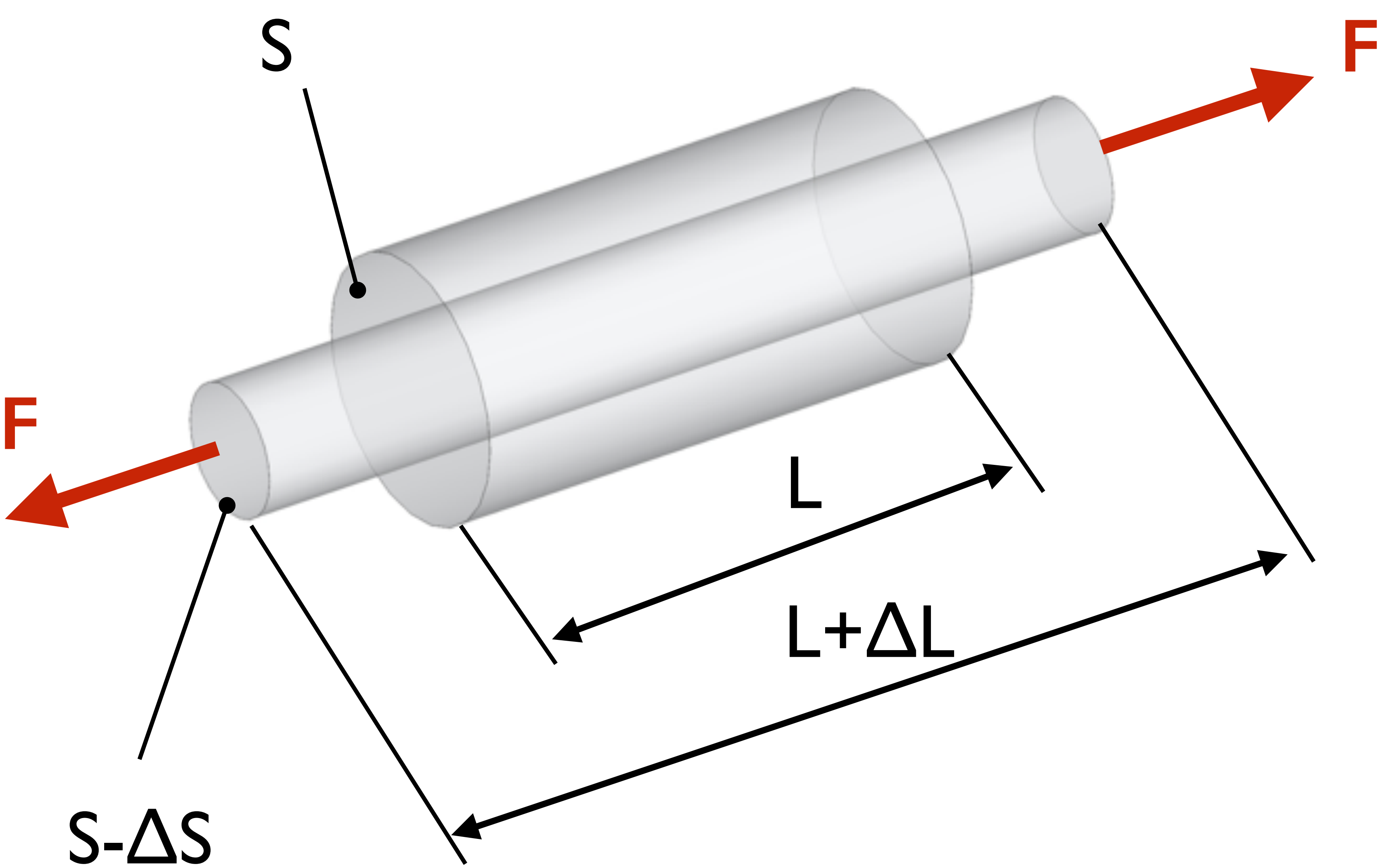
Sensors of force and pressure

AE3B38SME - Sensors and Measurement

Strain gauges



$$R=\rho\frac{L}{S}$$

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} - \frac{\Delta S}{S}$$

$$R \cong R_0 + \frac{dR}{d\rho}(\rho-\rho_0) + \frac{dR}{dL}(L-L_0) + \frac{dR}{dS}(S-S_0)$$

$$\Delta R = R - R_0 \cong \frac{dR}{d\rho}(\rho-\rho_0) + \frac{dR}{dL}(L-L_0) + \frac{dR}{dS}(S-S_0)$$

$$\cong \frac{L}{S}(\rho-\rho_0) + \frac{\rho}{S}(L-L_0) - \frac{\rho L}{S^2}(S-S_0)$$

we want to express the relative change $\Delta R / R$ of resistance to the relative deformation $\varepsilon = \Delta L / L$

$$\frac{\Delta S}{S} = -2\mu \frac{\Delta L}{L}$$

μ Poisson ratio

$$\frac{\Delta R}{R} = \frac{\Delta\rho}{\rho} + \frac{\Delta L}{L} - \frac{\Delta S}{S}$$

$$\frac{\Delta S}{S} = -2\mu \frac{\Delta L}{L}$$

$$\frac{\Delta R/R}{\Delta L/L} = 1 + 2\mu + \frac{\Delta\rho/\rho}{\Delta L/L}$$

piezoresistive coefficient

$$\frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon} = 1 + 2\mu + \pi_e E$$

