MICRO 372 - Advanced Mechanisms for Extreme Environments

Chapter 7

System aspects

Florent Cosandier

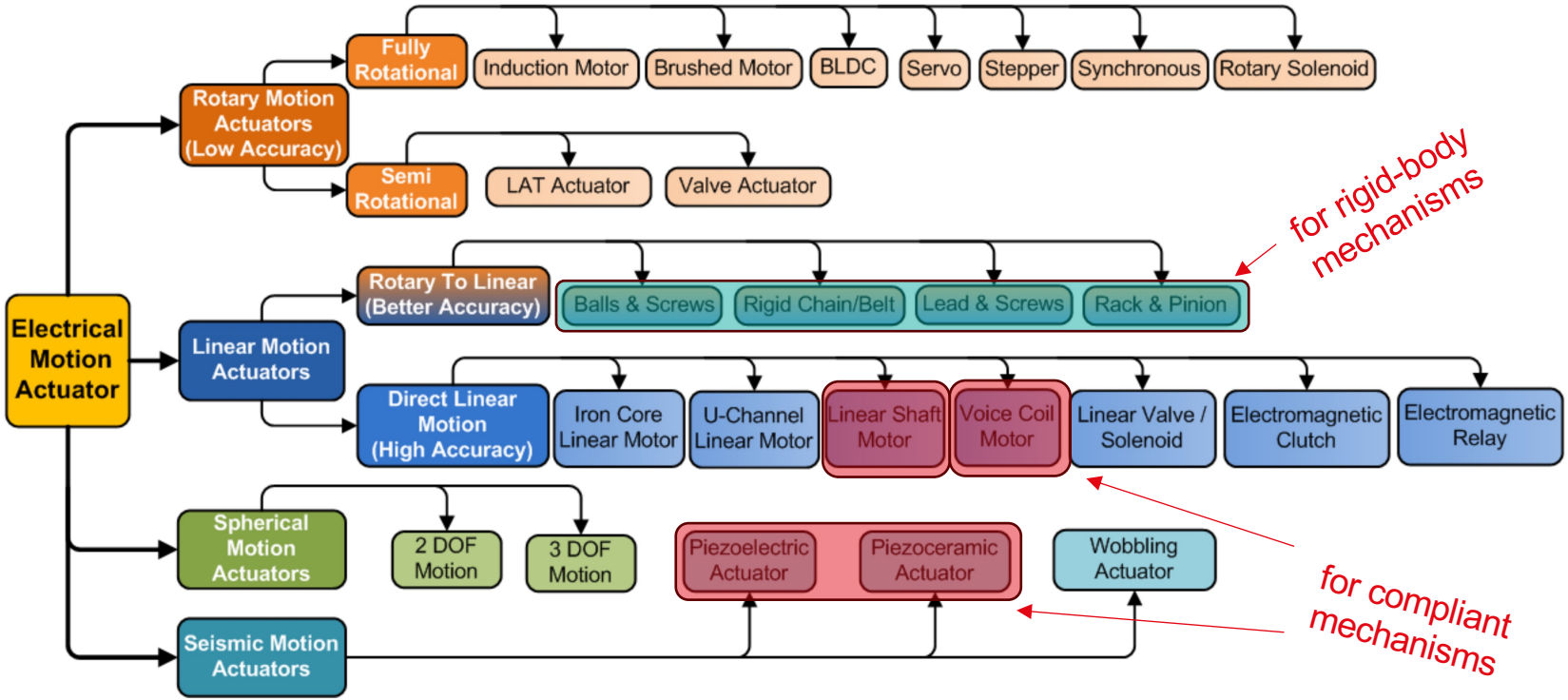
École polytechnique fédérale de Lausanne

