Measurements in Mechatronic design

Transducers

Quantities

- Current
- Voltage
- Torque
- Force
- Magnetic flux
- Distance
- Temperature

Measurement system

Voltage,
Current,
Force,
Torque,
Flux,
Temp,
Pressure

Amplification,
Filter,
Sampling

Multimeter,
Oscilloscope,
Freq.analyser,
Computer,
Control system

Supervision,
Industrial process,
other control

Purpose?

- Open loop.
  - Information to the user
  - Information to other systems
  - Supervision
- Closed loop
  - Feedback

How?

- **Direct measurement**
  - **Purpose made equipment using a physical phenomenon that directly links the measured quantity to the measurement signal**
- **Estimation**
  - **Indirect calculation of the desired quantity from other known (but not necessarily measured) physical quantities. E.g. if the motor voltage and the motor speed is measured, the flux can be estimated**

Galvanic isolation

- From a safety and disturbance point of view the instumentation, which uses the measured signal, is located on a different potential level than the point of the measurement.
- The electrical signal, that represents the measured quantity, must be on the same potential level as the instumentation.
- In other words: The measurement signal must be galvanic isolated from the measured quantity.

Current

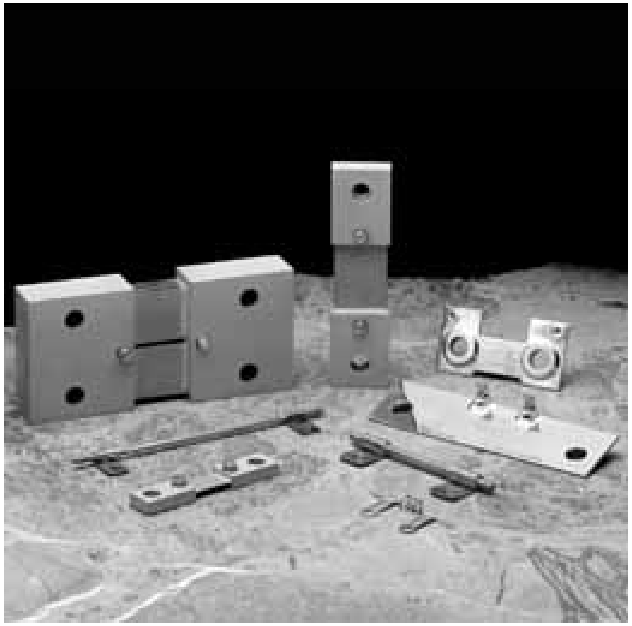
- Current shunt
- Coaxial or loop current shunt
- Rogowski coil
- Hall effect sensor
- Flux compensated hall effect
- …

Current shunt

$$v_a - v_b = R \cdot i + L \cdot \frac{di}{dt}$$

$$i = \frac{v_a - v_b - L \cdot \dfrac{di}{dt}}{R}$$

$$i \approx \frac{v_a - v_b}{R}$$



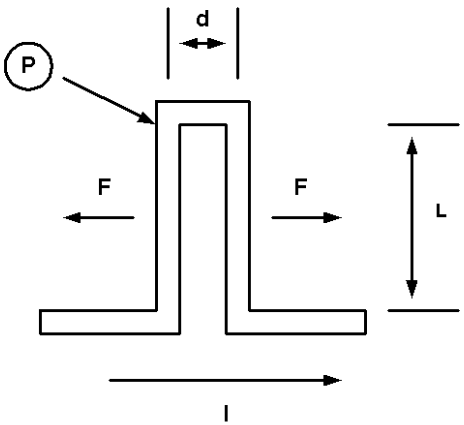
... if inductance and skin effect can be neglected

Coaxial/Loop shunt

$$v_a - v_b = R \cdot i + L \cdot \frac{di}{dt}$$

$$i = \frac{v_a - v_b - L \cdot \frac{di}{dt}}{R}$$

$$i \approx \frac{v_a - v_b}{R}$$



Both skin effect and inductance can be neglected!

Rogowski coil

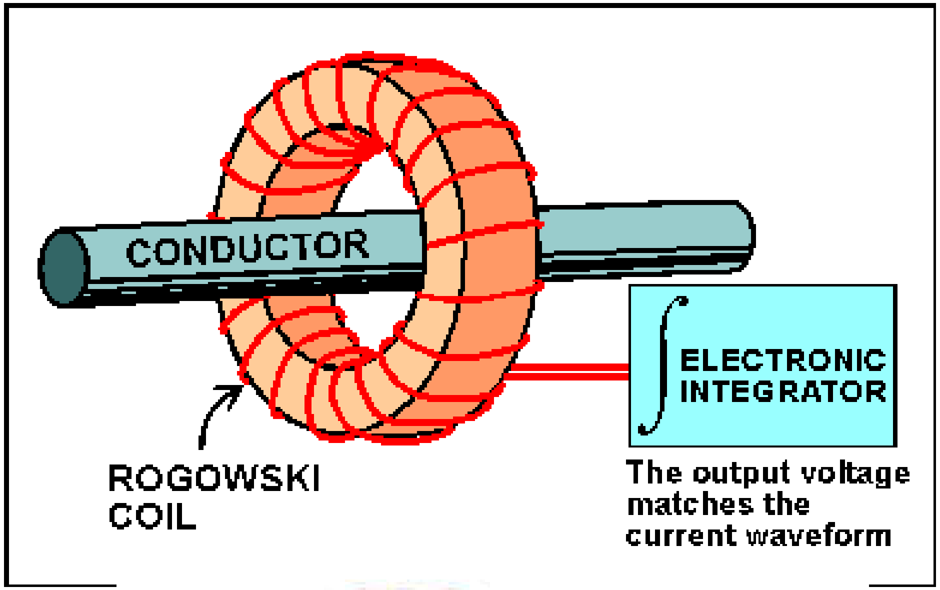
- Ideally linear (no saturable elements)
- Cannot measure DC-current

$$\oint_{around\ conductor} H \cdot dl = i$$

$$B = \mu_0 \cdot H$$

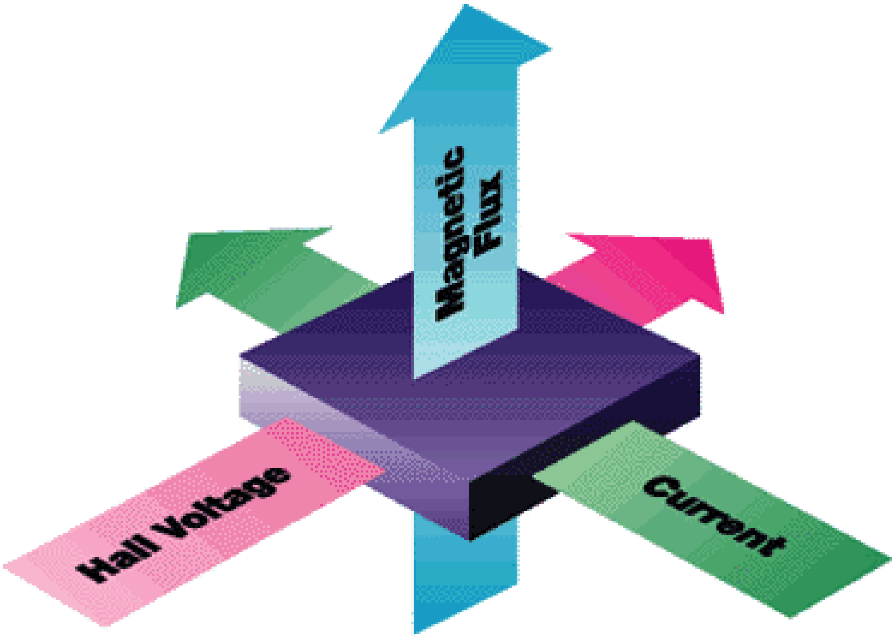
$$e = \frac{d\psi}{dt} = \frac{d}{dt}(N \cdot Area \cdot B)$$

$$i = k \cdot B = \frac{k}{N \cdot Area} \cdot \int e \cdot dt$$

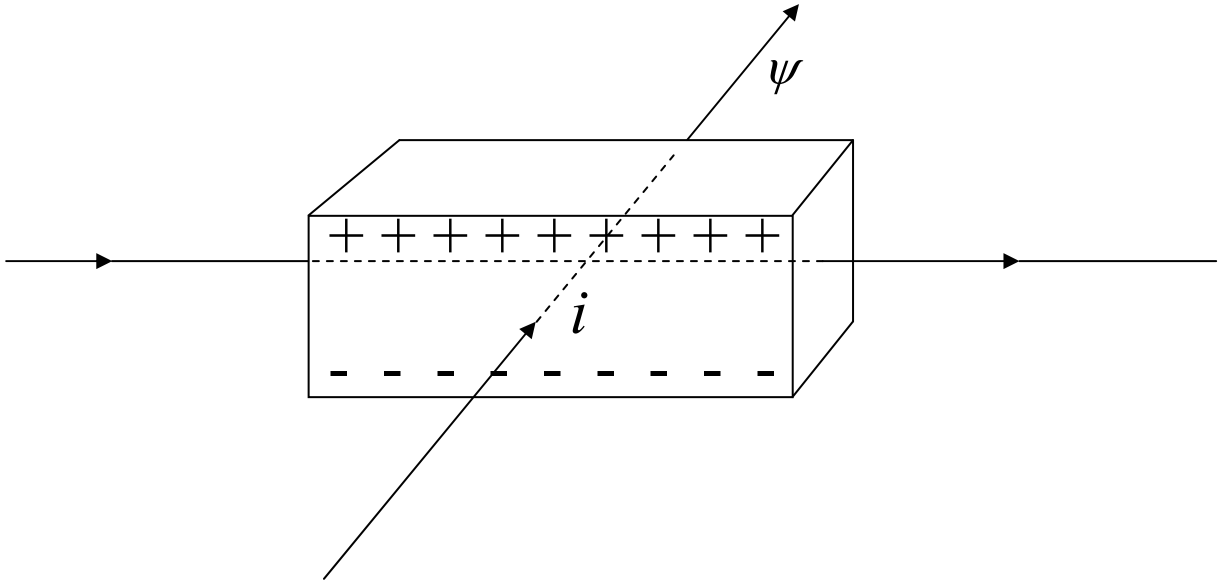


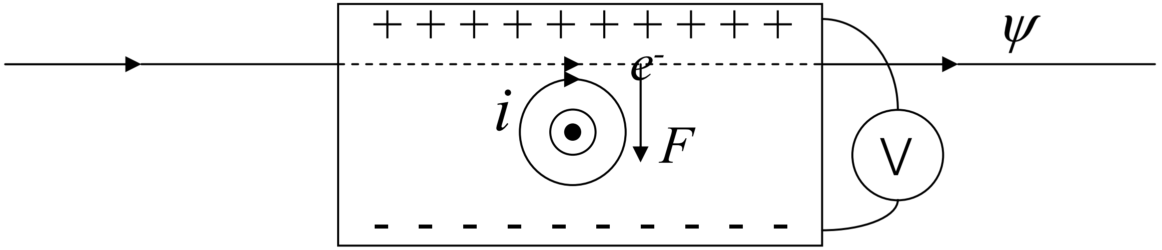
Hall effect sensors

- http://www.micronas.com/products/overview/sensors/index.php#linear
- The function of a Hall sensor is based on the physical principle of the Hall effect named after its discoverer E. H. Hall: It means that a voltage is generated transversely to the current flow direction in an electric conductor (the Hall voltage), if a magnetic field is applied perpendicularly to the conductor. As the Hall effect is most pronounced in semiconductors, the most suitable Hall element is a small platelet made of semiconductive material.