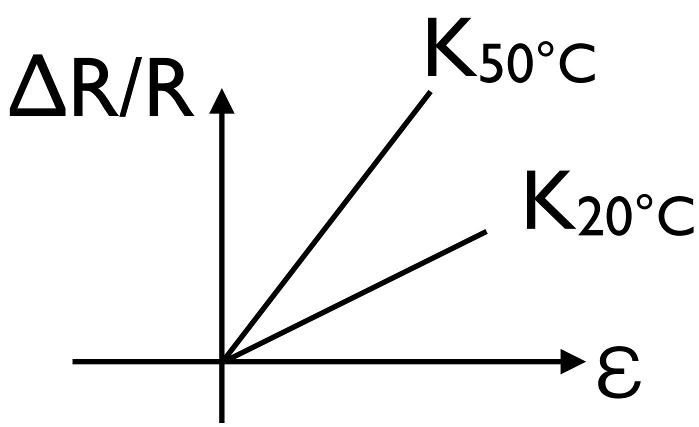
Young module

$$\frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon} = 1 + 2\mu + \pi_e E$$

$$\Delta R/R = C_1\varepsilon + C_2\varepsilon^2 + C_3\varepsilon^3 + \ldots$$

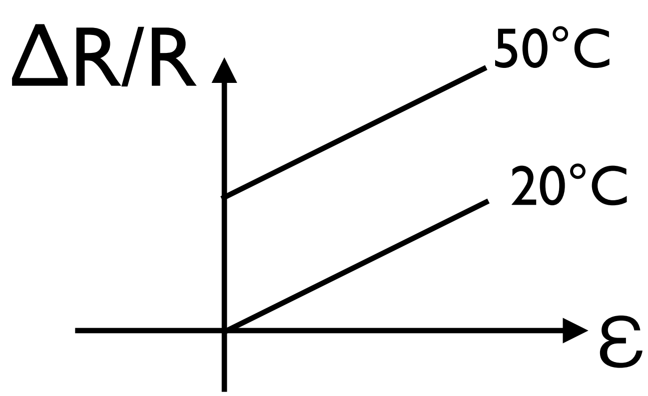
$$K = \frac{d\Delta R/R}{d\varepsilon}$$

strain gauge factor
(how large the response of the strain gauge is)



$$\alpha_K = \frac{\Delta K/K_{20°C}}{\Delta\vartheta}$$

temperature coefficient of sensitivity



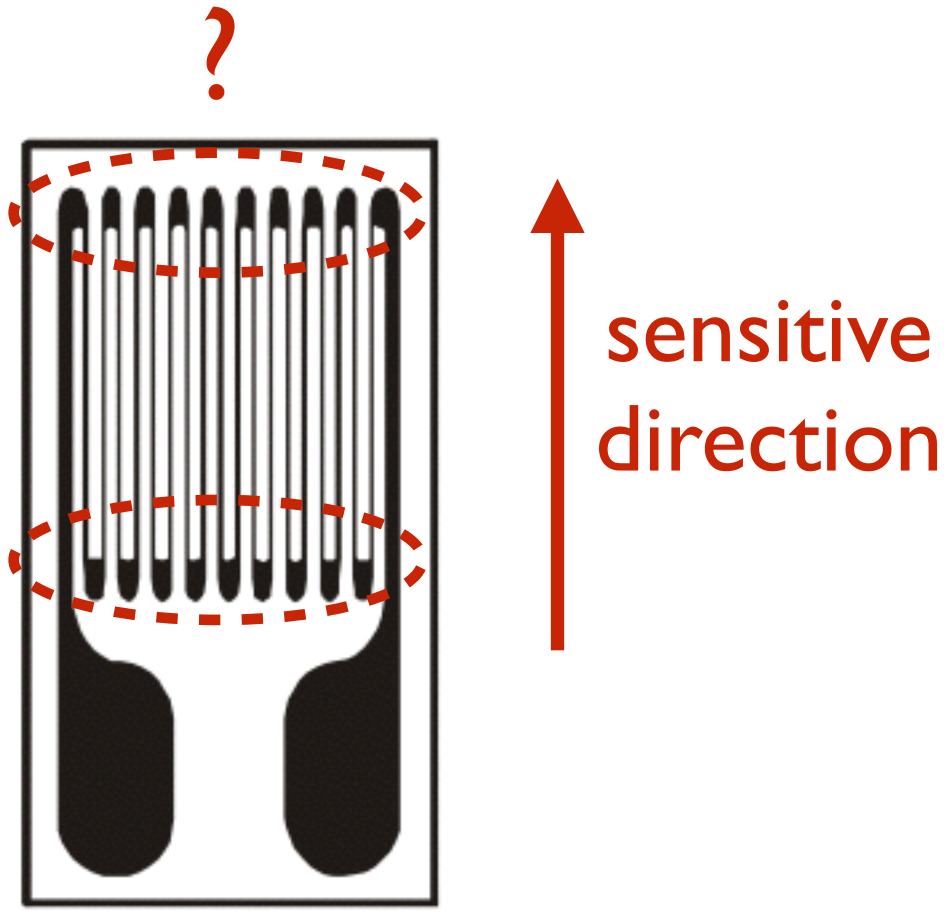
$$\alpha_R = \frac{\Delta R/R_{20°C}}{\Delta\vartheta}$$

temperature coefficient of resistance

Metal and semiconductor strain gages

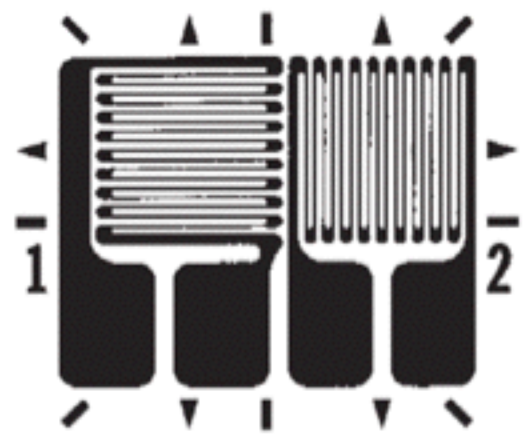
Parameter	Semiconductor	Metal
K	125	2÷4
C_2	4000	~0
α_R	12 ppm/K	0.2 ppm/K
α_K	16 ppm/K	5 ppm/K