https://www.space.com/40736-very-large-telescope.html

System aspects

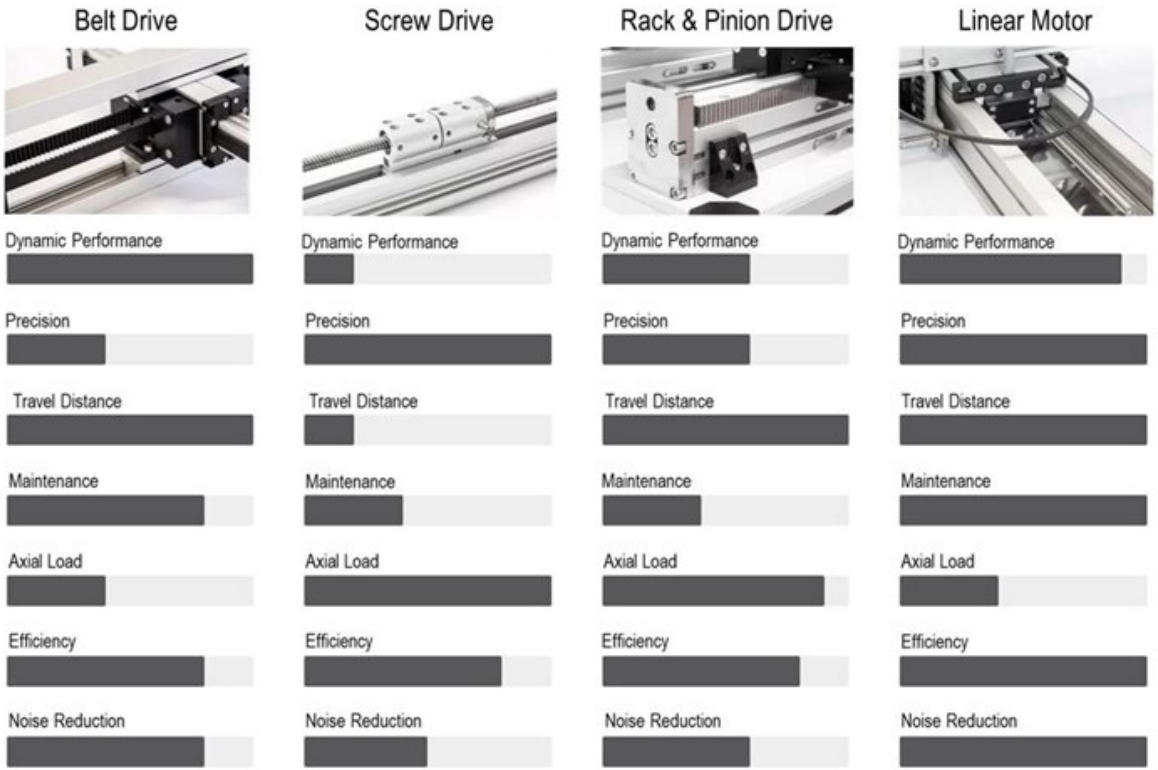
- Actuators
- Sensors

Electrical actuator types



Redekar, Abhijeet & Deb, Dipankar & Ozana, Stepan. (2022). Functionality Analysis of Electric Actuators in Renewable Energy Systems—A Review. Sensors. 22. 4273. 10.3390/s22114273.

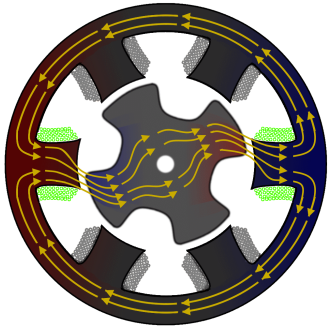
Linear actuator drive types

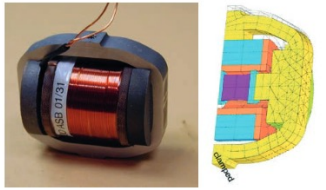


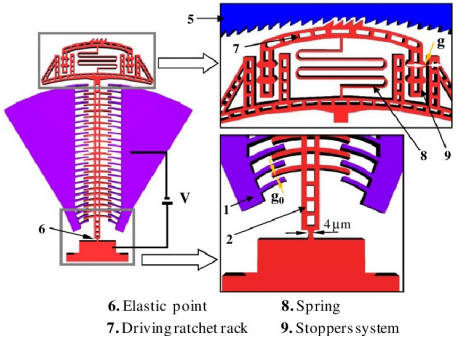
https://www.nookindustries.com/resources/blog/archive/comparing-modular-linear-actuator-drive-types/

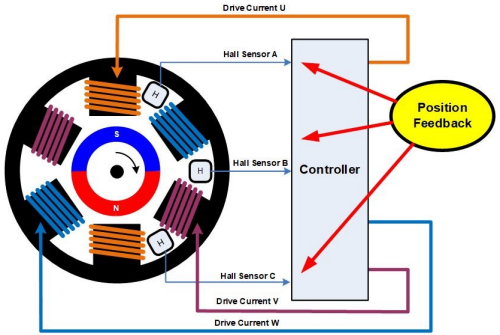
Electromagnetic actuators for flexures

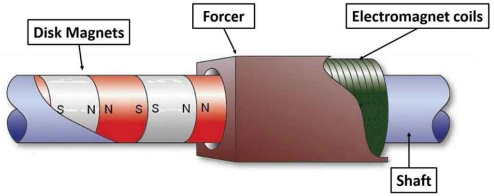
- Voice coils
- Reluctant actuators
- Magnetostrictive actuator
- Electrostatic motor
- DC rotors
- Linear shaft motor