Hall effect

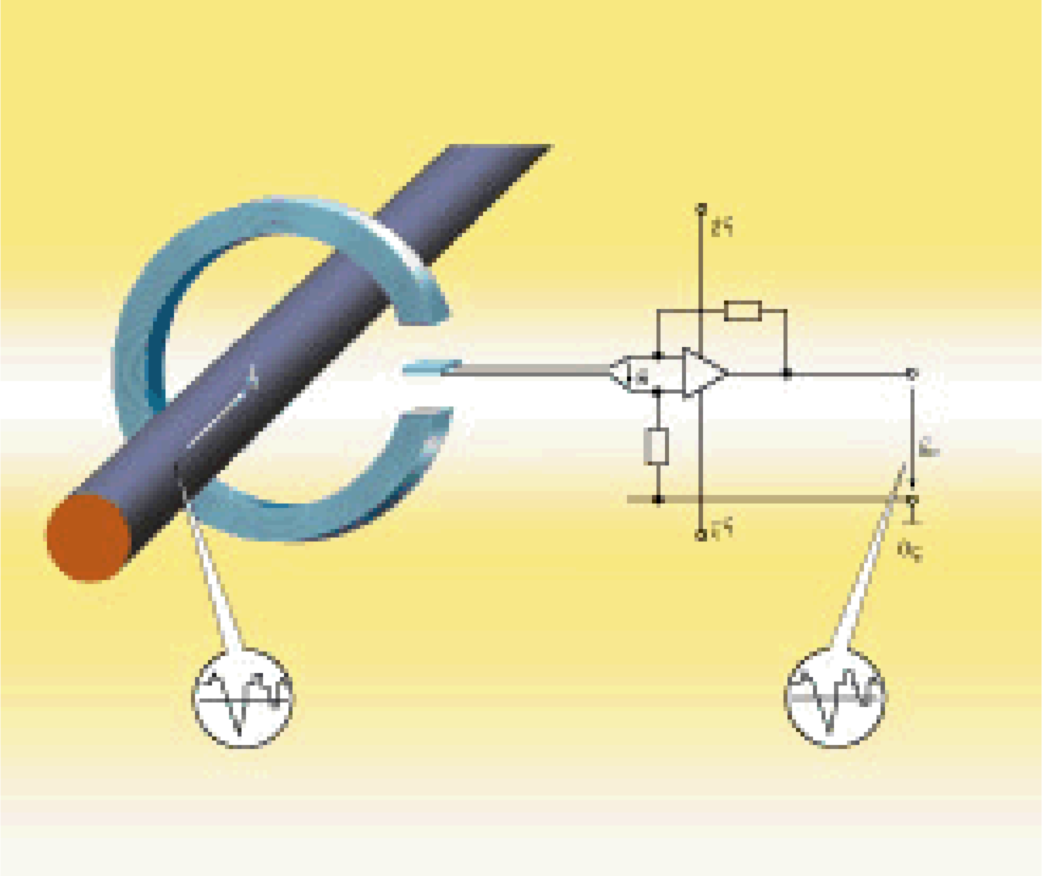




The magnetic force moves the <u>negative</u> charged carriers downwards

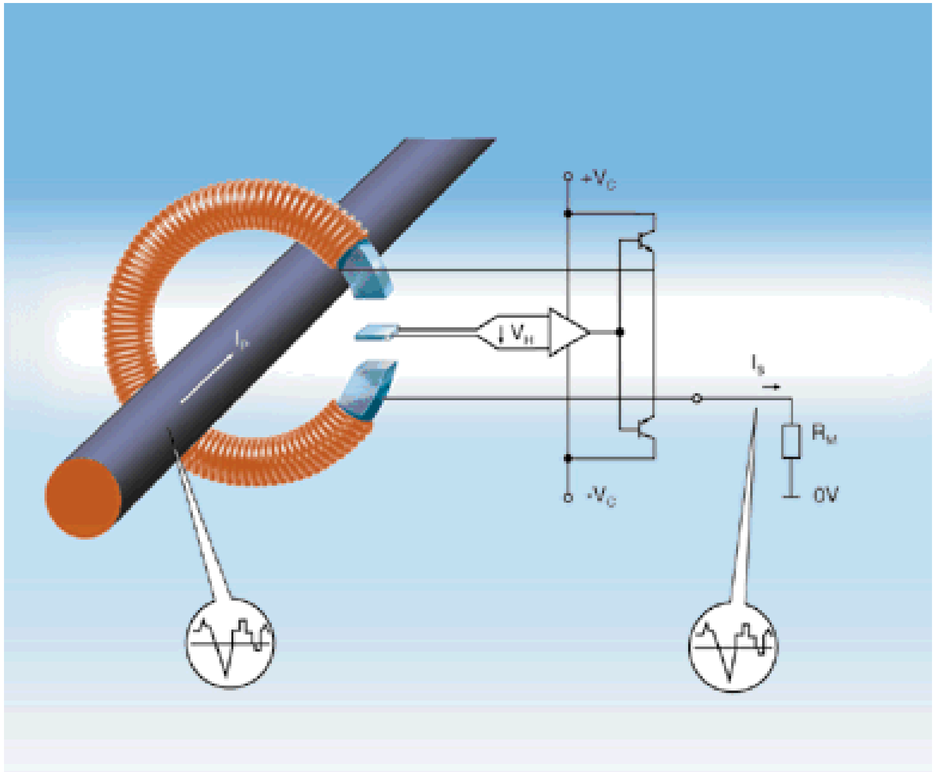
Open Loop Current Transducer

- The magnetic flux created by the primary current I_P is concentrated in a magnetic circuit and measured in the air gap using a Hall device.
- The output from the Hall device is then signal conditioned to provide an exact representation of the primary current at the output.

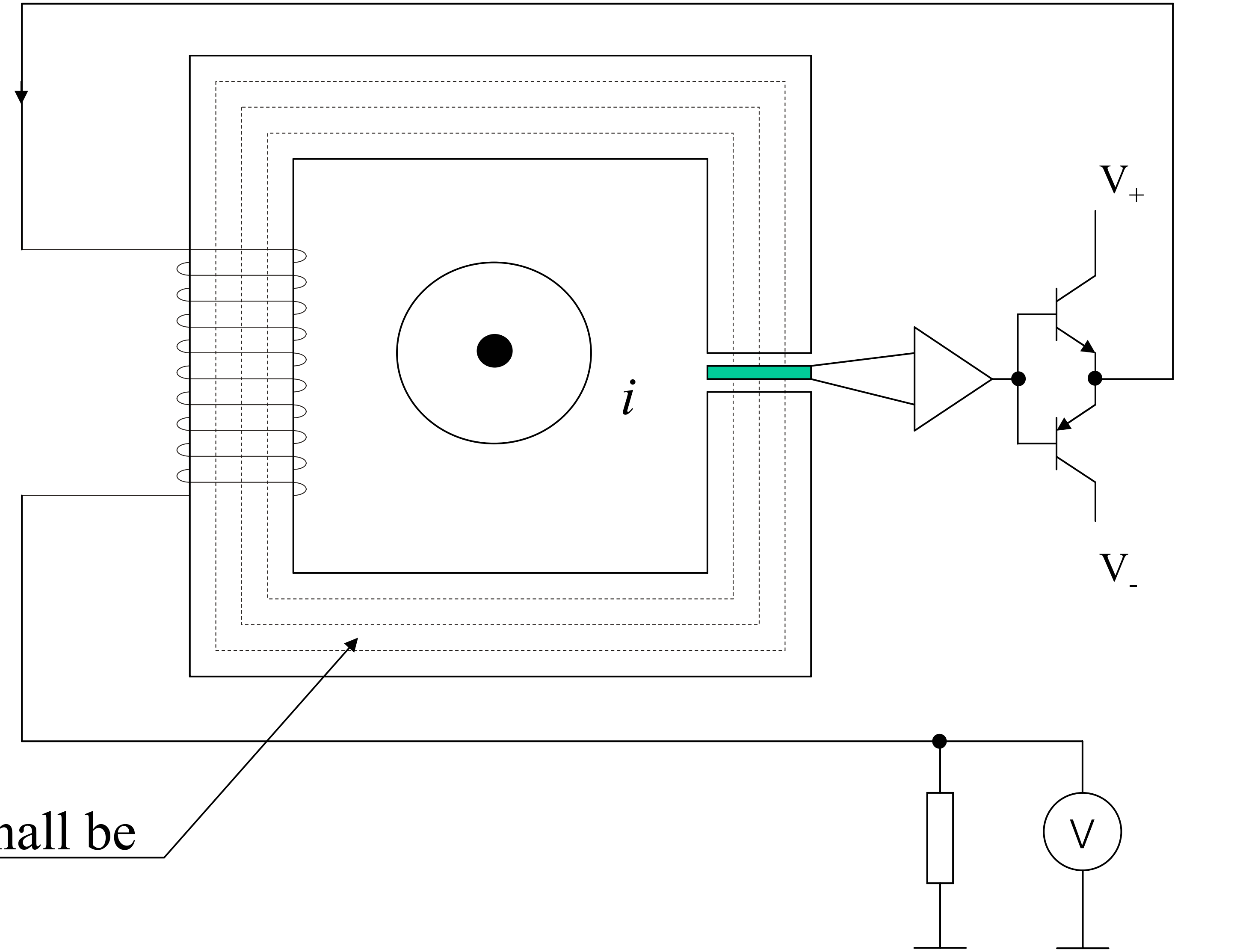


Closed Loop Current Tranducer

- The magnetic flux created by the primary current I_p is balanced by a complementary flux produced by driving a current through the secondary windings.
- A hall device and associated electronic circuit are used to generate the secondary (compensating) current that is an exact representation of the primary current.