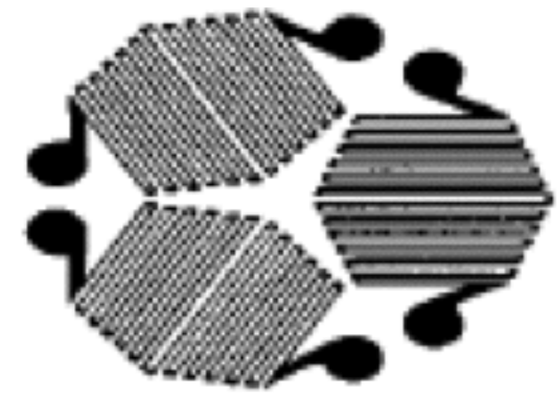
Bonded foil strain gauges

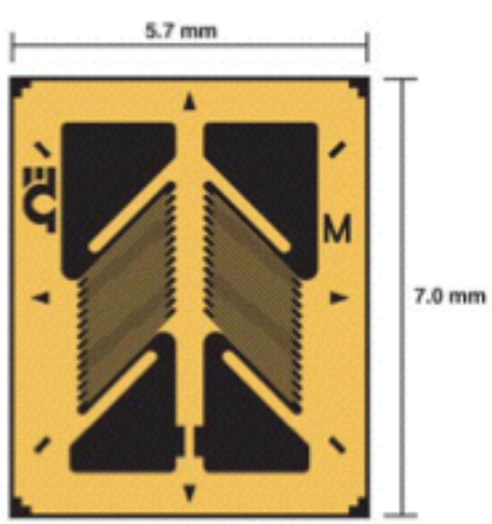


The epoxy resin both transmits the mechanical stress to the metal and provided the necessary electrical insulation

Other shapes of strain gauges to measure in multiple directions

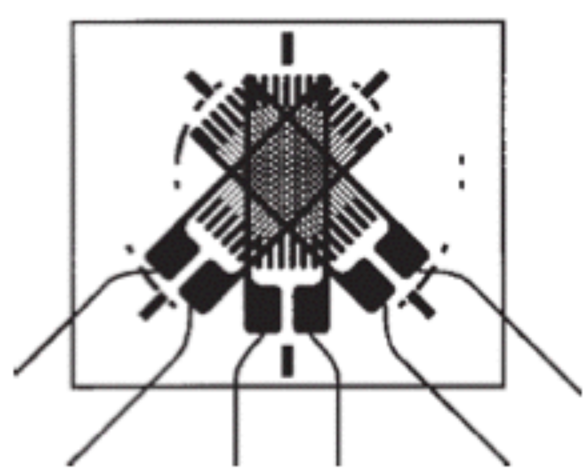


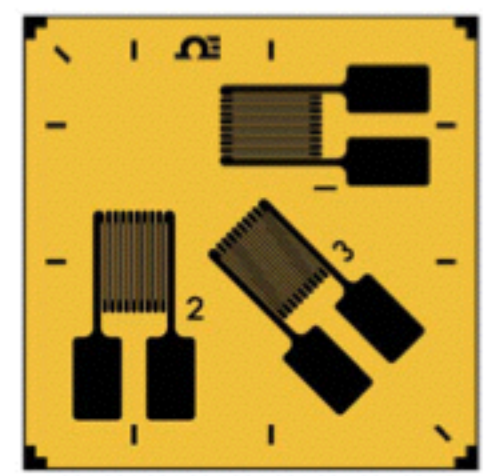




SGT-1/350-SY11

Stacked



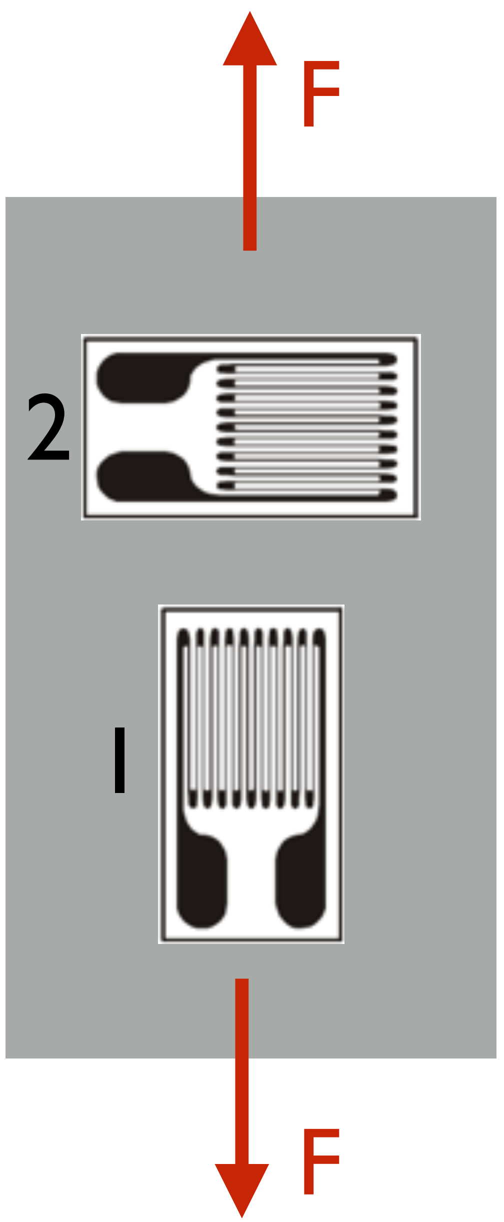


SGD-1/120-RYT21

Vishay, Omega Engineering, Hottinger-Baldwin

Problem: what if the temperature changes?