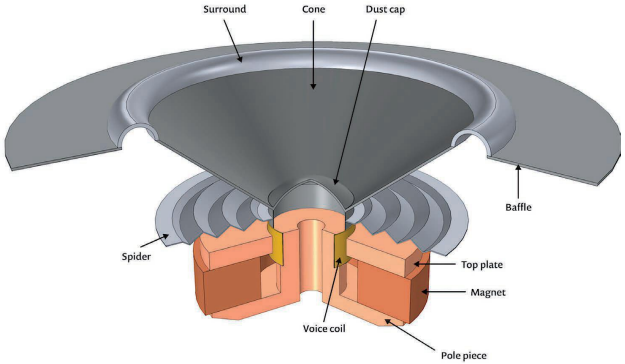


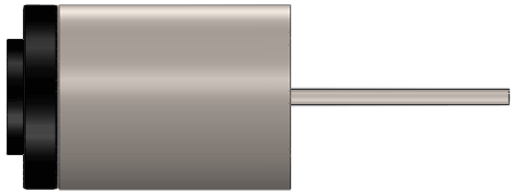




Voice coil motors

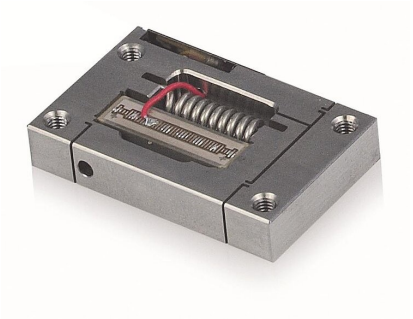
- **Typical actuator for flexure**
- Suitable for a wide range of applications requiring **precise and controlled continuous linear motion**.
- Can include **internal bearing or not.**
- **Flexure** actuation require generally **no bearing** (the flexure itself is the bearing).
- VCMs are often **compact in size** relative to the force they can generate.
- **Centring** within housing **is critical, as lateral gaps are tight**. Beware of **flexure parasitic motion** (lateral or rotational)!
- Main manufacturers: BEI Kimko, Moticont, H2W Technologies, …