Closed Loop Current Tranducer cont'd



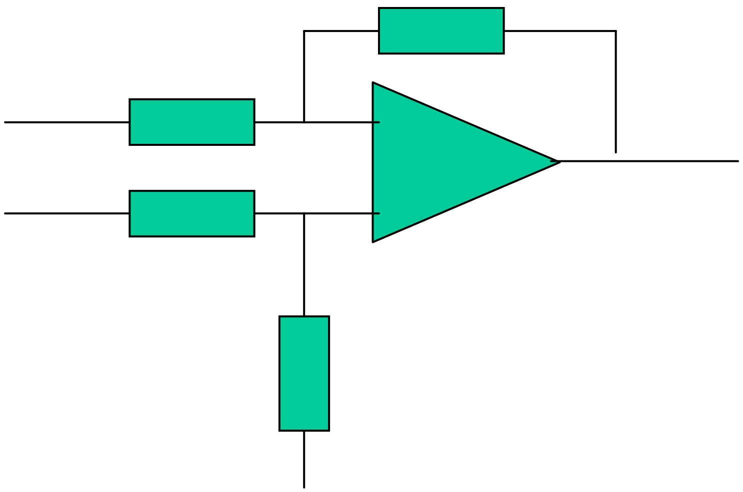
The flux shall be zero

Voltage

- Differential measurement
- Indirect via current

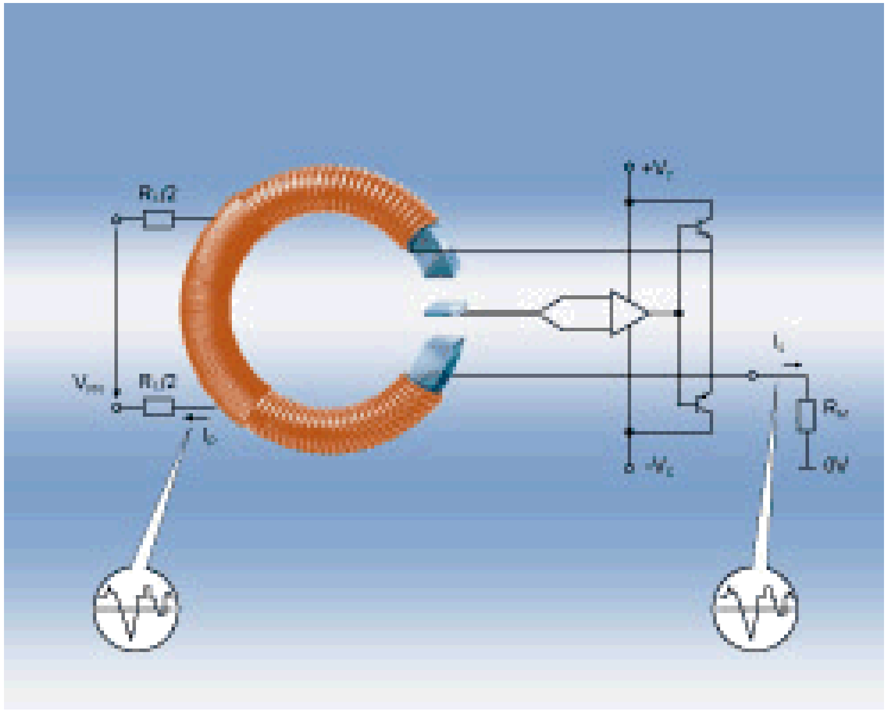
Differential voltage measurements

- **No galvanic isolation**



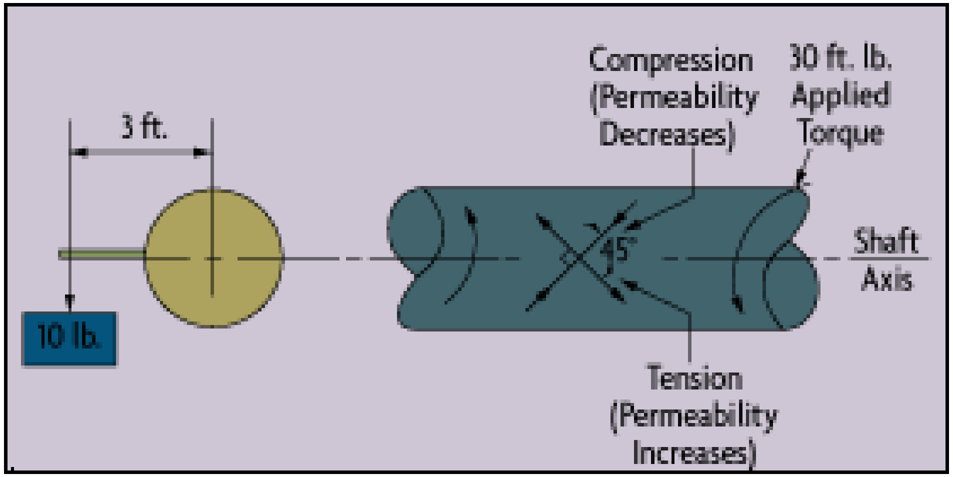
Indirect via current

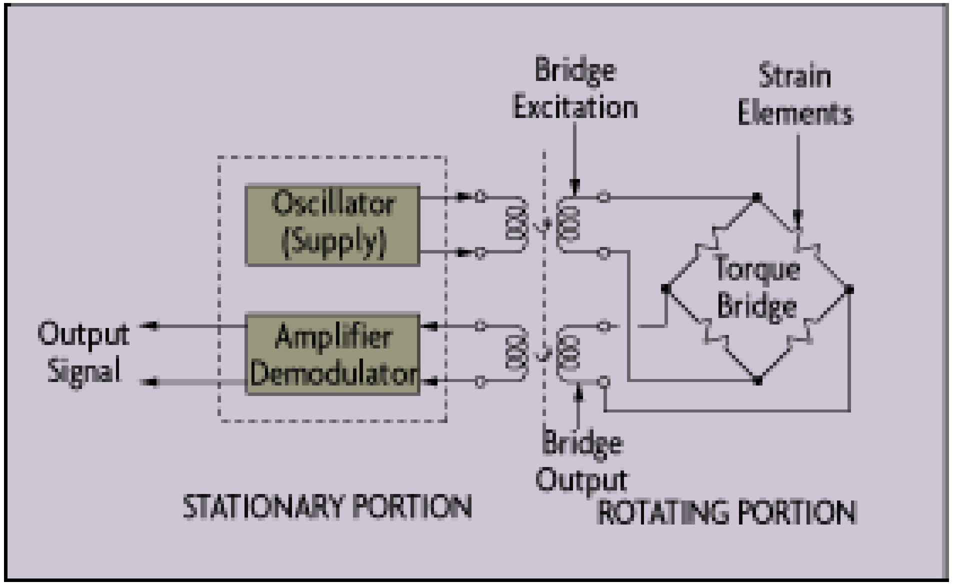
- A very small current limited by a series resistor is taken from the voltage to be measured and is driven through the primary coil
- Galvanic isolation



Torque

- http://www.omega.com/literature/transactions/volume3/force3.html
- The surface of a shaft under torque will experience compression and tension
- Displacement sensors:
  - Optical through toothed wheels
  - Magnetical through variable coupling
- Strain gauges or magnetostrictive strips ca be used.



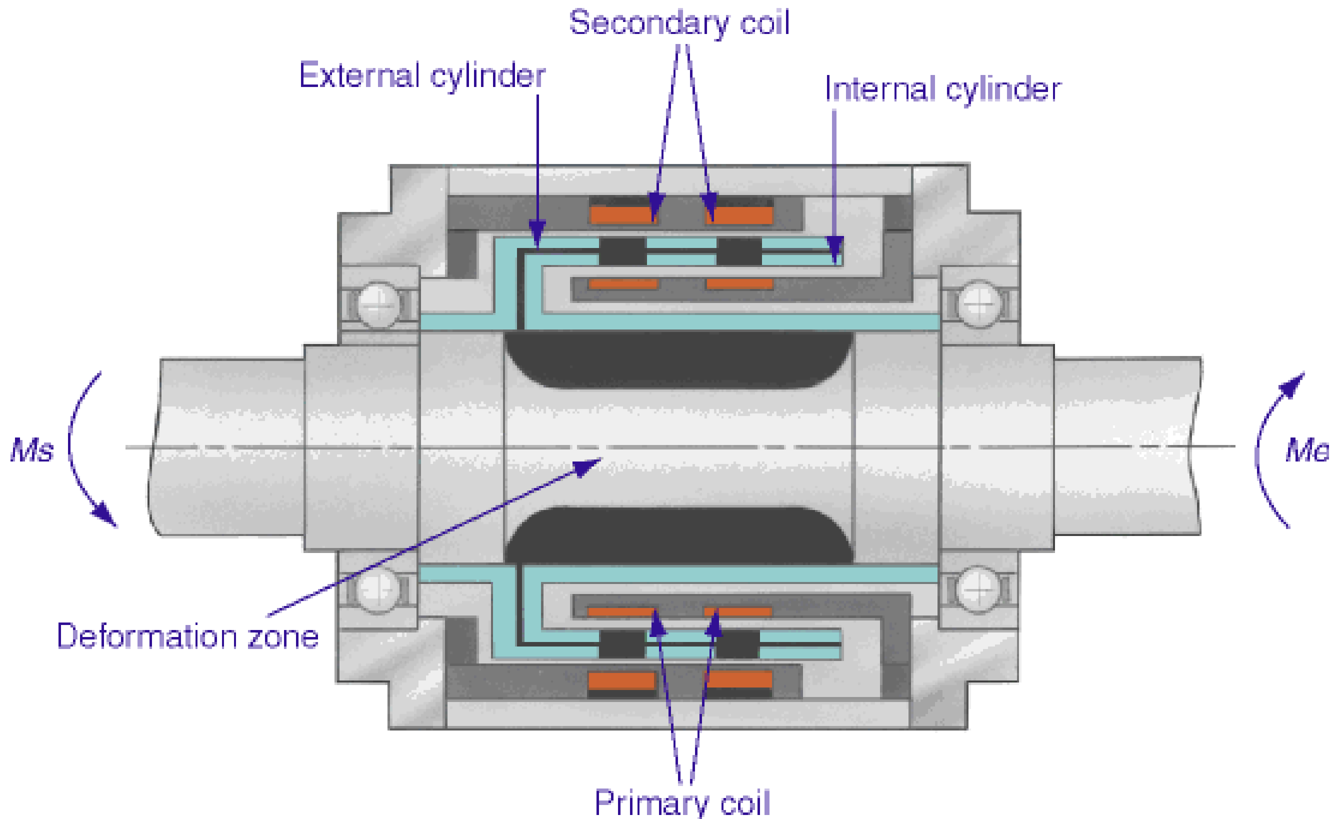


Torsional angle 1

- http://www.magtrol.com/torquetransducers/principles.htm:
- Simple and reliable, the TMB/TM/TMHS Series Torque Transducer measuring system is based on the principle of a variable, torque-proportional transformer coupling. The principle has been adapted by Magtrol for the measurement of torque. The measuring system consists of two concentric cylinders, shrunk on the shaft on each side of the shaft's deformation zone, and two concentric coils attached to the housing.

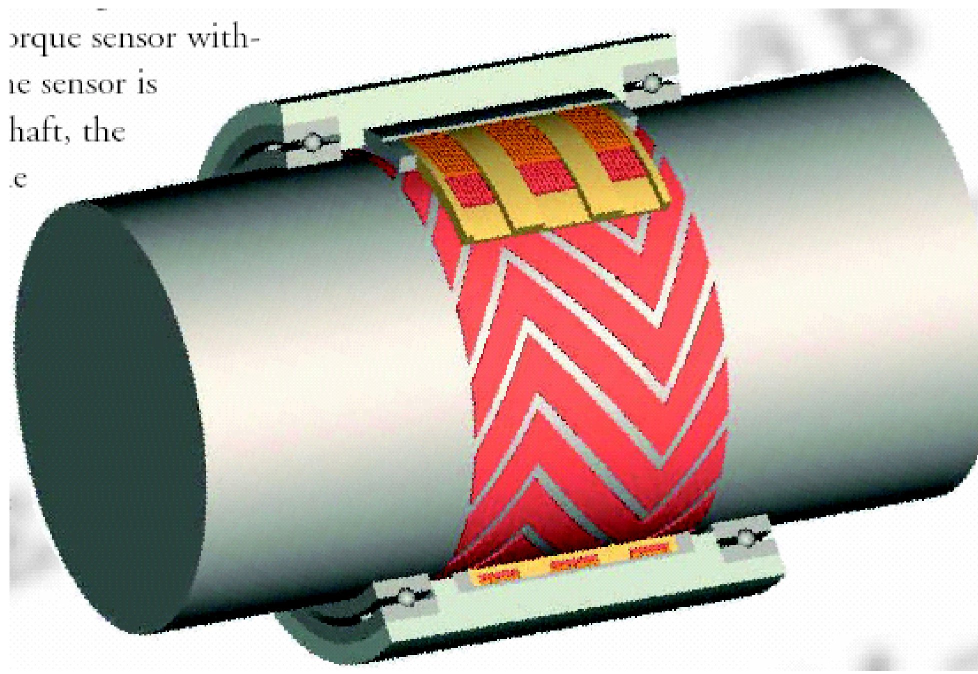
Both cylinders have a circularly disposed coinciding row of slots and rotate with the shaft inside the coils. A constant alternating current with the frequency of 20 kHz flows through the primary coil. When torque is applied, the slots on the two cylinders do not overlap. Instead, the deformation zone undergoes an angular deformation and the slots begin to overlap. Thus, a torque-proportional EMF is induced in the secondary coil.

The conditioning electronics convert the EMF into a voltage between +10 and -10 V, depending on the direction of the torque. Speed measurement is integrated by means of an inductive proximity transducer trained on a toothed path cut directly into the outer cylinder.