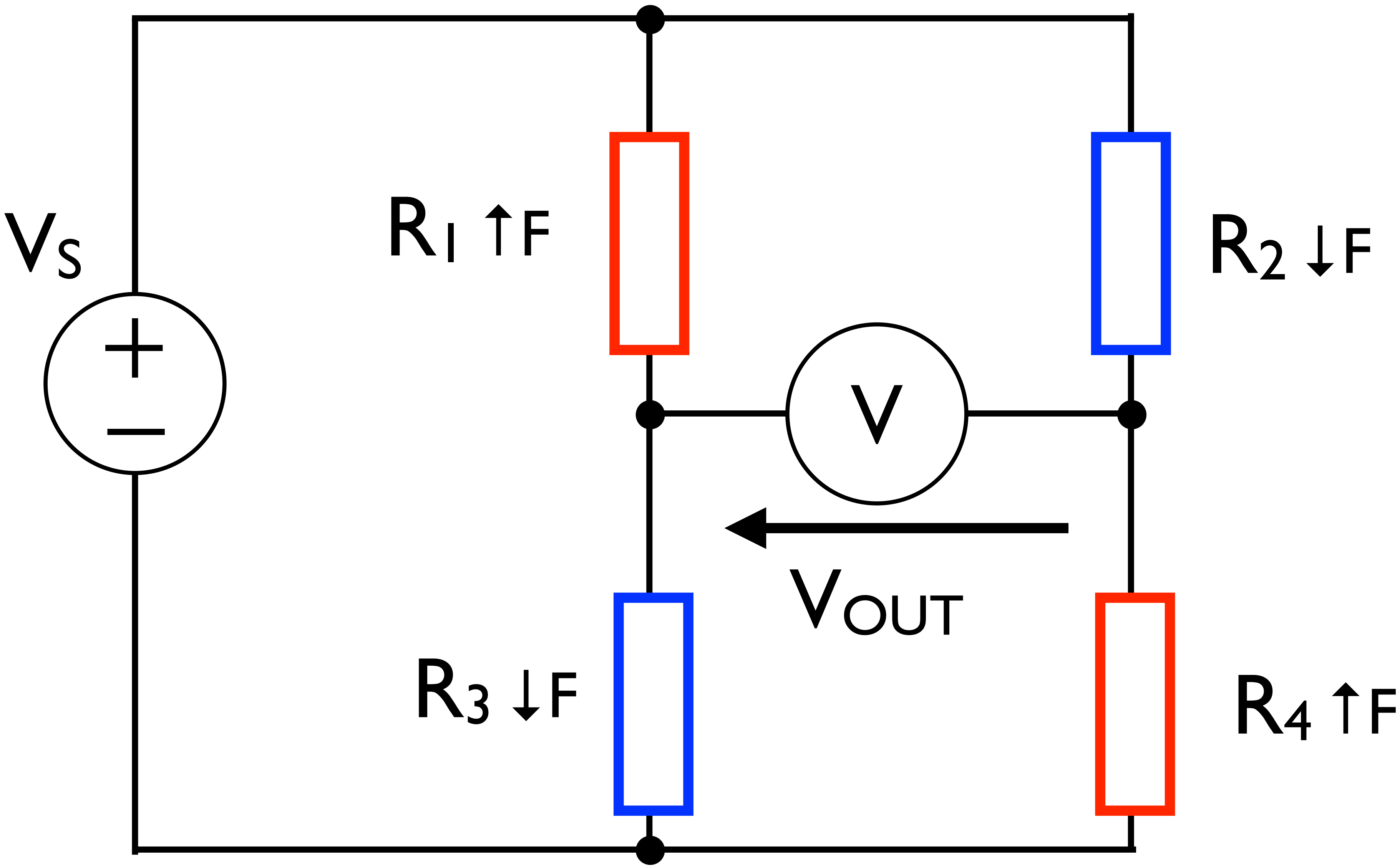
We must compensate ΔR due to temperature.
Basic principle: use two “identical” sensors, only one of which measures the force.



