## Measurement

from tables: $U_V = V * X\% + (2 \text{ or } 3) * \text{resolution}$ (if DC: 2, AC: 3)

$P_V = \frac{U_V}{V}$

$P_i = \frac{U_i}{i}$

$U_c = \sqrt{P_V^2 + P_i^2}$

$U_R = R * U_c$

## Testing

**Brinell Hardness**: indenter: Hardened steel ball, non-ferrous: 500 Kgf, steels: 3000 Kgf

**Ultrasonic**: typ. freq.: 0.1–15 MHz, max freq.: 50 MHz. Can't be used with: Ferrous objects

**ECI**: Based on: Electromagnetic Induction, max. depth: 6 mm, why: Skin effect

**Liq. Penetration dis.**: depth restriction, & can't be used with internal defected specimen.

**X-ray**: radiographic inspection, dark area means: lower density, The film is called: Radiograph.

Why conductive liquid can't be measured with a capacitive system? = Conductivity of the liq. shorts circuit the capacitor/s.

## Sensors

**Resistive Sensors**: $R = \rho \frac{L}{A}$, $GF = \frac{dR/R_0}{\varepsilon}$

**Capacitive**: $C = \varepsilon_0 \varepsilon_r \frac{A}{d}$, application: distance (for distance < sensor's diameter), acceleration, & pressure sensor.

**Capacitive pressure sensor**: Uses a pressure sensitive diaphram as one electrode, whereas the other electrode is fixed.

**Inductive sensor**: based on Faraday's Law of induction; $U(t) = -L * \frac{di}{dt}$, Most important advantage of inductive proximity sensor: Doesn't require physical contact.

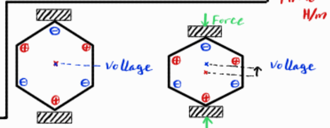
$L = \mu_0 * \mu_r * N^2 * \frac{A}{L}$, $\mu_0 = 4\pi * 10^{-7}$ H/m

**LVDT**: An electromechanical sensor used to measure linear displacement. **RVDT**: Same concept as LVDT except that it's rotary.

Main Adv.: LVDT & RVDT doesn't require an electrical contact between the moving part and the coil assembly, making these sensors very reliable.

| Characteristics | Capacitive Proximity | Inductive Proximity |
|---|---|---|
| Range | 0.1–60 mm | 3–60 mm |
| Speed | Up to 5 KHz | Up to 50 Hz |
| Diameter | 3–40 mm | 12–60 mm |
| Sensitive to | Most materials conductive & isolating | Ferrous materials Less-sensitive to non-ferrous metals |

**Inductive proximity**: An oscillator creates a magnetic field that radiates from the coil at the sensing face. When a ferrous target enters this magnetic field, small independant electrical currents called eddy currents are induced on the metal's surface. This changes the reluctance (natural frequency) of the magnetic circuit, which in turn reduces oscillation amplitude.




**Piezoelectric sensor**: Some substances generate an electrical charge and an associated potential difference when they are subjected to mechanical stress or strain.

**Disadvantage**: Can't be used for purely static measurements, as a static force results in a fixed amount of charge.

$S_q = \frac{\partial q}{\partial F}$ → Force, $S_q = \frac{1}{A} \cdot \frac{\partial q}{\partial P}$ → Pressure → In [pC/N]

$S_v = \frac{1}{d} \frac{\partial v}{\partial P}$, $\boxed{\partial q = C * \partial v,\ C = K * \frac{A}{d}}$ → $S_q = K * S_v$ → Voltage sensitivity → In [mV·m/N]

**Thermocouple**: Consists of 2 different electrical conductors generating a temperature-dependant voltage in the microvolt rang as a result of the thermoelectric effect (seeback effect). Temp. rang −200 to 2300 °C. **disadvantage**: bad accurcy.

**Piezoelectric pressure sensor**: Same as capacitive & resistive strain gauge sensors, except that this one can handle much higher pressure range.