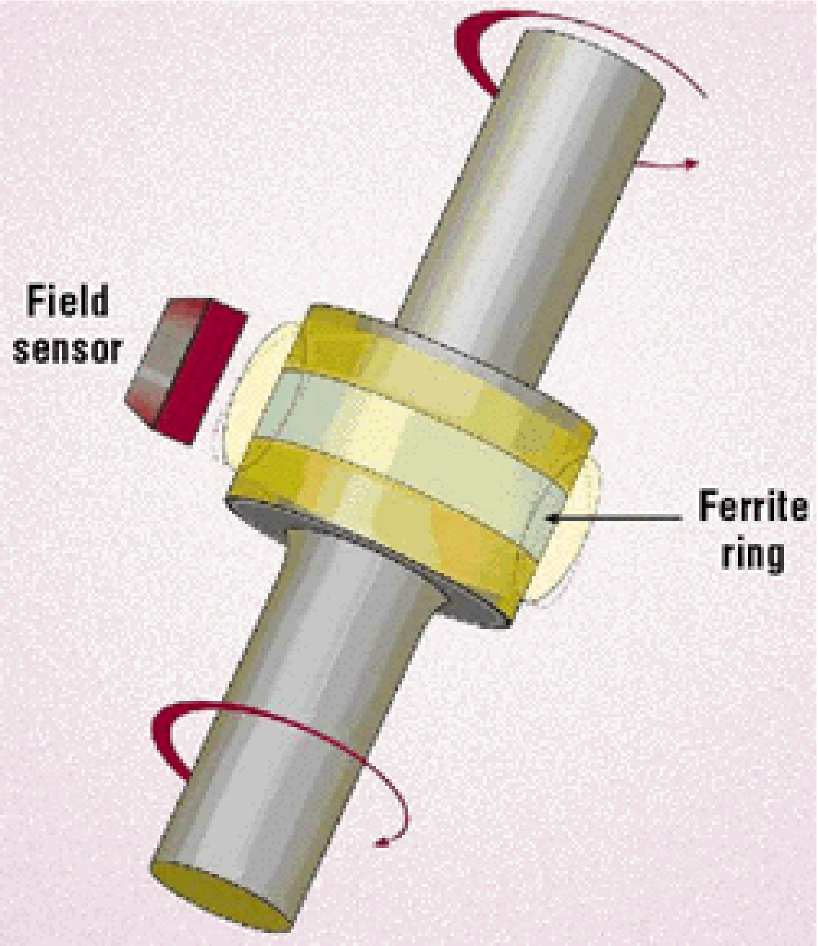
Magnetostriction 1 - Torductor

- A transformer with one middle and two outer windings.
- The coupling between the middle and outer windings is changed in opposite directions when a torque is applied.



Magnetostriction 2

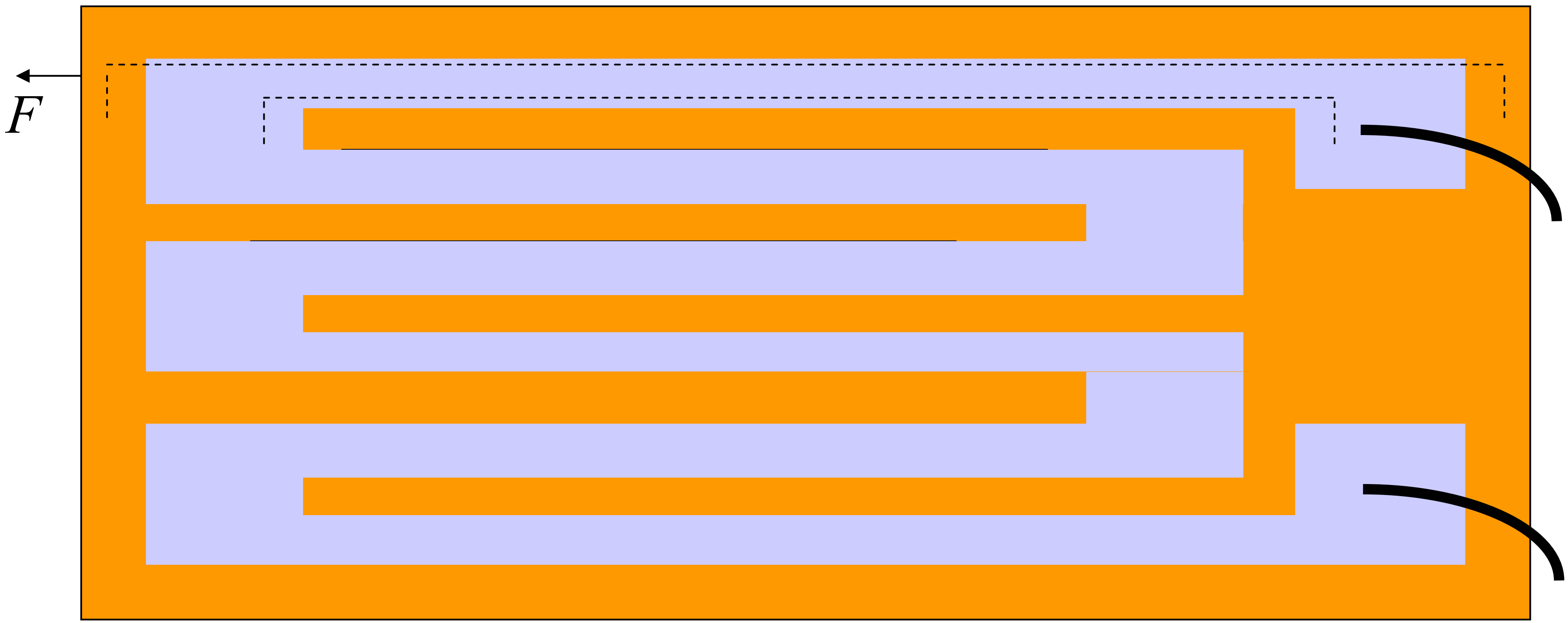
- http://www.ameslab.gov/News/Inquiry/2000/torque.html
- A sensor using a small ring of the **cobalt-ferrite** composite would be strategically placed on the steering column. As a driver turned the wheel, the magnetization of the cobalt-ferrite ring would change in proportion to the amount of force applied by the driver. The change would be detected by a nearby field sensor that would interpret how much force should be applied to turn the wheels and then relay the information to an electrical power-assist motor.
- **Terfenol-D** is a rare-earth, magnetostrictive compound that Ames Lab helped develop in the 1980s. It possesses a much higher degree of magnetostriction, but can cost up to 100 times more than the cobalt-ferrite composite.



Force

- http://www.wesmar.se/sok/Produkter/Vagning_Lastceller.shtml
- **Strain gauge + spring principle**

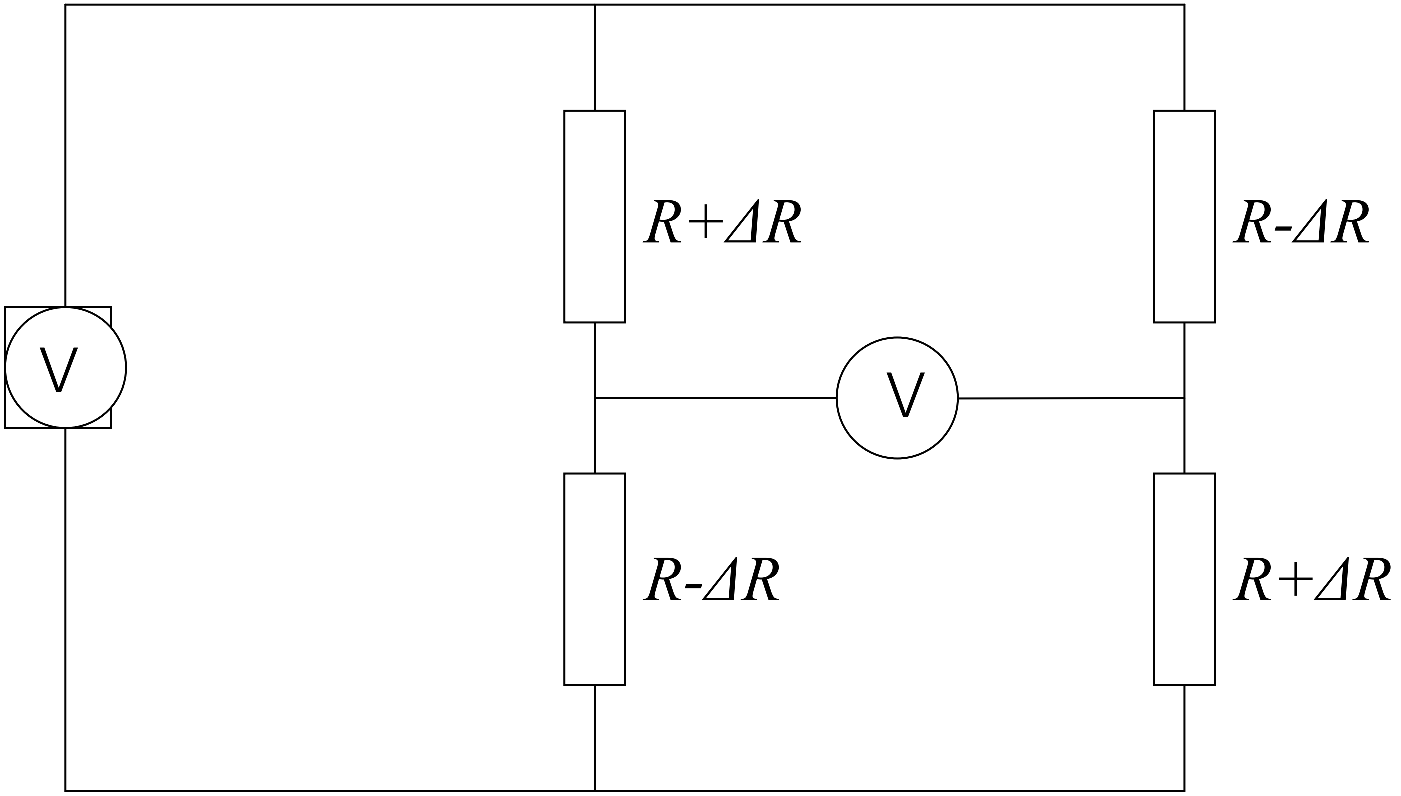
Strain gauge



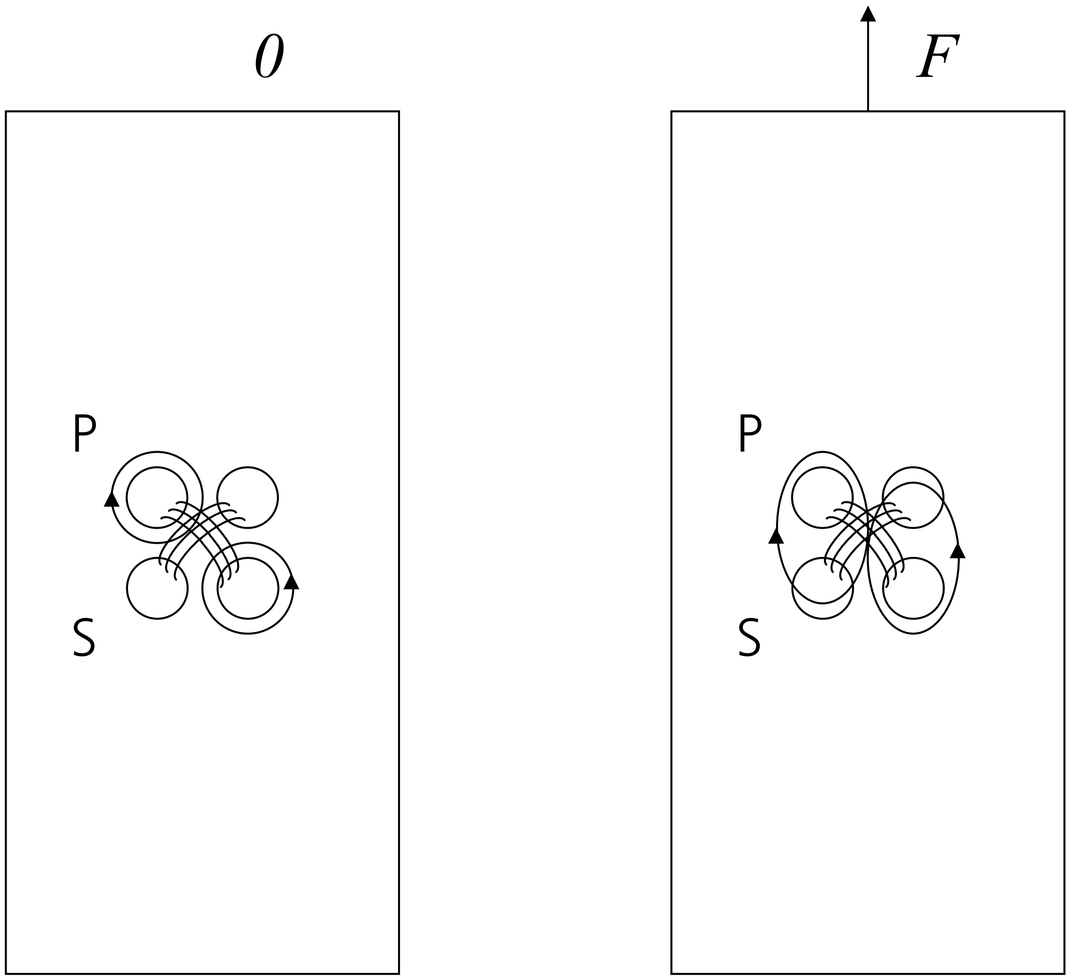
When a force is applied, the conductors become longer and more tiny, the resistance increases, R -> R+ΔR