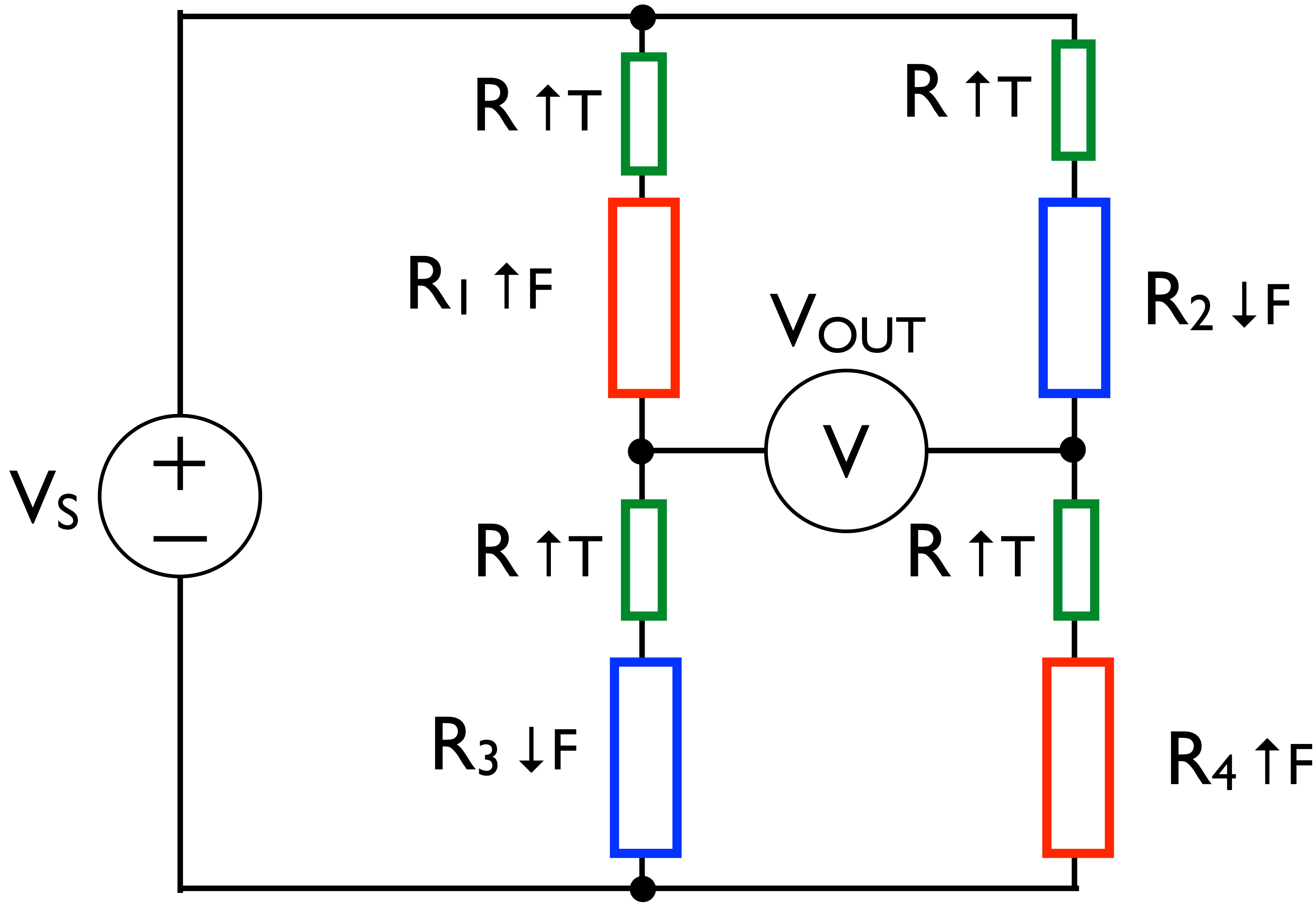
R_2 depends only on temperature

R_1 depends on F and temperature

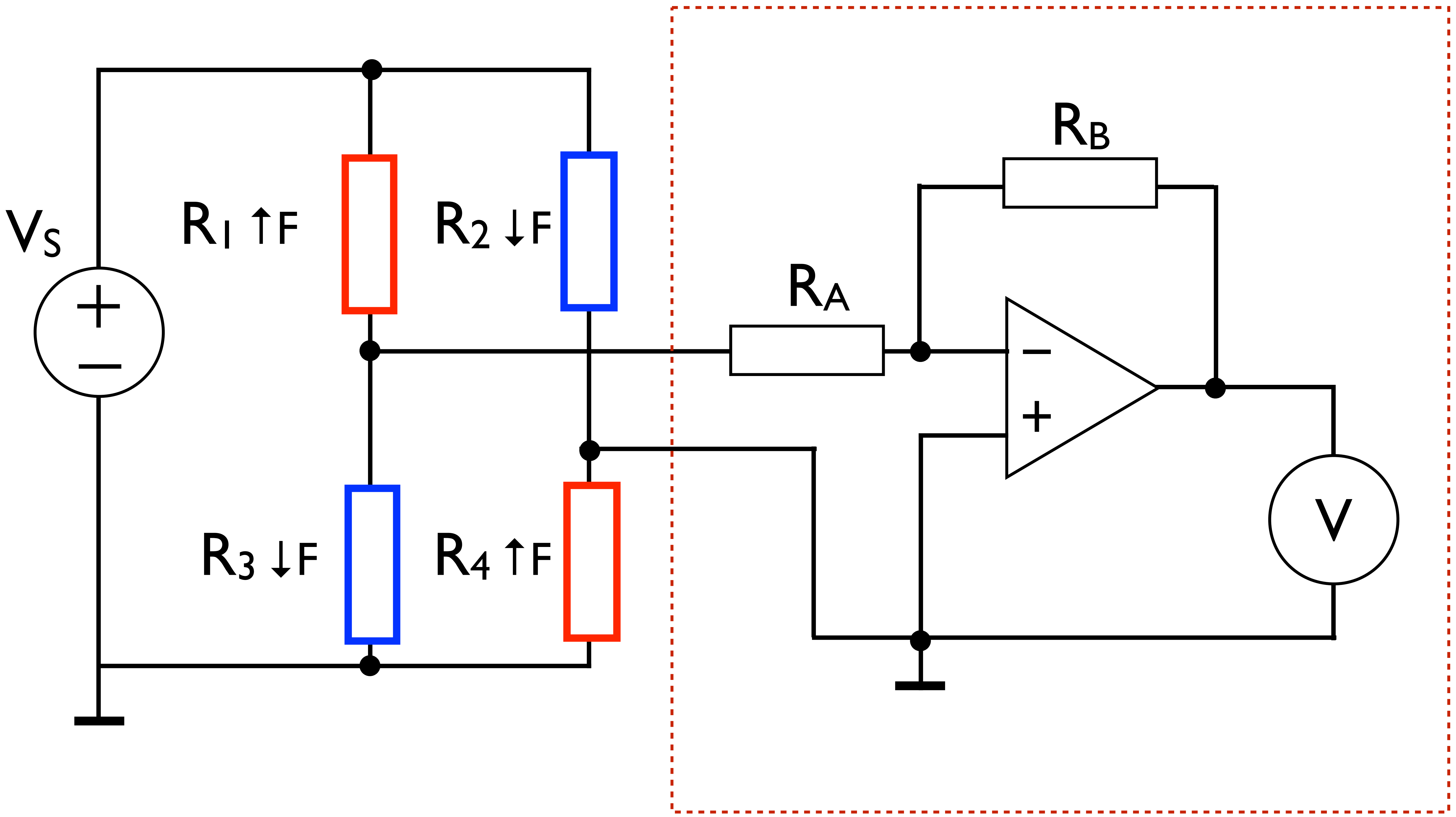
Other solution: use a full bridge and identical sensors