**Hall effect sensor**: Hall effect is the production of a voltage difference (Hall voltage) across the sides of an electrical conductor as a result to an applied magnatic field perpendicular to the current. Compaired to inductive sensor, hall sensor has one major advantage: In inductive sensors we need an alternating magnatic field, where in Hall sensor we can detect static magnatic as well.

**Adv. when used as electronic switches**: cheaper, more reliable, and can operate at much higher freq. than a mech. switches.

**Photo Diode**: is a semiconductor converting light into an electrical current.

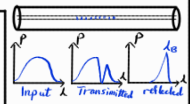
**Photo Transistor**: Consists of a bipolar transistor encased in a transparent case.

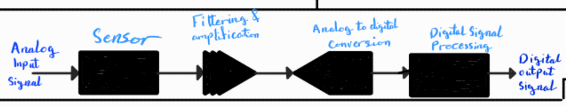
**Fiber Bragg Grating (FBG) Sensor**: Can be used as an inline optical filter to block certain wavelengths (used for Wavelength Division Multiplexing), or as a wavelength-specific reflector sensitive to strain and temperature.

**disadv.**: since FBG is sensitive strain & temp., we have to seperate them for an accurate output.

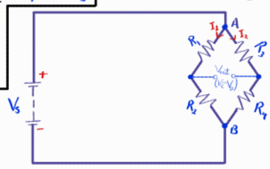
Bragg wavelength $\lambda_B$ shifts by $d\lambda$:

$$\frac{d\lambda}{\lambda_B} = \underbrace{C_S}_{\text{Coeff. Strain}} * \underbrace{\varepsilon}_{\text{strain (mech. \& temp included)}} + \underbrace{C_T}_{\text{Coeff. for change of the refractive}} * \underbrace{dT}_{\text{temp. change}}$$



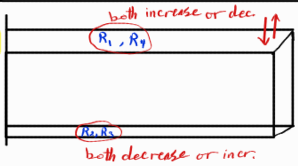

**Wheatstone Bridge**:




**Balanced bridge**: $V_{out} = 0$ → $\boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$

$V_{out} = V_s * \frac{R_2}{R_1 + R_2} - V_s * \frac{R_4}{R_3 + R_4}$

**For typical full bridge**: $R_1 = R_2 = R_3 = R_4$




**Adv. of wheatstone bridge**: $GF \cdot \varepsilon = \frac{V_{out}}{V_s}$ ⟸ $\boxed{\frac{V_{out}}{V_s} = \frac{dR}{R}}$ ($\varepsilon$: Strain, $V_s$: Vin)

I) For a balanced bridge ($V_{out} = 0$), a high amplification for the output voltage can be used to get a high resolution of the measurement.

II) A symmetrical bridge compensates thermal influences electrically.

III) A symmetrical bridge compensates unwanted mechanical strain orthogonally to the measuring direction electricall.

**Sensitivity of Diff. strain Gauge Bridges:**

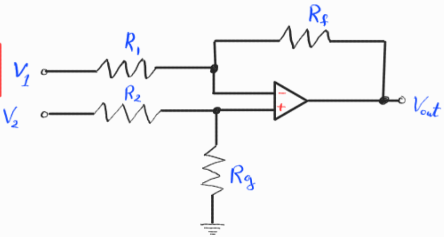
Full bridge (4 active strain gauges): $\frac{V_{out}}{V_s} = GF \cdot \varepsilon$

Half bridge (2 active strain gauges): $\frac{V_{out}}{V_s} = \frac{1}{2} GF \cdot \varepsilon - \frac{1}{2}$

Quarted bridge (1 active strain gauge): (but no temperature compensation)

**Differential amplifier**: Low differential voltages have to be amplified.

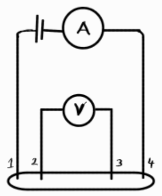
$\boxed{V_{out} = (V_2 - V_1) * \frac{R_f}{R_1},\ \text{if } R_f/R_1 = R_g/R_2}$