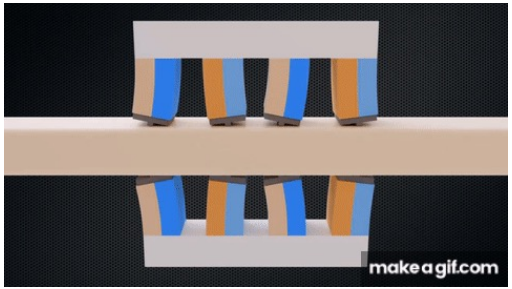


Piezoelectric actuators for flexures

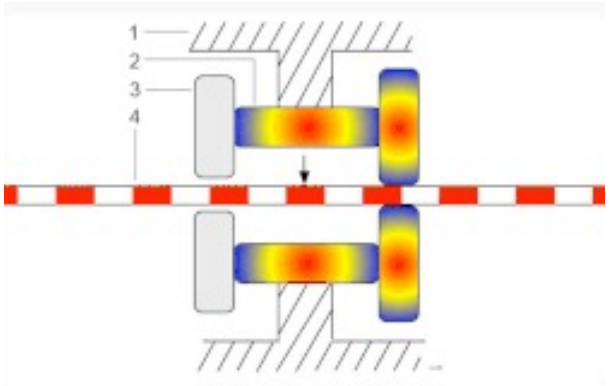
- Piezo stacks



- Piezo leg



- Inchworms



Piezo motors

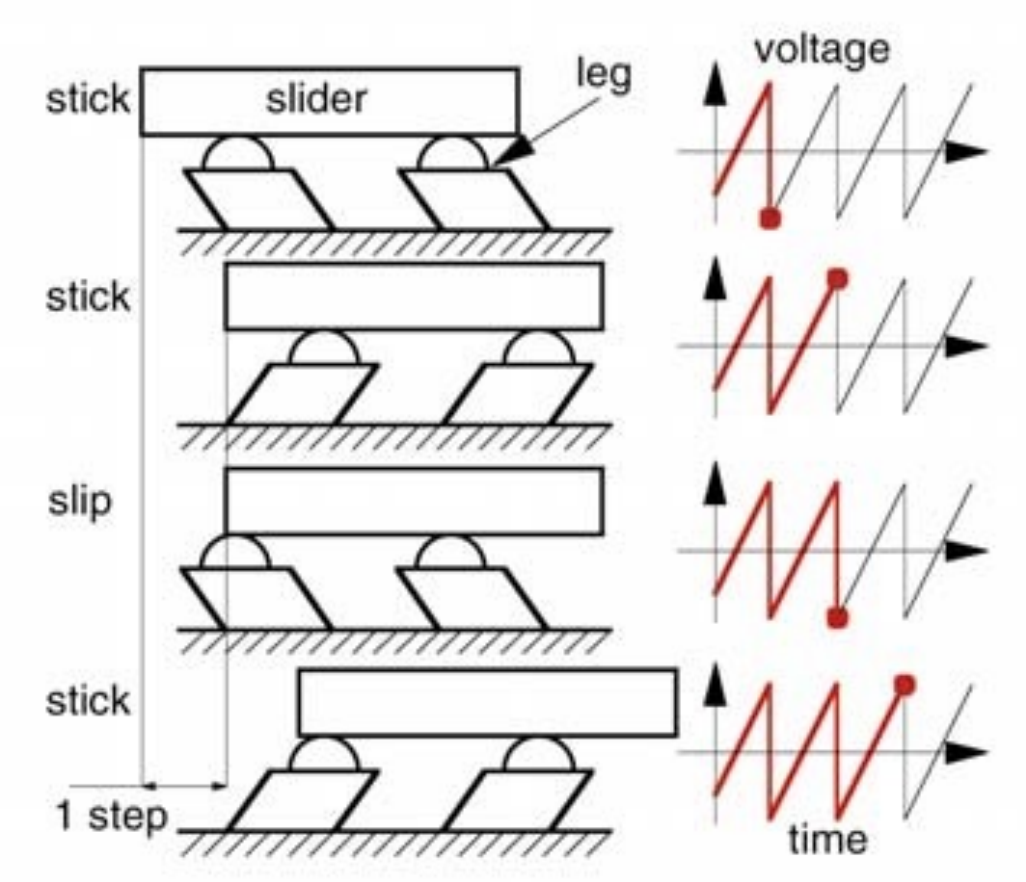
PI Piezo Motor Precision Positioning Solutions

Inertia Motors PiezoWalk® Ultrasonic PiezoMike Mini-Rod

pi-usa.us

video link

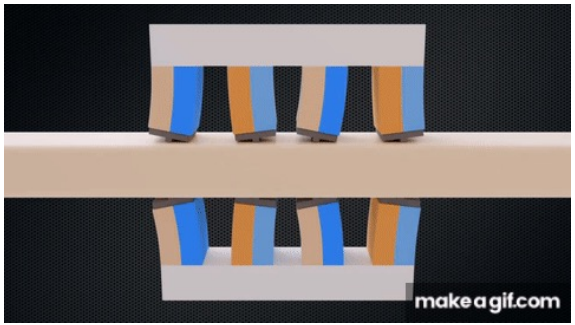
Stick-slip phenomenon



Mazerolle, S. & Rabe, Renzel & Varidel, T. & Breguet, Jean-Marc. (2003). Positioning, Handling and Measuring inside a Scanning Electron Microscope.

Characteristics of piezo motors

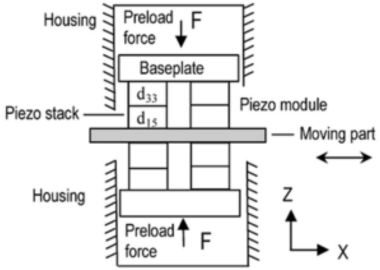
- Can achieve **extremely precise motion**. But **strokes are very small**, so the **motion** is generally **amplified**, or **repeated at high frequency**.
- In contrast to classical linear actuators, **several components** (leadscrew, gearbox, bearings, …) **can be dispensed** with piezoactuators because the linear motion is generated directly.
- This makes it possible to realize **very compact, low mass, high-load devices**.
- Typically consumes **very little power** (piezo actuator behaves like a capacitor).
- **Voltage driven.**
- **High stiffness.**
- **UHV-compatible**.
- Fully **nonmagnetic actuators**.