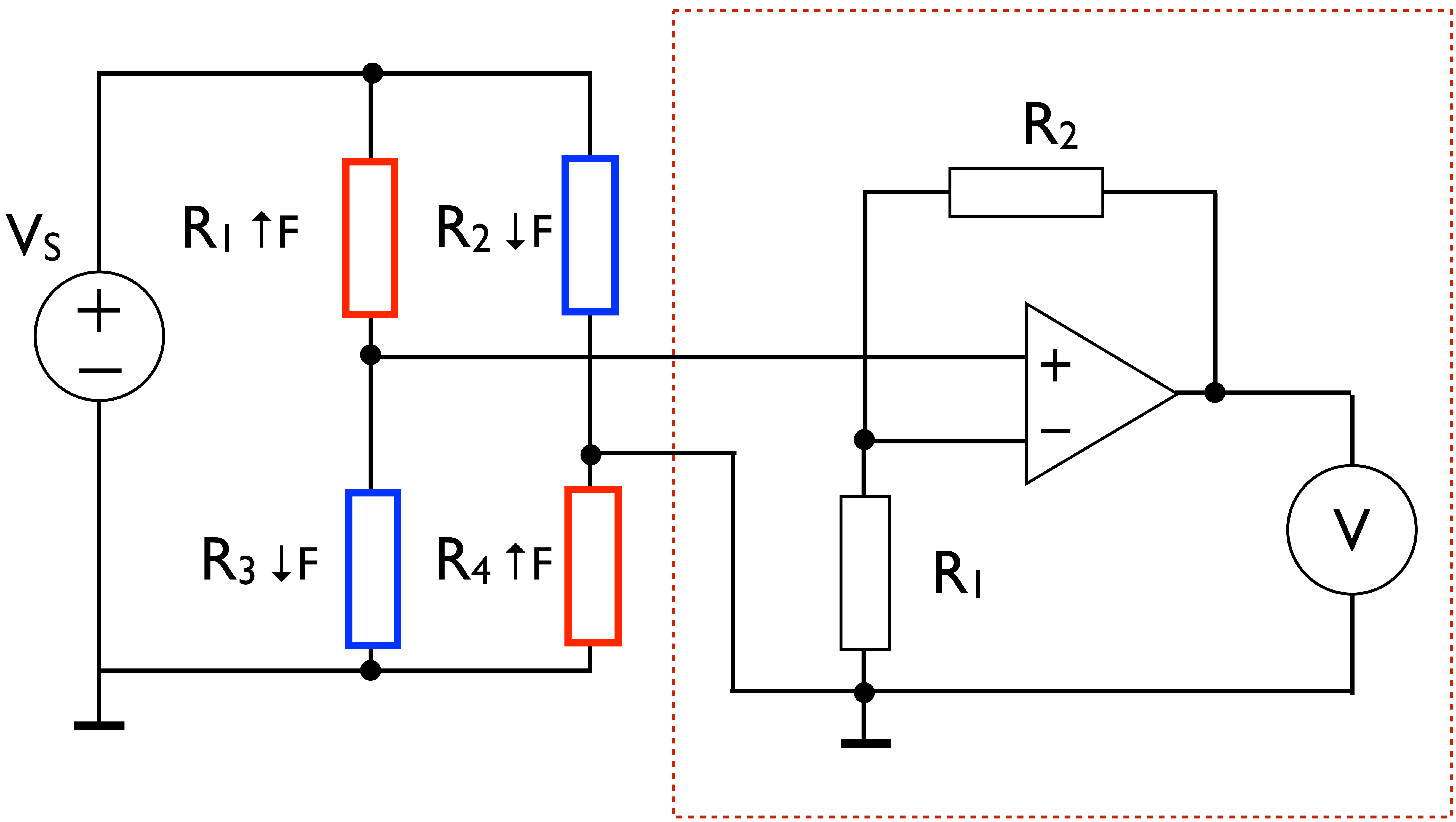
Other solution: use a full bridge and identical sensors



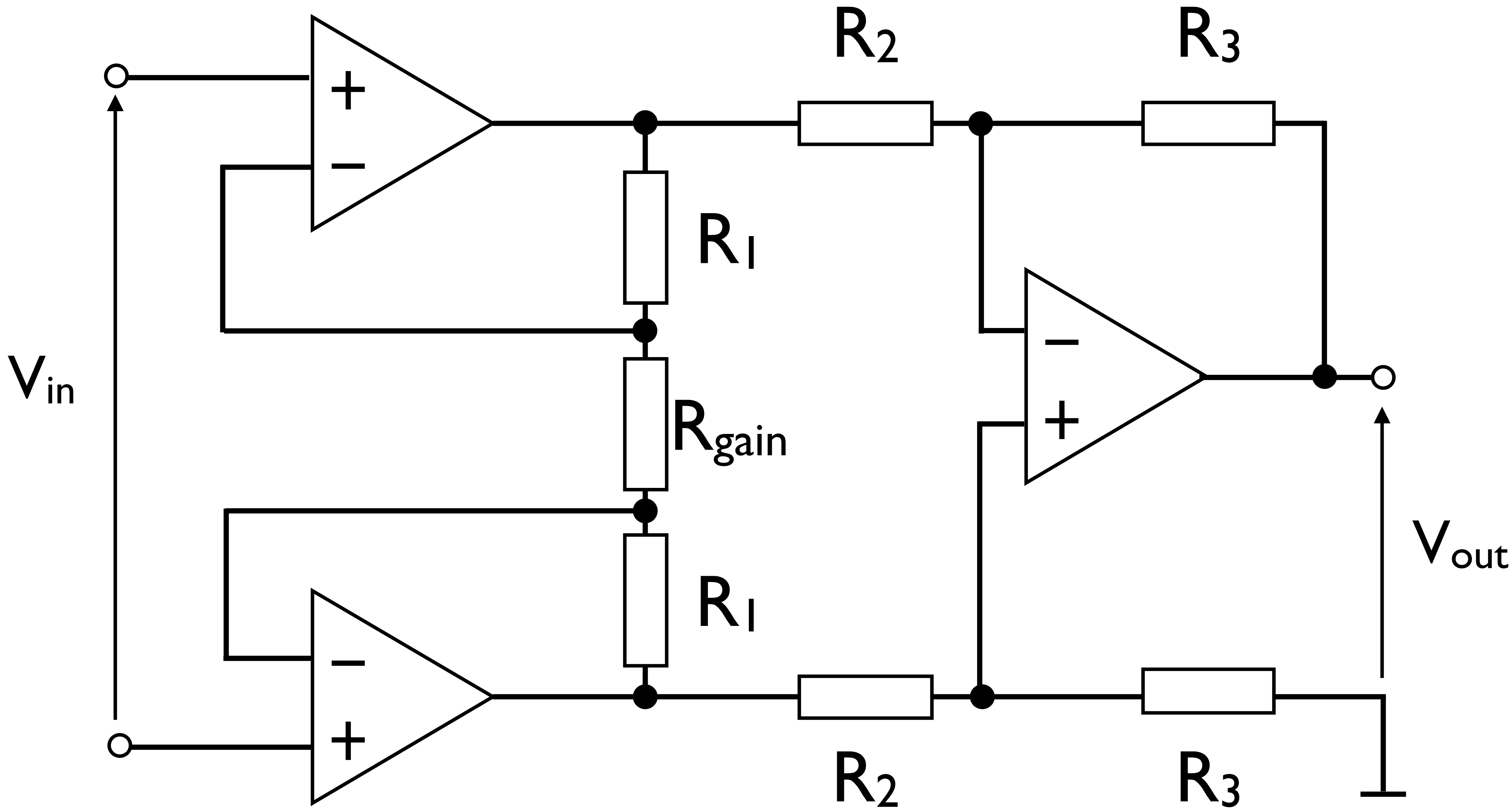
How to amplify the voltage output?