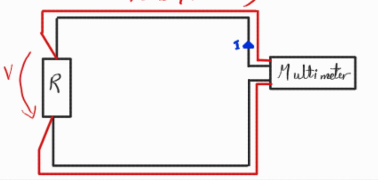

**Instrumentation Amplifier**:

$\boxed{A = \left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2}}$

**Four-Terminal sensing** (Kelvin connection): By the use of separate pairs of current-carrying and voltage sensing cables, a voltage drop in combined lines because of the line resistance can be avoided. Kelvin connections are typically used to measure the voltage drop at a current sensing (shunt) resistor. As shunt resistors are typically very small (mOhms), an accurate layout is necessary.




A way of measuring current flow precisely




**More Piezo electric sensors**:

dielectric constant (Permittivity) of the crystal ↳ $K = \varepsilon_0 \cdot \varepsilon_r$ → dielectric constant; $\varepsilon_0 = 8.854 * 10^{-12}$ F/m

**More of Thermo Couple**: $V = E(T_{sense}) - E(T_{ref})$

Maximum possible error from data sheet: (around ± 1.5°)

A & B' must be from the same material of A & B / material with the same thermoelectric properties.

**Interpolation**:

| E(T) | T |
|---|---|
| $E(T_1)$ | $T_1$ |
| $E(T_2)$ | $T_2$ |
| $E(T_3)$ | $T_3$ |

$$\frac{E(T_1) - E(T_3)}{T_1 - T_3} = \frac{E(T_2) - E(T_3)}{T_2 - T_3}$$

**Capacitive Proximity sensor**: There are two electrodes (at diff. potentials) housed in the sensing head and positioned to operate like an open capacitor. A conductive or non-conductive target increases the capacitance of this capacitor.

**Resistive Touch screen**: Two transparent conductive layers of indium tin oxide (ITO) are separated by a small air gab and insulating spacer dots. A stylus or finger bends the flexible top cover, creating an electrical contact between the two conductive layes.

**4-Wire resistive touch screen**: uses four conductive bars, two on top side, & two on the bottom. At the touching point, the voltages between the pair of bars is equal (due to the short circuit between the two layers).

**Surface Capacitive touch**: A glass substrate is covered with ITA coating and a small ac voltage is applied. When the finger touches the screen, a small charge is transferred to the finger. This creates a voltage drop on that part of the screen, and the touch is detected.

**Projective Capacitive touch**: A PCT/PCAP consists of a ITO matrix behind a thicker glass/acrylic cover. Capacitance coupling will occur between the finger and the electrodes. The capacitance coupling makes the electrostatic capacitance between the X & Y electrodes change.

| | Resistive | Surface capacitive | Projected capacitive |
|---|---|---|---|
| Accuracy | High | Medium | High |
| Multi-touch | No | Yes | Yes |
| Durablity | Low | Medium | High |
| Costs | Low | Medium | High |
| Usable with gloves or stylus | Yes | Yes (but only thin cotton gloves) | No |

**Actuators**: Can be classified by their type of input energy, e.g. | **Electrically Powered Actuators**:

**Electro Magnetic actuator**: A solenoid consists of a coil, a plunger and a spring in a common case. If current flows through the coil, the coil acts like an electro magnet, pulling the (steel) plunger. The spring is used for the return path. Solenoids are often used for simple linear actuators and for controlling valves. Solenoid valves are often used in automotive application for example, as fuel injectors or as intake and outtake valves of combustion champers.

**DC Motor**: Consists of an electromagnet as its stator and a coil as its rotor. Current flowing through the coil inside the magnetic field of the stator, a lorentz force is generated, turning the rotor. For continuous rotation, the direction of the current in the rotor (so called communication) has to be changed peridically. Two types of DC motors: 1- Brushed , 2- Brushless

**Brushed DC Motor**: The brushes (Often made of carbon) in a dc motor have two functions: 1- Carrying the current to the rotating part (rotor). 2- Switching the current flow with the commutator.