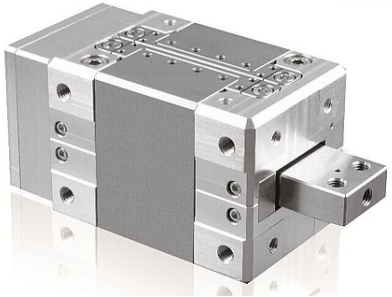


- **Temperature dependence** of the piezo effect. Thus, strokes are reduced to about 30% at cryogenic temperatures.

Piezo motor example

- **Self-locking actuator** for **hexapod applications for active optical alignment in astronomy**
- **Stroke**: up to 20 mm
- **Resolution**: 50 pm
- **Push/pull capability**: ± 800 N
- **Actuator mass**: 1.2 Kg
- **Actuator volume**: 340 cm^3
- **Stiffness**: 45 N/um
- **Dynamic range** over 2 mm travel: >10,000,000





Sensors

Position sensor technologies compatible with compliant mechanisms:

- **Contactless**:
  - Capacitive
  - Optical: interferometer, autocollimator, laser triangulation
  - Encoder: optical or magnetic
  - Eddy current

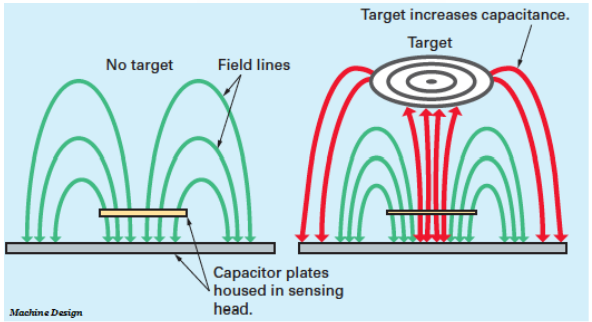
- **Contact**:
  - LVDT
  - Strain gauges

Capacitive sensor

- Principle: A capacitor creates an **electric field between two conductive plates** when the voltage is applied. Capacitance names the ability of a capacitor to accumulate electric charging. It is the effect of the combination of the area of overlap on the two plates, the **distance between the plates** and the relative permittivity of the material.

- Measuring range 0.05 mm to 10 mm
- Typical resolution < 1 nm
- Repeatability 0.0005% Full scale output (FSO)
- Frequency < 10 kHz
- Typical weight 1 g to 100 g
- Thermal range -50 °C to + 200 °C

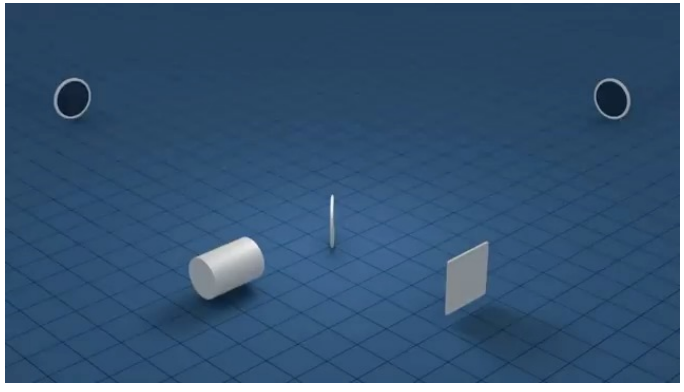
robu.in

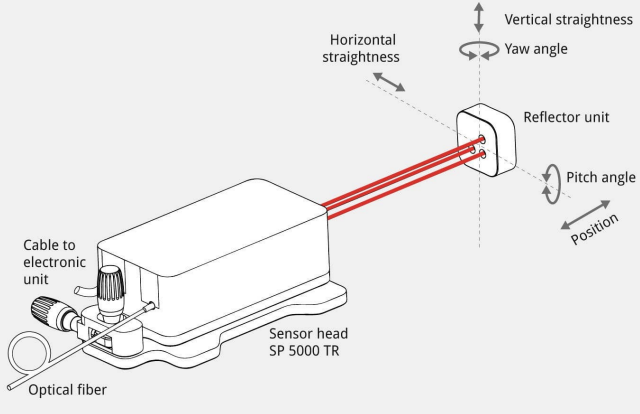


Interferometer

- Principle: splitting of the light into two beams that travel different optical paths and are then combined to produce interference