How to amplify the voltage output?

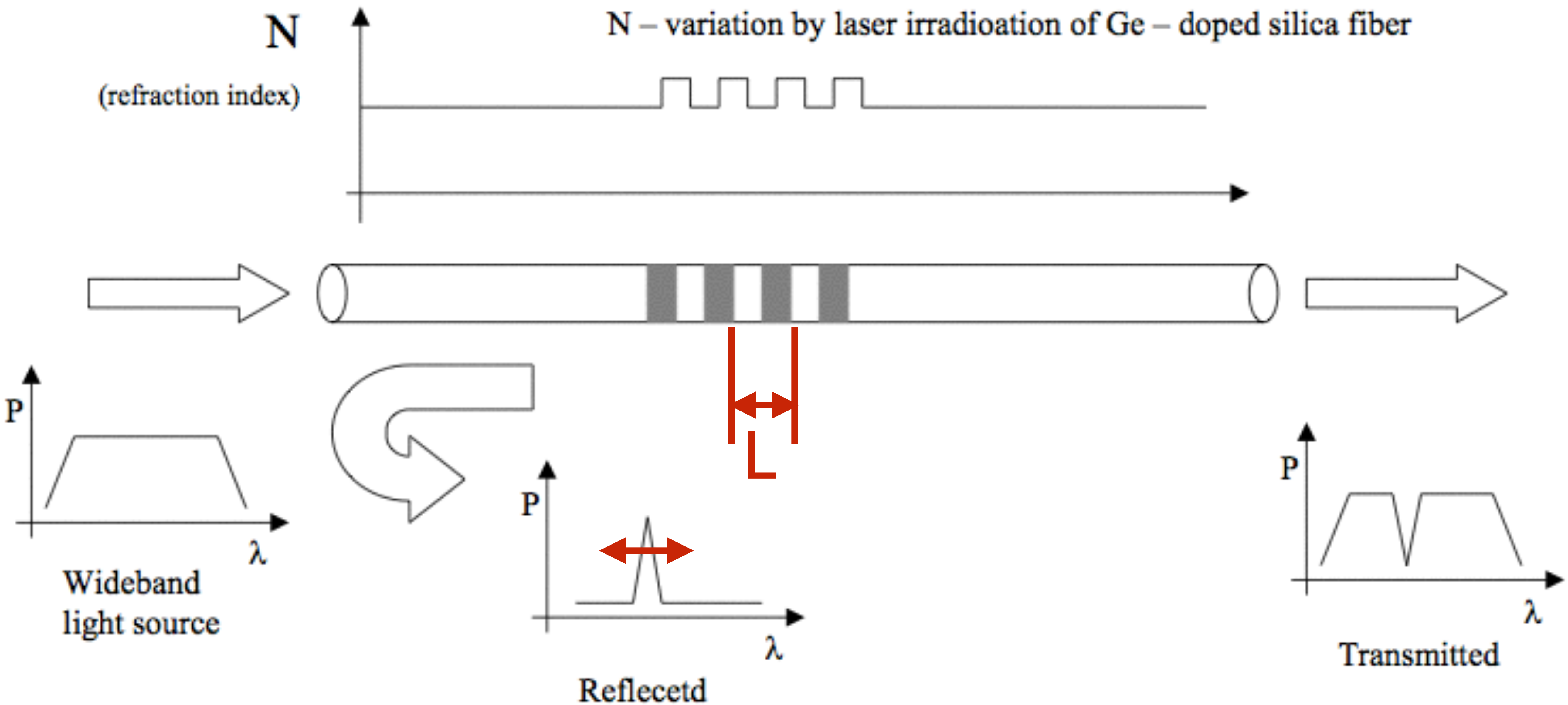


Solution: instrumentation amplifier

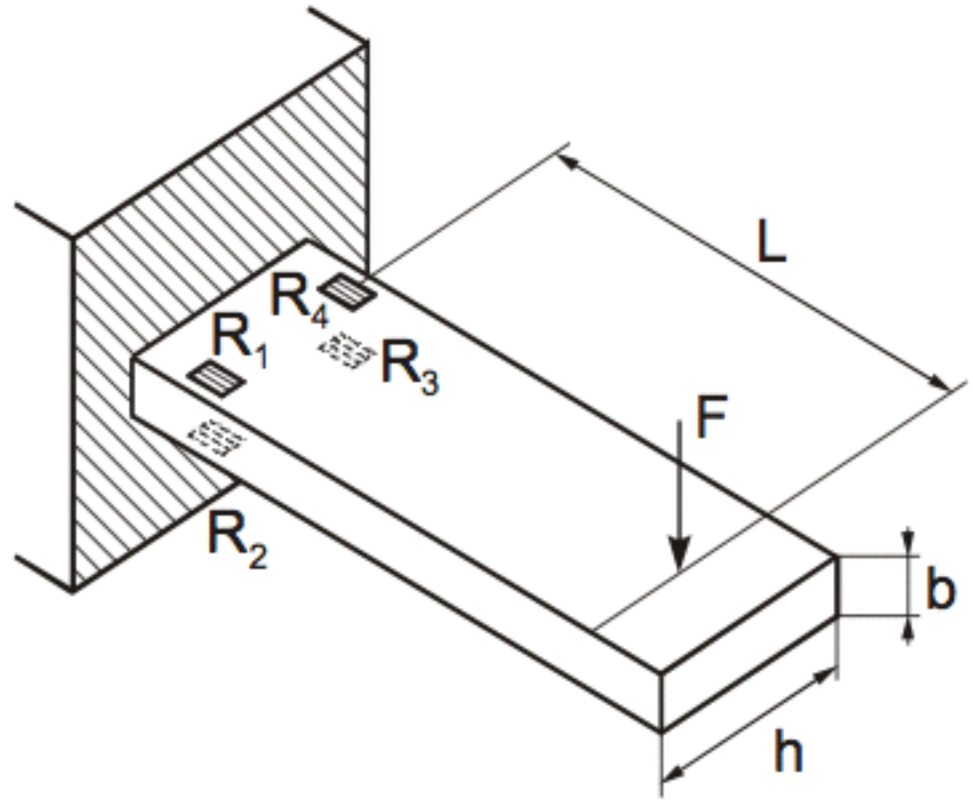


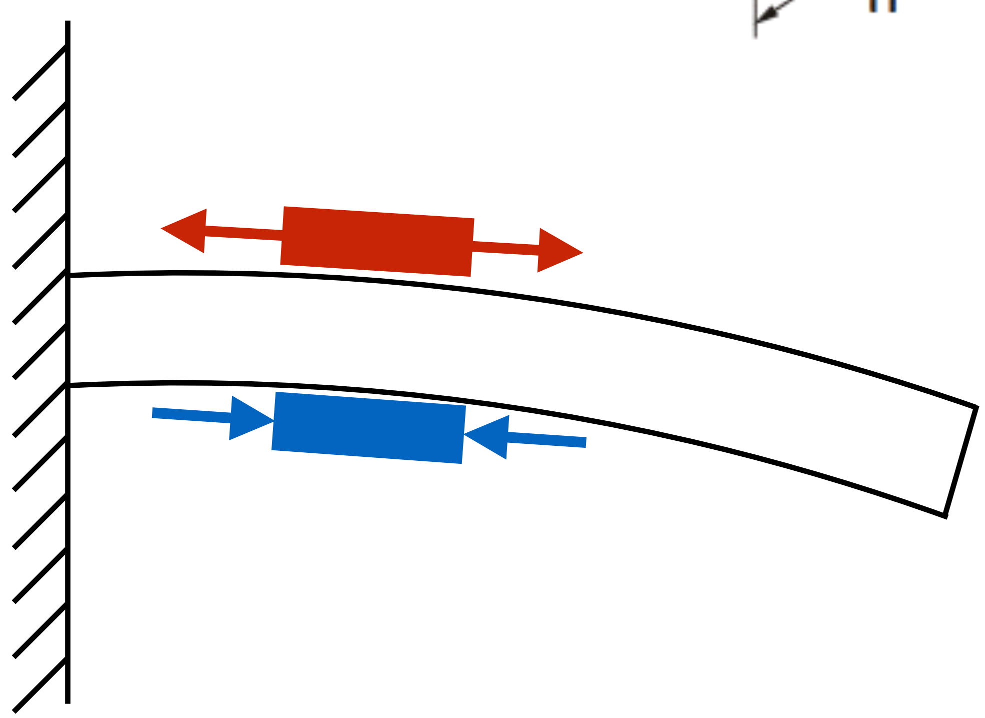