Bridge

Strain gauges in the different resistor positions



Magnetostriction *Pressductor*



Magnetic flux

- **Hall effect sensors**
- **Coil and Voltage integration**

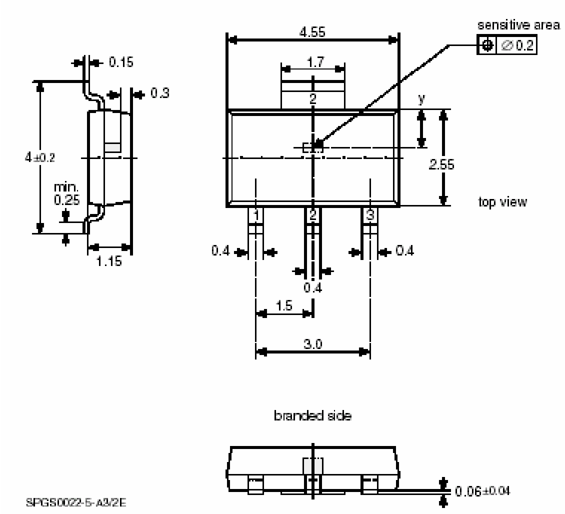
Hall data example

3.6. Electrical and Magnetic Characteristics

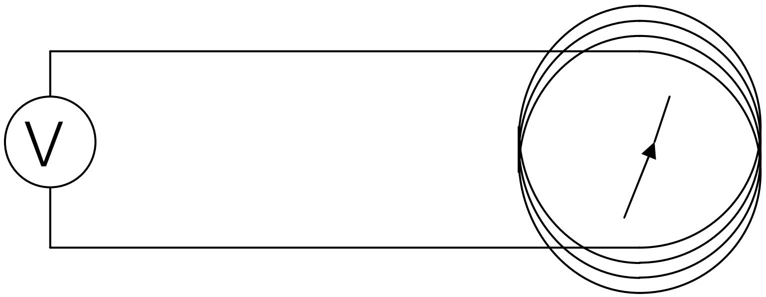
at Recommended Operation Conditions (Fig. 3–2 for T_A and V_{DD}) as not otherwise specified in the column “Conditions”.
Typical characteristics for T_J = 25 °C, V_{DD} = 6.8 V and –50 mT < B < 50 mT

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Conditions
I_{DD}	Supply Current	1	11	14.5	17.1	mA	T_J = 25 °C, $I_{OUT1,2}$ = 0 mA
I_{DD}	Supply Current over Temperature Range	1	9	14.5	18.5	mA	$I_{OUT1,2}$ = 0 mA
V_{CM}	Common Mode Output Voltage $V_{CM} = (V_{OUT1} + V_{OUT2}) / 2$	2, 3	2.1	2.2	2.3	V	$I_{OUT1,2}$ = 0 mA,
CMRR	Common Mode Rejection Ratio	2, 3	–2.5	0	2.5	mV/V	$I_{OUT1,2}$ = 0 mA, CMRR is limited by the influence of power dissipation.
S_B	Differential Magnetic Sensitivity	2–3	42	48.5	55	mV/mT	–50 mT < B < 50 mT T_J = 25 °C

3.1. Outline Dimensions



Flux measurement with coil and voltage Integration



- **Integrate voltage from sensing coil**
- **DC impossible, due to no induction and due to drift**

$$B = \frac{\phi}{Area} = K \cdot \int e \cdot dt$$

Estimation

- **Use known relations, eg:**
  - **DC motor:** $$u = R \cdot i + L \cdot \frac{di}{dt} + \omega_r \cdot \psi_m \Rightarrow \psi_m = \frac{u - R \cdot i - L \cdot \frac{di}{dt}}{\omega_r}$$
    - **Works best with averages and Ldi/dt disregarded**
  - **AC coil:** $$u = R \cdot i + L \cdot \frac{d\psi}{dt} \Rightarrow \psi = \int \frac{u - R \cdot i}{L} dt$$
    - **NB! Difficult due to integrator drift**

Observers

- **Correct the model with measurements**
- **Example: simple coil where flux linkage is sought.**
- **An Observer is a P-controlled model!**

$$u = R \cdot i + \frac{d\psi}{dt}$$

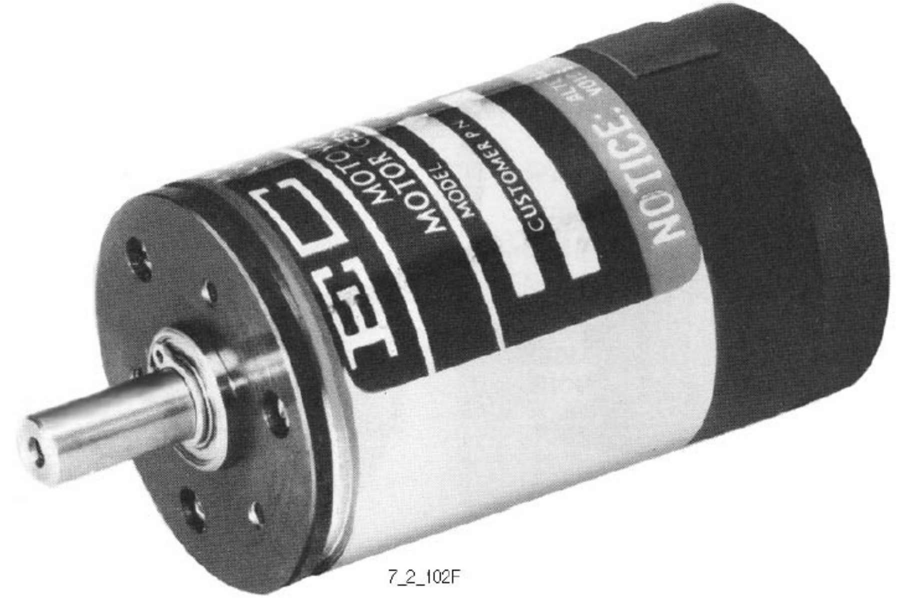
$$\psi = L \cdot i$$

$$\frac{d\hat{\psi}}{dt} = u - R \cdot i + k \cdot R \cdot \left(i - L^{-1}\hat{\psi} \right) =$$

$$= u - R \cdot (1-k) \cdot i - k \cdot R \cdot \hat{i}$$

Speed : Tacho

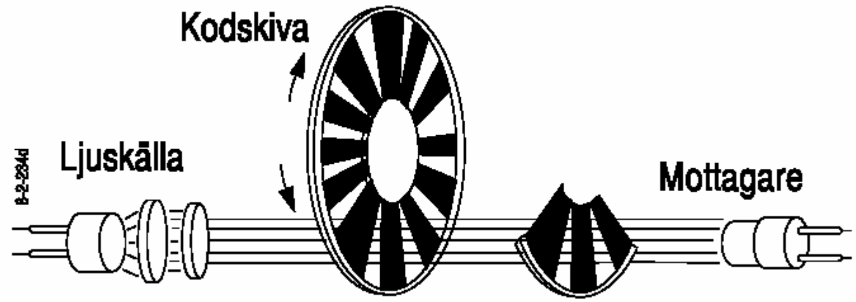
- **Tachometer generators**
  - A DC machine
  - No load – long lifetime (> 20000 h)
  - Linearity error < 0.5%
  - Ripple < 5%



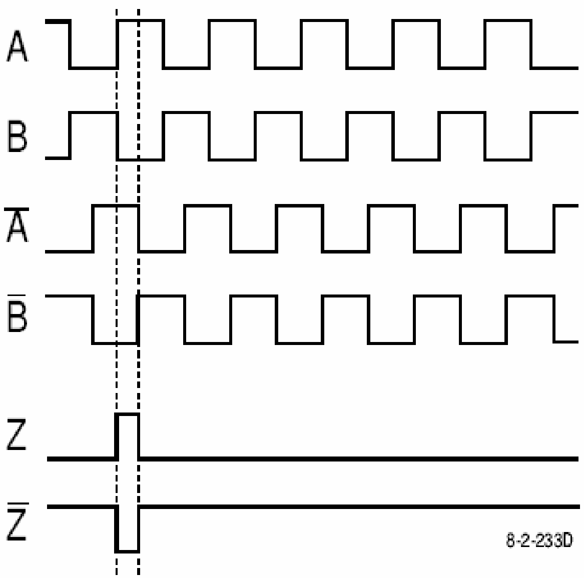
Likströms-takogenerator

Speed : Optical pulse

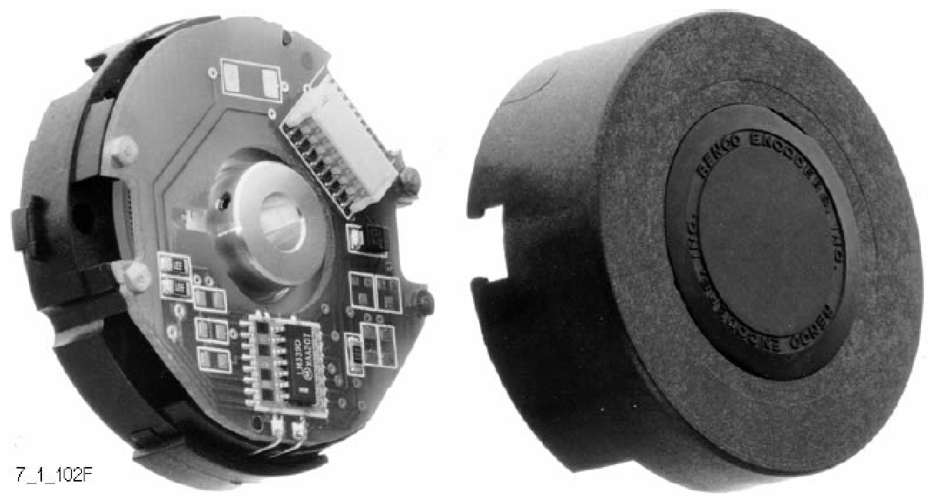
- **Pulse counter**
  - 2 channels + reference pulse



