current will be maximum at the surface and will lessen as the depth increases
- Bridge excited at high frequency (~ 1 MHz)

Eddy-current non-contacting transducer



As the target approaches the probe, the eddy currents become stronger – changes the impedance of the active coil and causes a bridge unbalance, which can be related to the target position

Eddy-current non-contacting transducer

- Flat targets, of same diameter as probe or larger are preferred
- Output drops for target size 1/2 of probe diameter – the output is also prone to reduced linearity
- Curved-surface targets behave as a flat surface for shaft-diameter > 4 probe diameter
- Special four-probe systems are available for measuring orbital motions of rotating shafts, and centering and alignment operations
- Can be used for position measurement and vibrating motion measurement

Capacitance Pick-ups

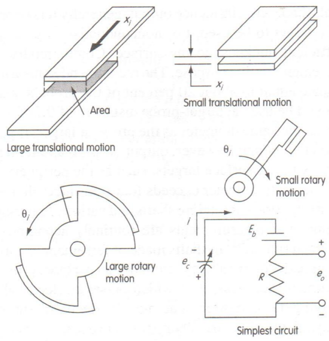


Fig. 4.29 *Principles of capacitive displacement sensing.*

Table 4.1

Configuration	*Range*	*Nominal capacitance*	*Sensitivity*
Long-range linear	10.0 mm	10 pF	0.94 fF/µm
Long-range rotation	1.5 rad	10 pF	6.9 fF/mrad
Short-range linear	100 µm	10 pF	100 fF/µm
Short-range rotation	17 mrad	10 pF	580 fF/mrad

Capacitane Pick-up

- Capacitance is given by: $C = \dfrac{\varepsilon_o \varepsilon_r A}{x}$

  C (capacitance, F), A (plate area, m^2), x (plate separation, m), ε_o is electric constant (8.854×10^{-12} F/m), ε_r is relative static permittivity or dielectric constant

- Non-linearity is given by $\eta = \dfrac{\Delta h}{h + \Delta h}$

Example: Capacitance based Transducer

- A capacitance-based displacement transducer of area 200 mm^2 and distance between plates of 5 mm, is filled with air.
- What is the sensitivity of the transducer?
- What is the maximum possible displacement of the plates so that the nonlinearity does not exceed 3%?
- What is the sensitivity if we have the plate of width 14 mm is moving parallel to itself, while maintaining a gap of 5 mm?

Example: Capacitance based Transducer (contd.)

Given: h = 5 mm; w = 14 mm; A = 200 mm^2; ε_0 = 8.85 pF/m; ε_r = 1; η = 3%

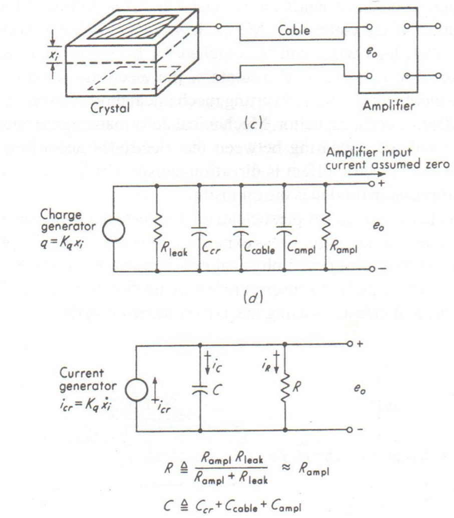
Solution:

- Want sensitivity when plate moved out: $\frac{\Delta C}{\Delta h} = \frac{\varepsilon_o \varepsilon_r A}{h^2}$
- Non-linearity: $\eta = \frac{\Delta h}{h + \Delta h}$
- Want sensitivity when plate moved parallel to itself $\frac{\Delta C}{\Delta A} = \frac{\varepsilon_o \varepsilon_r}{h}; \Delta A = w \Delta l$

Piezoelectric Transducers

- Certain materials (crystal, ceramic or biological matter) generate electric charge within them upon deformation – called *piezoelectric effect*
- The piezoelectric effect is linear and reversible
- The piezoelectric effect is direction sensitive (tension produces certain polarity, compression produces opposite polarity)
- Used in instruments for measuring force, acceleration or pressure
- Material includes:
  - natural crystals (quartz, rochelle salt)
  - synthetic crystals (lithium sulfate, ammonium dihydrogen phosphate)
  - polarized ferroelectric ceramics (barium titanate)
  - some polymer films

Piezoelectric Transducers



Metal electrodes attached on the faces for connecting lead wires

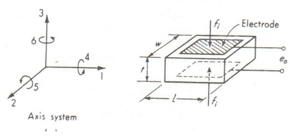
These plates have a capacitance effect

Mechanical effect generates a charge

Piezo-electric element can be thought of as a charge generator and a capacitor

Piezoelectric Transducers (contd.)

- Deformation of the material can occur in many different modes
  - Thickness expansion
  - Transverse expansion
  - Thickness shear
  - Face shear



- The mode of deformation depends on shape and orientation of body relative to crystal axes and location of electrodes
- Two family of constants – *g* constants and *d* constants, are considered
- g_{33} = field produced in direction 3/stress applied in direction 3
- d_{33} = charge generated in direction 3/force applied in direction 3

Homework
(Submit: Tuesday 21/3/22)

- Bring at least 3 examples where the gauges that we have discussed are being used?
- Think of at least one unmet need which can addressed by using one or more of these gauges? Alternatively, come up with an original application for any of the gauges discussed.