- Measuring range up to tens of meters
- Typical resolution 50 pm
- Repeatability 1 um
- Speed up to a few m/s
- Typical weight 100 - 200 g (with cables)
- Thermal range -20 °C to 80 °C



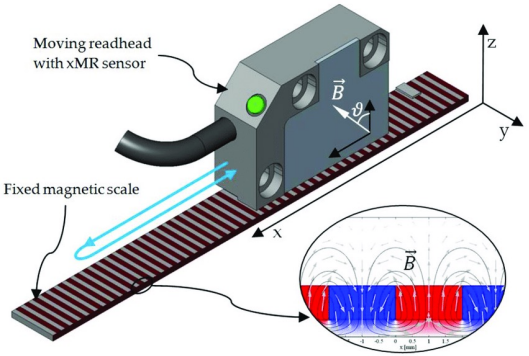


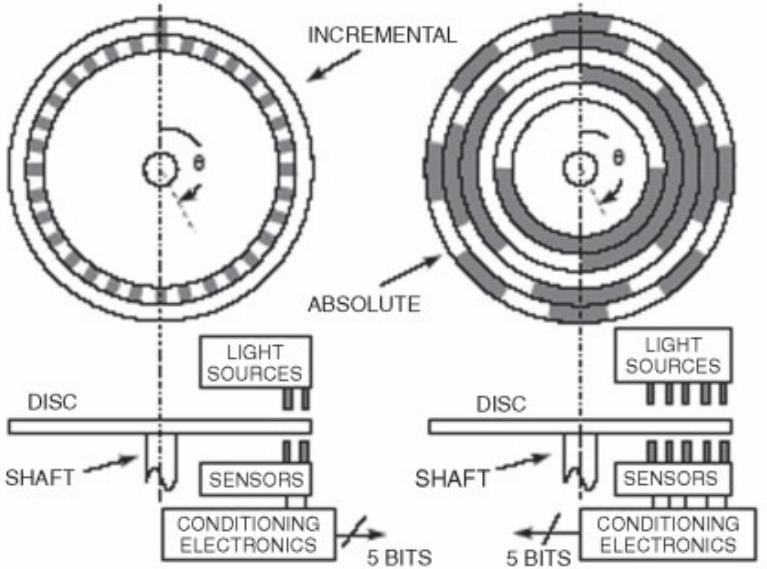
sios-precision.com/

Optical (or magnetic) encoder

- Principle: Optical encoder detects the the optical pulse signals that have passed through the slit, converts them into electrical signals, and outputs them

- Measuring range up to a few meters
- Typical resolution 1nm
- Repeatability tens of nm
- Frequency/speed up to 600 kHz / 15 m/s
- Typical weight 100 to 500 g
- Thermal range -40 °C to 100 °C



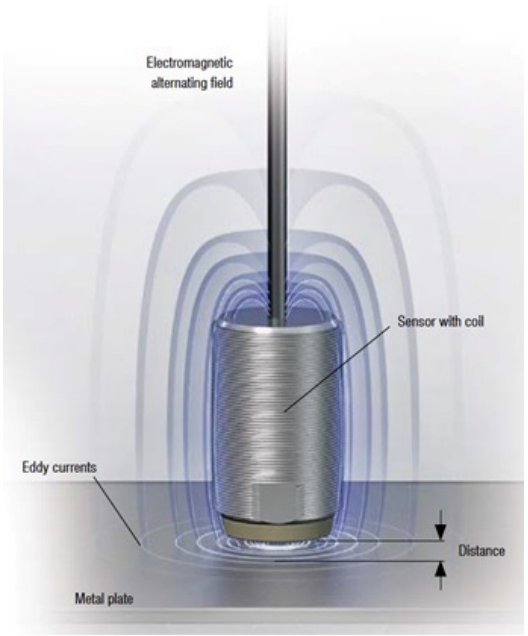


etching-meltec.com

Eddy current sensor

- Principle: The eddy currents' effect on the impedance of the coil is measured. The controller calculates the impedance by looking at the change in the amplitude and phase position of the sensor coil.