Uppbyggnaden hos en inkrementell pulsgivare



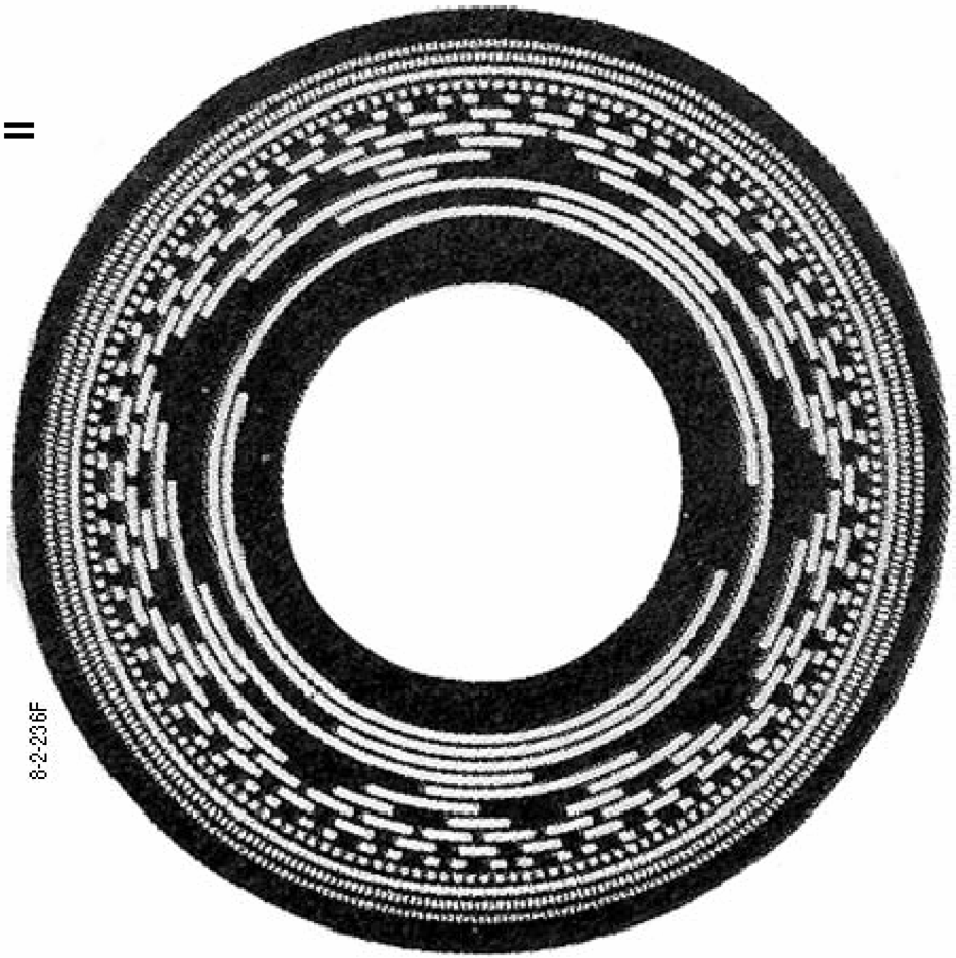
Pulståg från inkrementell pulsgivare.



Roterande inkrementell pulsgivare.

Position : Optical absolute

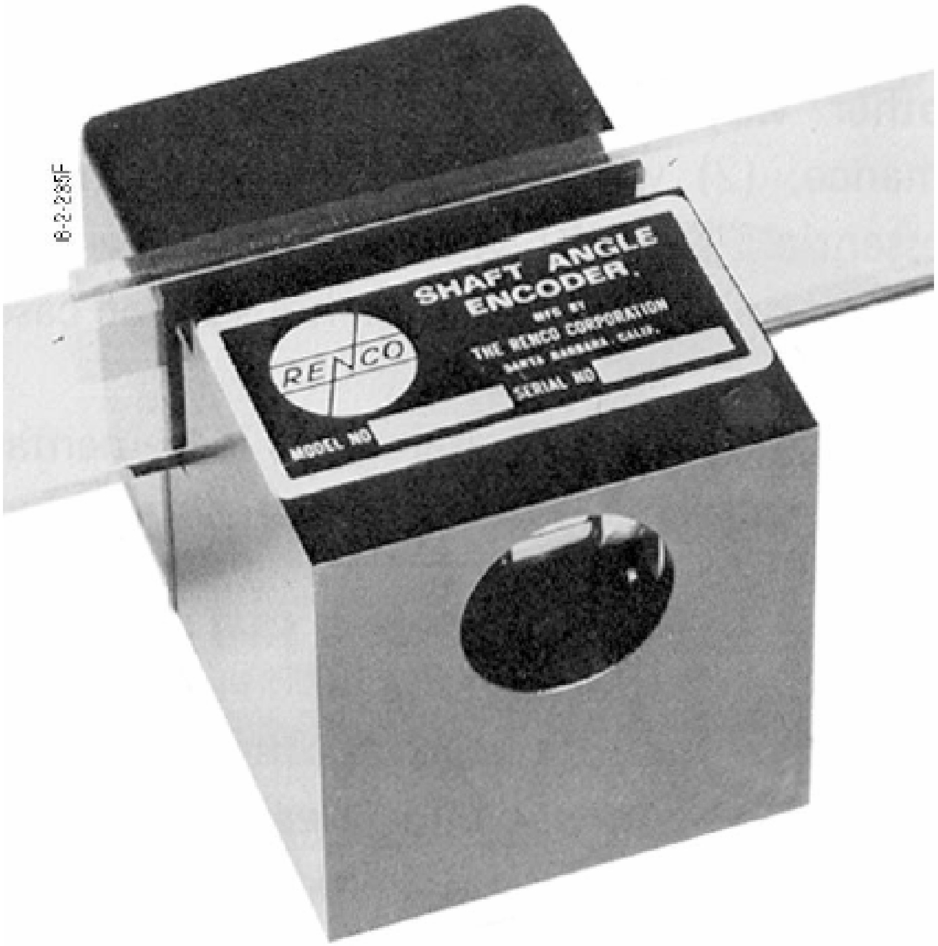
- **Typical 10 bit pulses = 1024 steps/turn**



Kodskiva till en roterande absolut pulsgivare

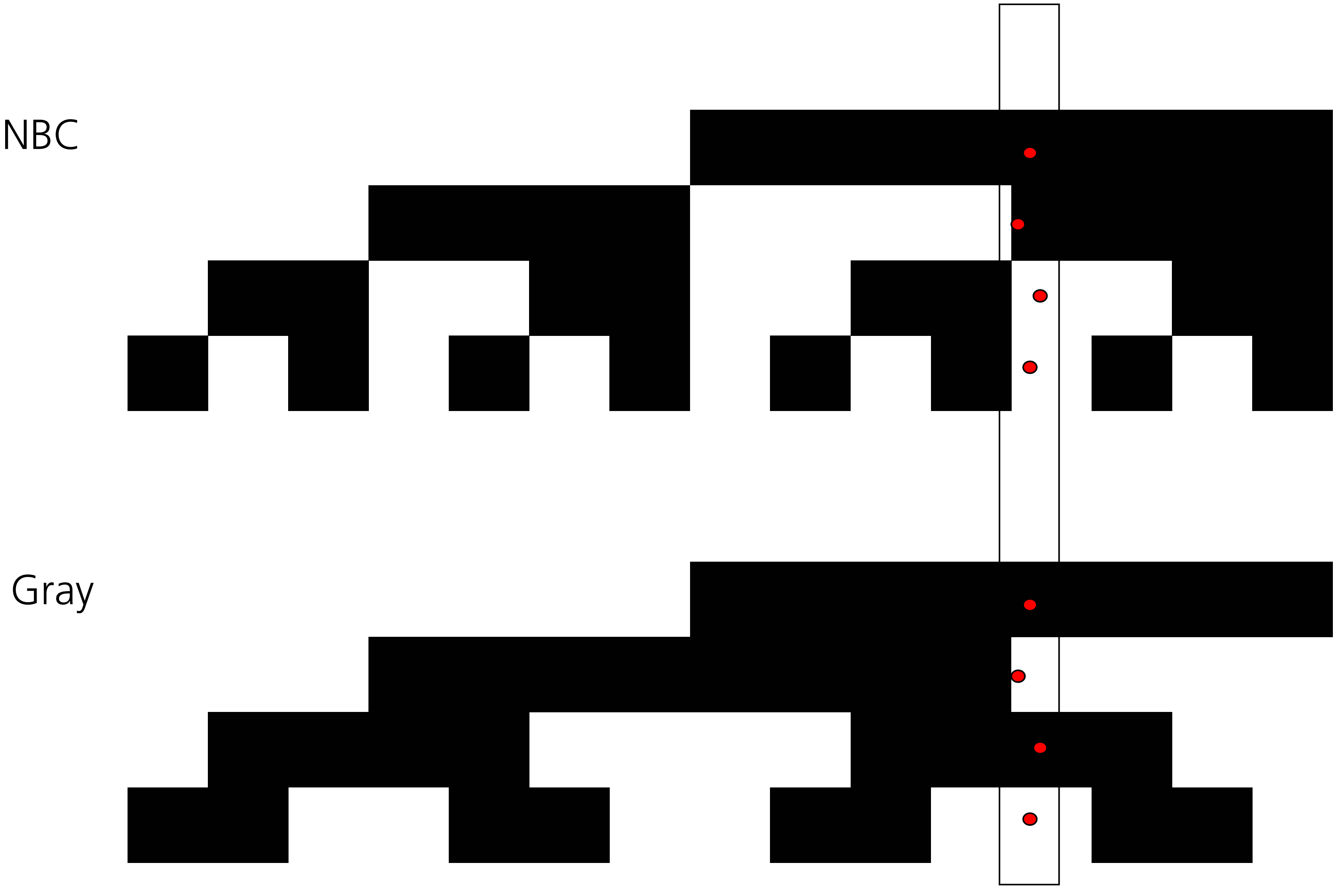
Speed : linear pulse

- **Difficult to handle (long and thin)**



Linjär inkrementell pulsgivare

NBC- and Gray-code

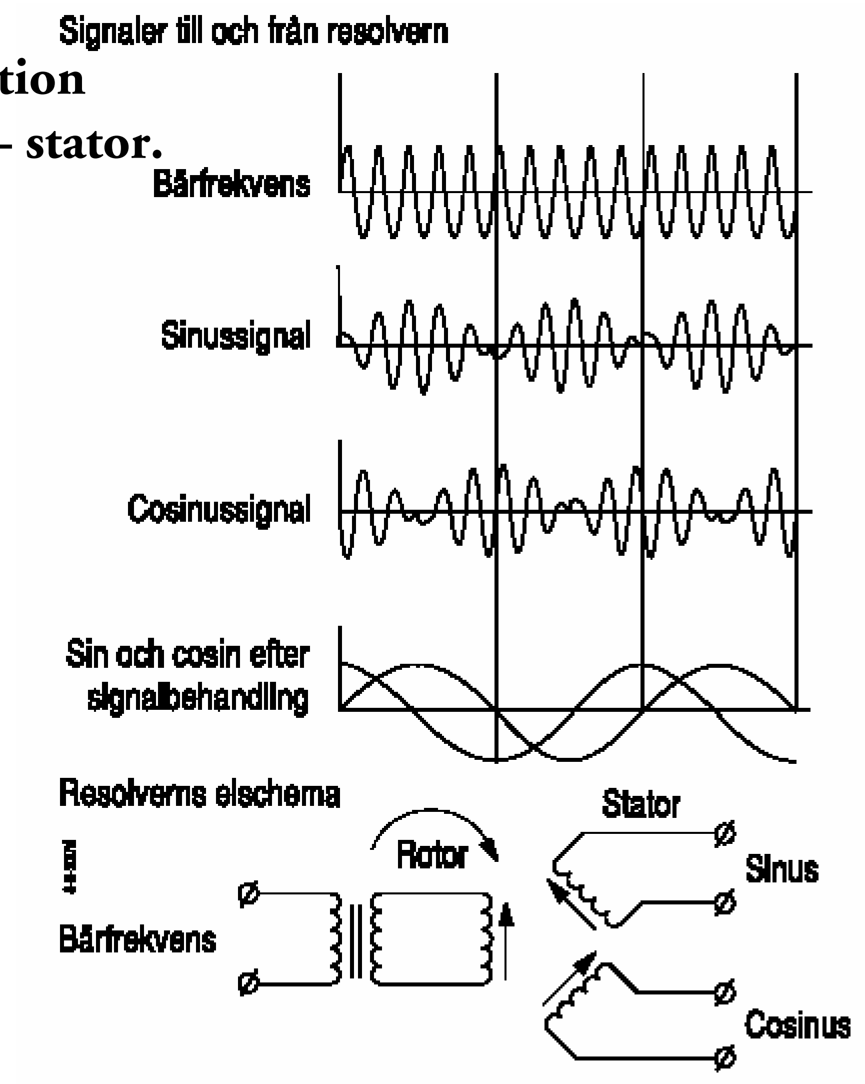


Position : Resolver

- **Modulation of carrier signal via position dependent magnetic coupling rotor – stator.**