**Disadvantages**: 1) Losses due to brushes friction. 2) Brush material wears down due to friction, creating dust. 3) Resistance of the brushes causes a voltage drop, resulting in a power loss. 4) The repeated switching of current through the rotor coil causes sparks at the commutator contacts, causing electromagnetic noise (called brush fire). / Still used for simple low-power applications because of their low costs.

**Brushless DC (BLDC)**: Consists of a permanent magnet rotor and an external, electronically commutated (EC) magnetic field (therefore also called EC motor). As the rotor follows the magnetic field, the motor is a synchronous motor. Hall effect sensors (output signals a,b,c) are used to measure the angle of the rotor and control the commutation of the motor windings (output U, V, W).

**Advantages**: No wear on brushes (like DC-Motor) + Smaller losses (higher efficiency) + high power density + good for high rpm (unlike servo or stepper).

**Servomotors**: A rotary or linear actuator allowing the control of the angular or linear position as well as the velocity and acceleration is called a servomotor. The term is independant from the type of motor, but often electro dynamic dc or ac motors are used. Servomotors require a controller, reading in the positioning information, processing it and controlling the output signals for the motor driver.

**Piezo Electric actuator**: The piezo electric effect can be reversed. A high electric fields results in tiny changes in the width of the crystal. As this width can be changed with better-than-1µm Precision, Piezo cryslats are the most important tool for positioning objects with extreme accuracy. **A typical Piezo actuator needs a driving voltage of 150-200 V dc.** **Piezo Electric loud speaker/Buzzers**: Can be used in the range from 1 to 100 KHz and often used for signal generation in electronic devices. Ultrasonic piezo electric devices are also used for parking assistance. Due to the reversible piezo electric effect, the piezo membrance can be used as actuator and sensor. **Automotive Piezo electric Valves**: Actual common-rail systems use piezo injectors as they offer fast switching times and a flexible adaptation of the injection pattern. In addition, they can hondle high pressure inside the motor.

**Magnetostrictive Actuators**: During the process of magnetization, ferromagnetic materials charge their shape or dimention. The reciprocal effect, the change of the magnetic susceptibility (response to an applied field) of a material when subjected to a mechanical stress, is called the Villari effect. Examples: Magnetostrictive actuators are used as sound generators (sonars), valves, high force generators and low voltage actuators.

**Magnetorheological**: A magnetorheological fluid consists of microscopic magnetic particles (0.1 - 10 µm) in a carrier oil. Subjected to a magnetic field, the fluid increases its apparent viscosity up to the point of a viscoelastic solid. Magnetorheological Dampers: magnetorheological fluid can be used in shock absorbers or dampers. The fluid viscosity can be continously controlled with short response times by an applied magnetic field. **Due to the costs of such dampers**, they're only used in heavy industry or expensive sport cars.

**Fluidically Powered Actuators**: Examples: valves, Linear actuators

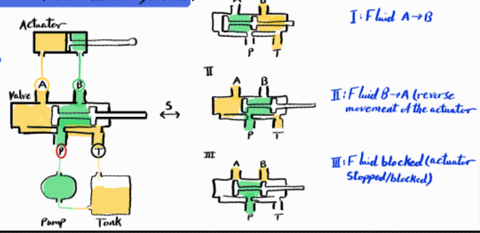
**Hydraulic actuators**: Pascals law.

**Advantages of Hydraulics**:
- High torque/mass ratio.
- Great flexibility of providing multiple actuators at diff. locations using same power source.
- Self-lubricant.
- No (high) voltages required.
- Efficient heat removal and reduced thermal problems.
- Stiffer system.

**disadvatiges** (Compared to electrically powered)
- Not as linear (because of valve nonlinearities, fluid friction, compressibility, thermal effect, general nonlinear constitutive relations.
- Leakage can create problems.
- Typically noisier than electric motors.
- Synchronization of multiple actuators more difficult.
- Typically more expensive.
- Typically less portable.