- Measuring range up to 10 mm typically
- Typical resolution 0.02 to 1 μm
- Repeatability <1 μm
- Frequency up to 100 kHz
- Typical weight 20 g
- Thermal range -50 °C to + 150 °C

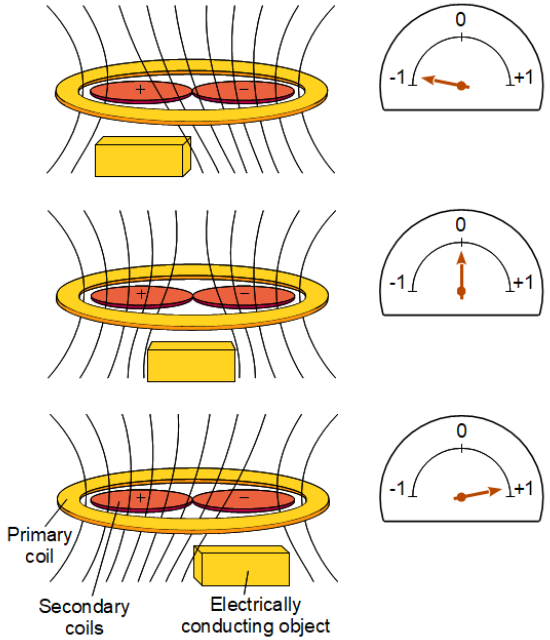


pandct.com

Inductive encoder

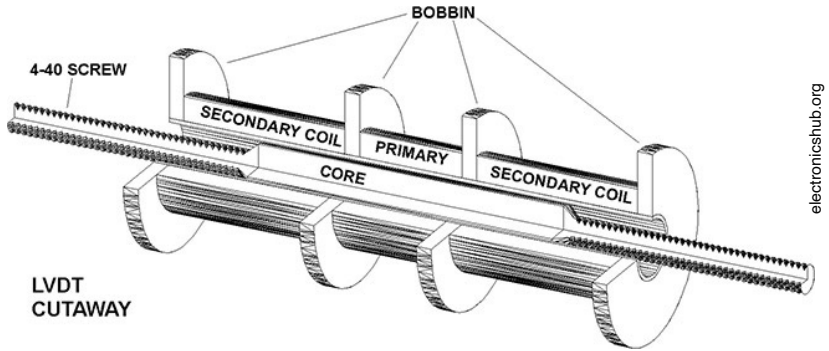
- Principle: **Differential transformer** of which the coupling between primary and secondary coils is modulated by a ferromagnetic of electrically conducting object (codewheel, scale, gear ...). The primary coil of the transformer generates a high-frequency magnetic field (1 – 2 MHz). The two secondary coils are arranged in a differential configuration that is perfectly symmetric with respect to the primary coil.

- Measuring range up to 20mm
- Typical resolution 0.02 μm
- Repeatability NA
- Speed up to 30 m/s
- Typical weight few g
- Thermal range -20 °C to 100 °C



Linear Variable Differential Transformer (LVDT)

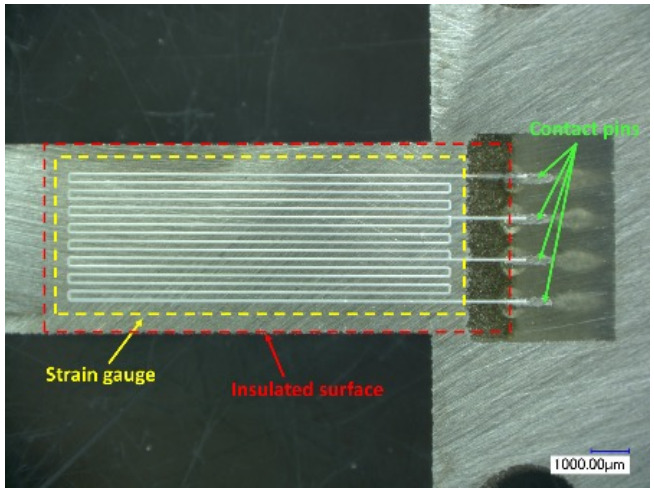
- Principle: LVDTs operate on the principle of a **transformer**. An LVDT measures displacement by associating a specific signal value for any given position of the core.
- Measuring range 1 mm to 1m
- Typical resolution <1 μm (1 mm range)
- Repeatability > 0.1 μm
- Frequency 1 to 10 kHz
- Typical weight 50 g
- Thermal range -20 °C to 80 °C