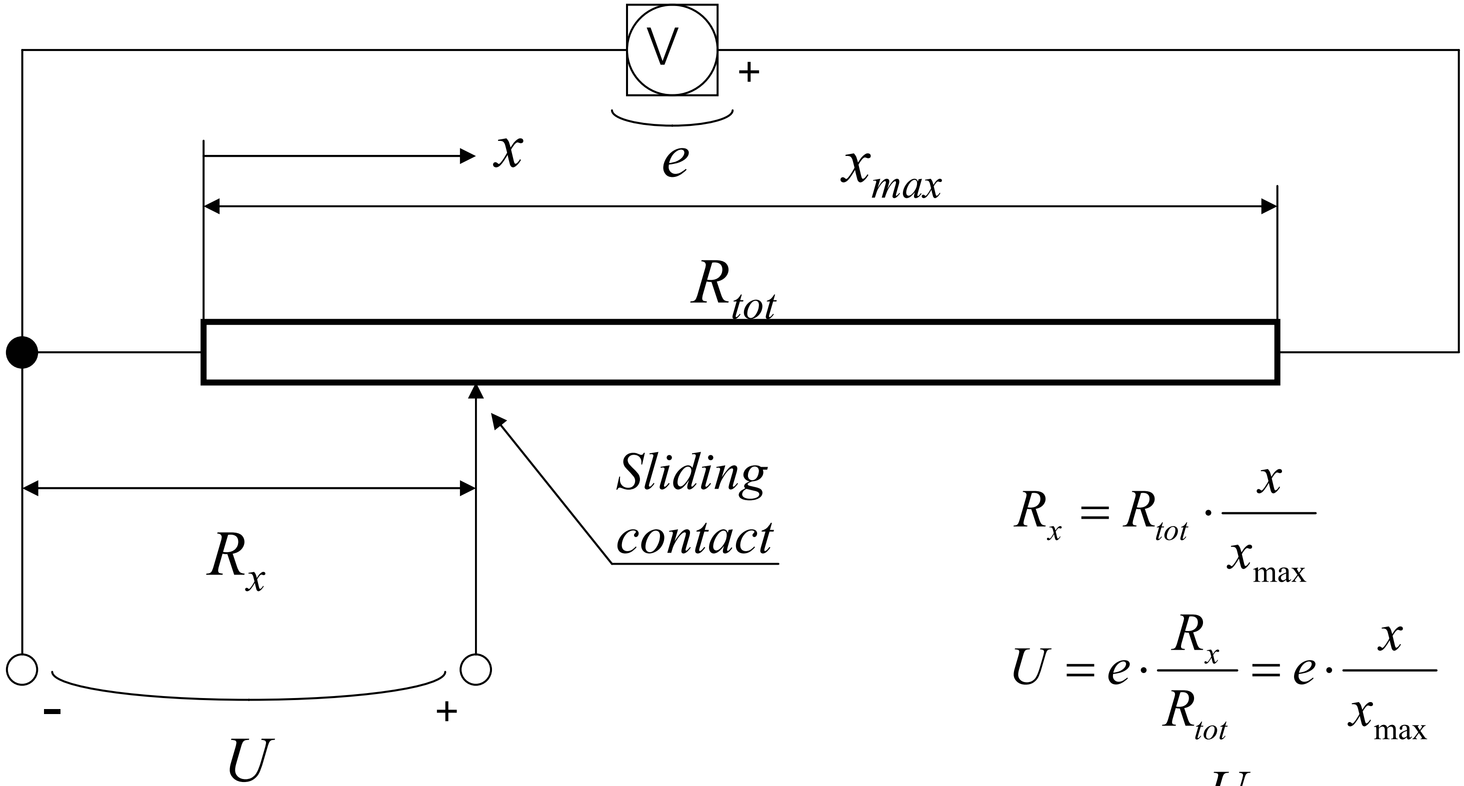
Kapslad resolver

Hålaxelresolver



Principschema för resolver

Position with potentiometer



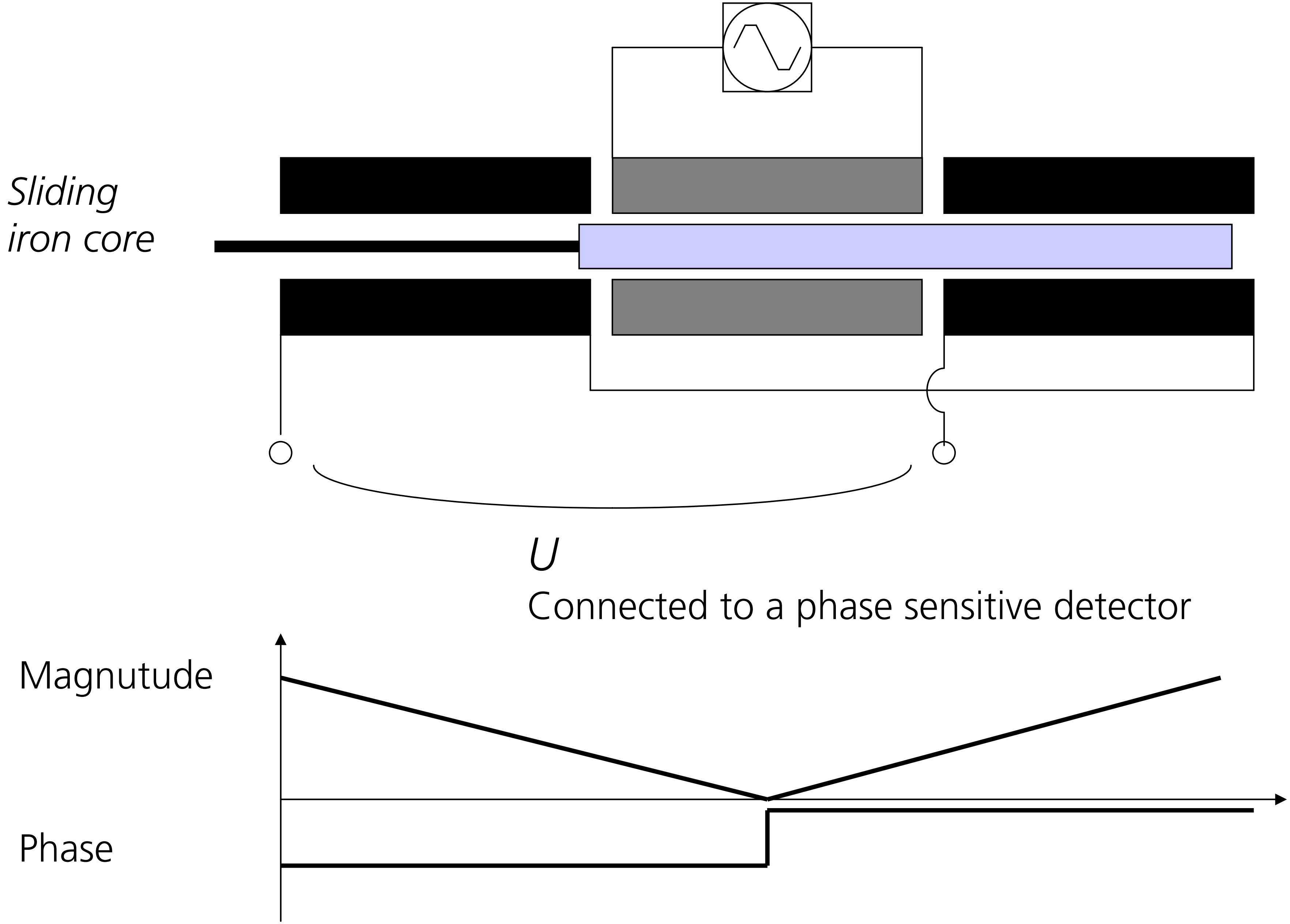
$$R_x = R_{tot} \cdot \frac{x}{x_{\max}}$$