Port P: Hydraulic pump
Port T: Storage tank
Port A/B: Double acting actuator

**Four-Ports-three-Ways Valve**:




**Pneumatic Actuators**: Operates similiar to hydraulic systems, but with 2 basic differences; 1- Air is the working fluid. Air is far more compressible than hydraulic oils, thus, compressibility has to be taken into account. 2- The outlet of the actuator and the inlet of the pump are open to the atmosphere.

**Pneumatic VS Hydraulic System**:

**Advantages**:
- Cheaper
- less weight
- Fewer problems with leakage

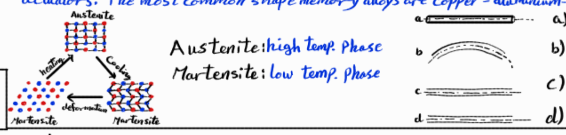
**Disadvantages**:
- Only suitable for low & medium-duty tasks (Pressure 500KPa to 1 MPa)
- More nonlinear
- less accurate

**Thermal Expansion Actuator**: Uses a medium which expands when heated. Often waxes are used (which expand when melted and contract when they solify). Used in thermostates or thermostatic valves.

**Thermically Powered Actuators**: Especially bi-metall & Shape memory alloys are heated by an electric current flowing through them.

**Thermo bimetal actuator**: Most important thermal atuator. Is composed of two seperate metal joints which expand at different rates when heated. Typical metal combinations are steel & copper or steel & brass. A common app. for bimetals are temp. dependant switches, used for thermostates. Above a certain temp. the bimetal actuator opens or closes an electrical switch.

**Shape Memory Alloys**: is an alloy that can be deformed when cold but returns to its pre-deformed (remembered) shape when heated. For special apps, they can be a lightweigh, solid-state alternative to hydraulic, pneumatic, & electromechanical actuators. The most common shape memory alloys are copper-aluminium-nickel (cheap) and nickel titanium (better Performance).

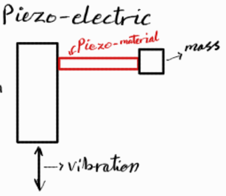



**Electro-Chemically Powered Actuators**: Working Principle: Gas-proof extensible enclosure with two electrodes. If a dC voltage is applied, dependant on the polarity gas is generated or absorbed. For a higher acluator speed and force, multiple cells are stacked.

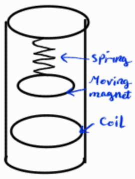
**Energy Harvester**:

Piezo-electric

Vibrating machine:

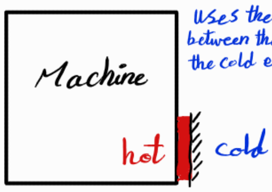



Electromagnetic




**Generating heat machine**:

Thermoelectric generator (TEG, based on Seebeck effect)




Uses the heat difference between the hot machine and the cold environment.

Why hydraulic actuators are used in excavator not electro dynamics?
High forces are needed but usually one for one actuator per time.
So, one central hydraulic pump can be used to power different actuators.

**Force calculations**

$$P_1 = P_2 \Rightarrow \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$V_1 = V_2$$

$$A_1 \cdot h_1 = A_2 \cdot h_2$$

$$\boxed{F_1 = F_2 \cdot \frac{d_1^2}{d_2^2}} \Rightarrow \boxed{F_2 = F_1 \cdot \frac{d_2^2}{d_1^2}} \qquad \boxed{h_1 = h_2 \cdot \frac{d_2^2}{d_1^2}}$$

What kind of actuator would you use for self-expanding stent without any external power supply?
= Shape memory alloy actuator (thermally activated by the warm blood).

Explain the working principle of such a stent?
= The stents are crimped to the artery diameter at low temperatures. When they are inserted into the human body, the blood is heating them up and the stent gets its final (larger) diameter.