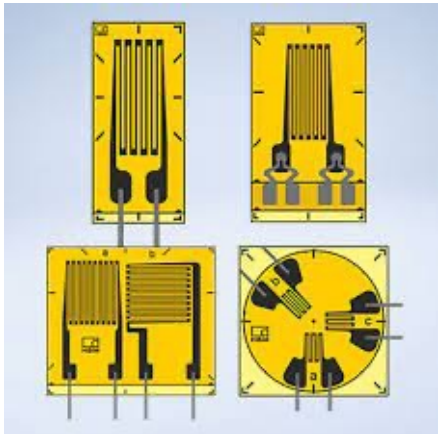
electronicshub.org

Strain gauges

- Principle: Strain gauges convert the applied force, pressure, torque, ect., into an electrical signal which can be measured. Force causes strain, which is then measured with the strain gauge by way of a change in electrical resistance, due to elongation and Poisson ratio related contraction of conductor lateral dimensions.
- Gauge factor (sensitivity) superior to 2
- Linearity better than 99.9%
- Printed insulation and strain gauge by AerosolJet Printing on a 300 µm-thick flexure element. (top picture)

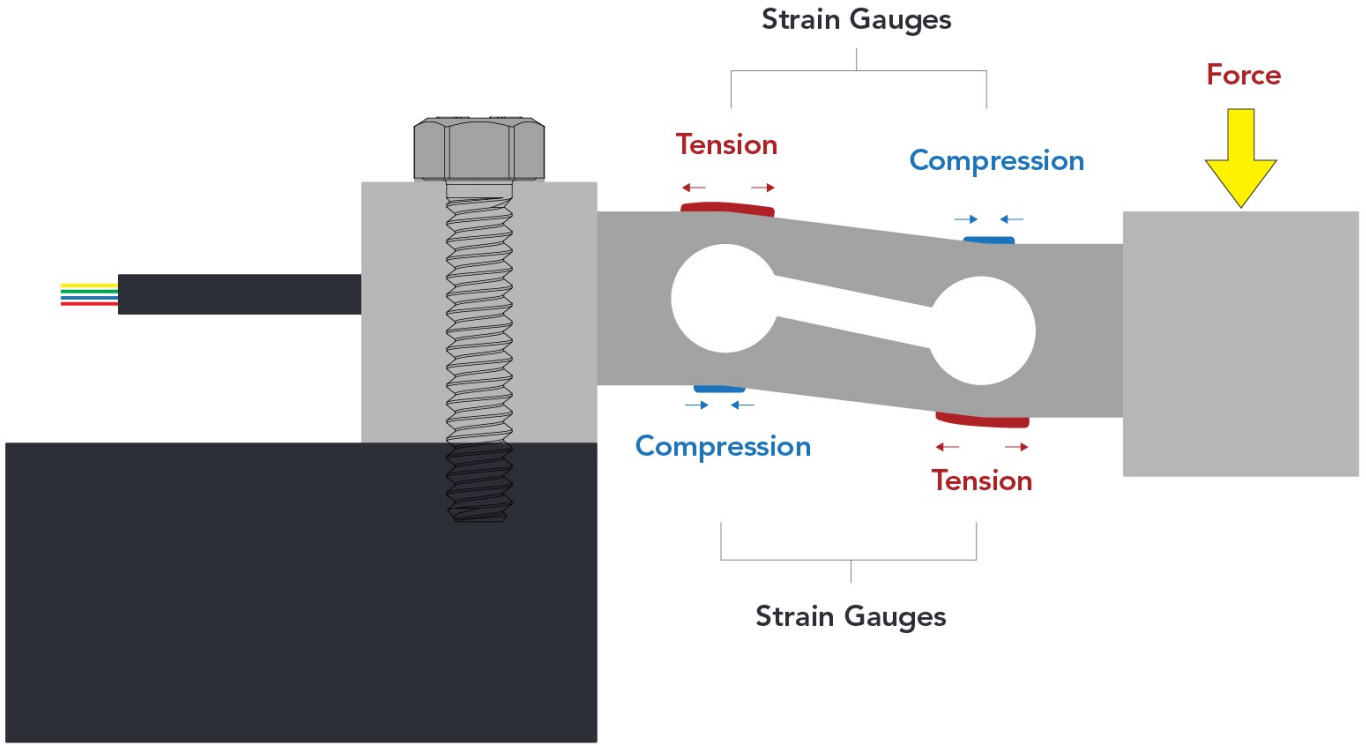


azosensors.com



https://www.intro.co.th/product/20848-24927/strain-gauges

Strain gauges as component of a load-cell



anyload.com