$$U = e \cdot \frac{R_x}{R_{tot}} = e \cdot \frac{x}{x_{\max}}$$

$$x = x_{\max} \cdot \frac{U}{e}$$

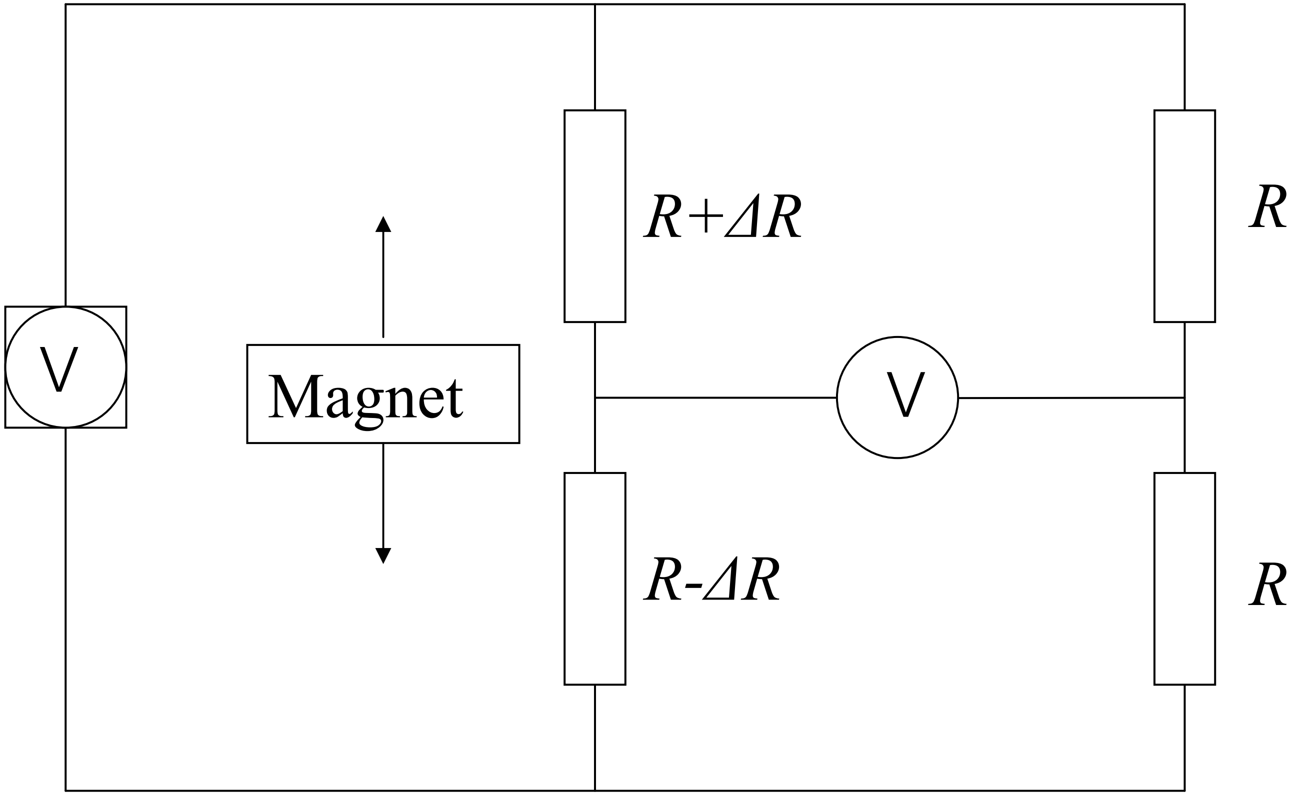
Length <2 m
Lineartity 0.1%

Differential transformer

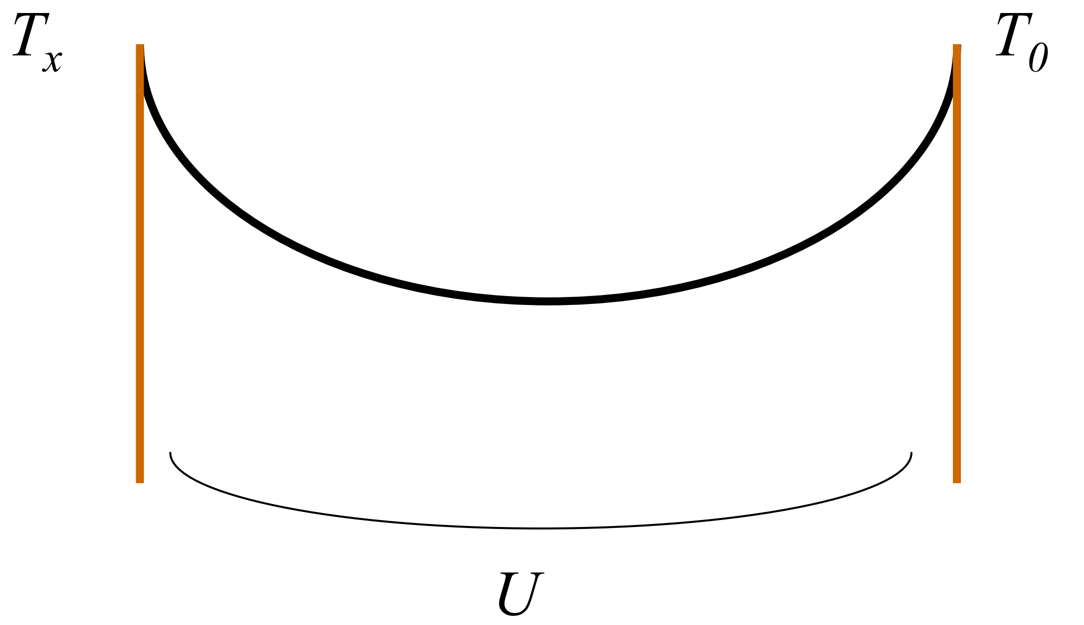


Field plate (Fältplatta)

A semiconductor component of which the resistance changes when a mangetic field is applied. The movement of the magnet can be measured with a bridge circuit.



Temperature with thermocouple



•A thermocouple is the connection point, preferably welded or soldered, of two different metals, e.g. constantan and copper.

•Two thermocouples, connected as above, measure the temperature difference ($T_x - T_0$)

•To measure absolute temperature, one of the temeratures T_x or T_0 must be known, either measured or being kept at a known reference temperature in an owen or in a vessel with ice and water

Thermocouples

- Cu-Constantan T $<400^{o}$
- Fe-Constantan J $<700^{o}$ (1200^{o})
- NiCr-Constantan E $<900^{o}$ (1000^{o})
- NiCr-NiAl K $<1370^{o}$
- Pt-PtRh S $<1000^{o}$ (1760^{o})
- PtRh-PtRh(?) R $<1800^{o}$

Temperature
Resistance versus temperature

$$R_t \approx R_r \cdot \left[1 + \alpha_r \cdot \left(t - t_r\right)\right]$$

$$R_t = R_0 \cdot \left[1 + \alpha_0 \cdot \left(t - 0\right)\right] = R_0 \cdot \left(1 + \alpha_0 \cdot t\right)$$

$$R_{20} = R_0 \cdot \left[1 + \alpha_0 \cdot \left(20 - 0\right)\right] = R_0 \cdot \left(1 + \alpha_0 \cdot 20\right)$$

$$R_t = R_{20} \cdot \frac{\left(1 + \alpha_0 \cdot t\right)}{\left(1 + \alpha_0 \cdot 20\right)}$$

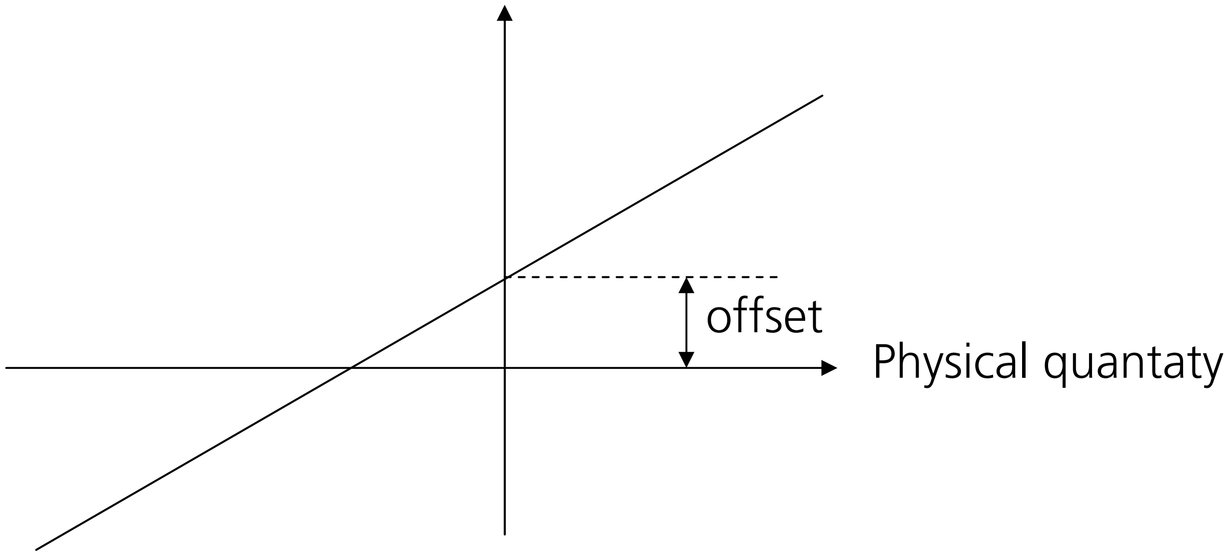
Standardised termometer resistance

- **Cu** **$-50^o – 150^o$ (180°)** **α_0=0.00429/°C** **R_0=233/2330Ω**
- **Ni** **$-60^o – 250^o$ (360°)** **α_0=0.00617 /°C** **R_0=100Ω**
- **Pt** **$-200^o – 850^o$ (1000°)** **α_0=0.003925 /°C** **R_0=100Ω**

Other materials for temperature measurement

- Silicon
- Thermistors (semiconductors)
- Integrated circuits (AD590)

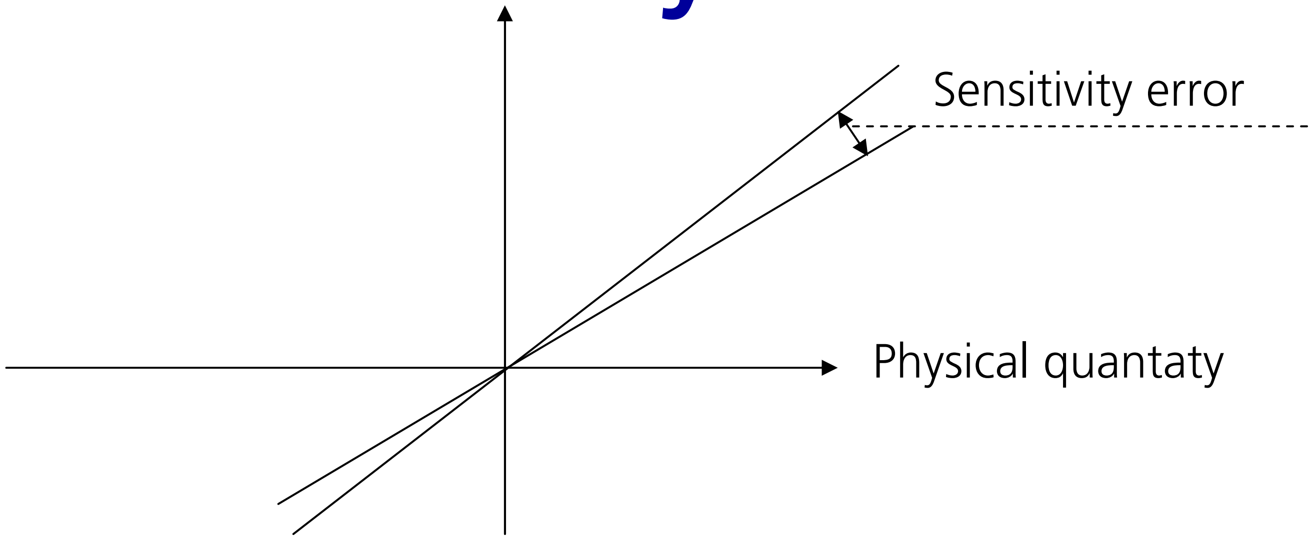
Transducer offset error



<u>**Counter measure**</u>

- **Bridge balancing**
- **Calibration**
- **Correction in computer**

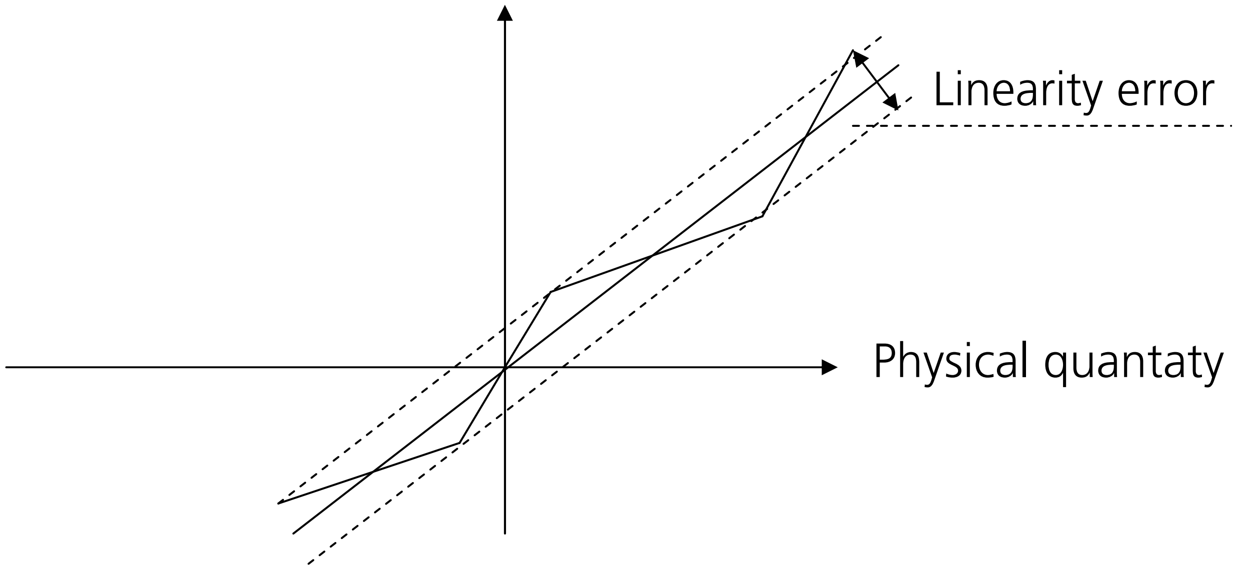
Sensitivity error



<u>**Counter measure**</u>

- **Change amplification**
- **Calibration**
- **Correction in computer**

Linearity error



<u>Counter measure</u>

- **Calibration**
- **Calibration curve in computer**

Temperature error

- **<u>Counter measure</u>**
- **Calibration versus temperature**
- **Measure (or estimate) temperature**
- **Calibration curve in computer**

Drift (time variation)

- **Sensitivity or offset error increases over time**

- **Regular, eg. once every year, check and calibrate (or repair or replace)**

- **Remember, a small error is accepted as long as transducer specification is fulfilled.**