$$V_{out} = \left(\frac{2R_1}{R_g} + 1\right)\frac{R_3}{R_2}(-V_{in})$$

Fiber Bragg Grating sensors



How to measure force

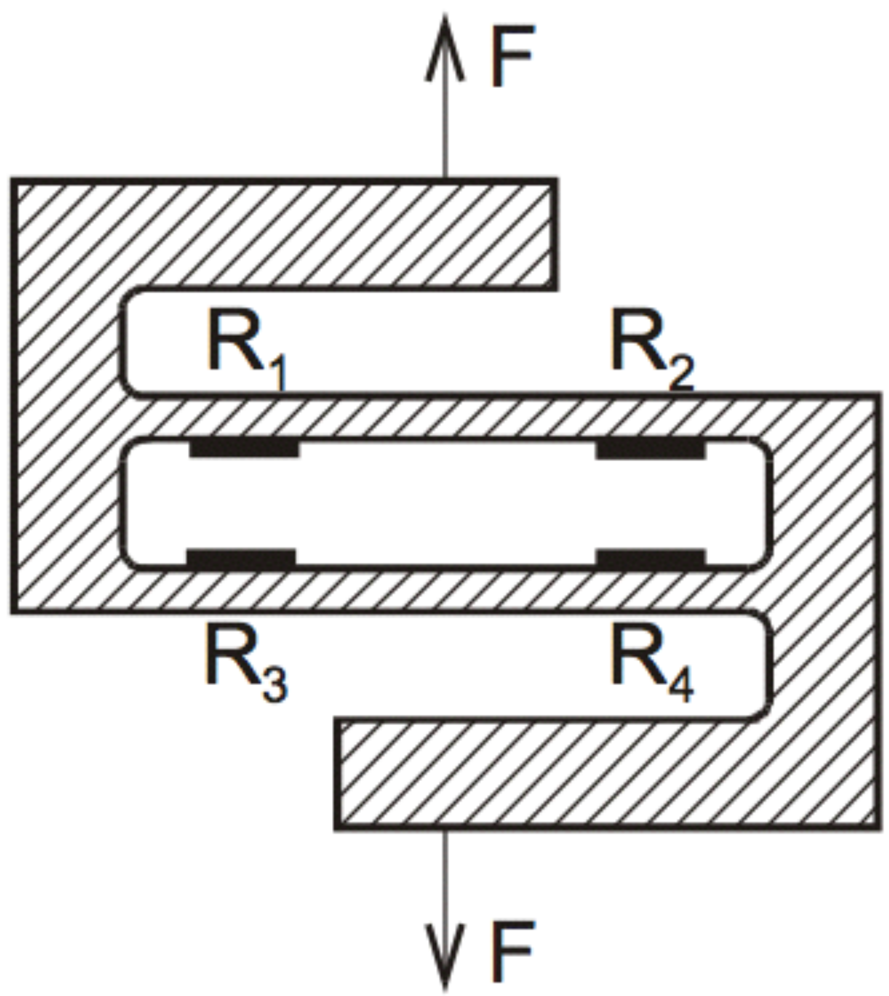




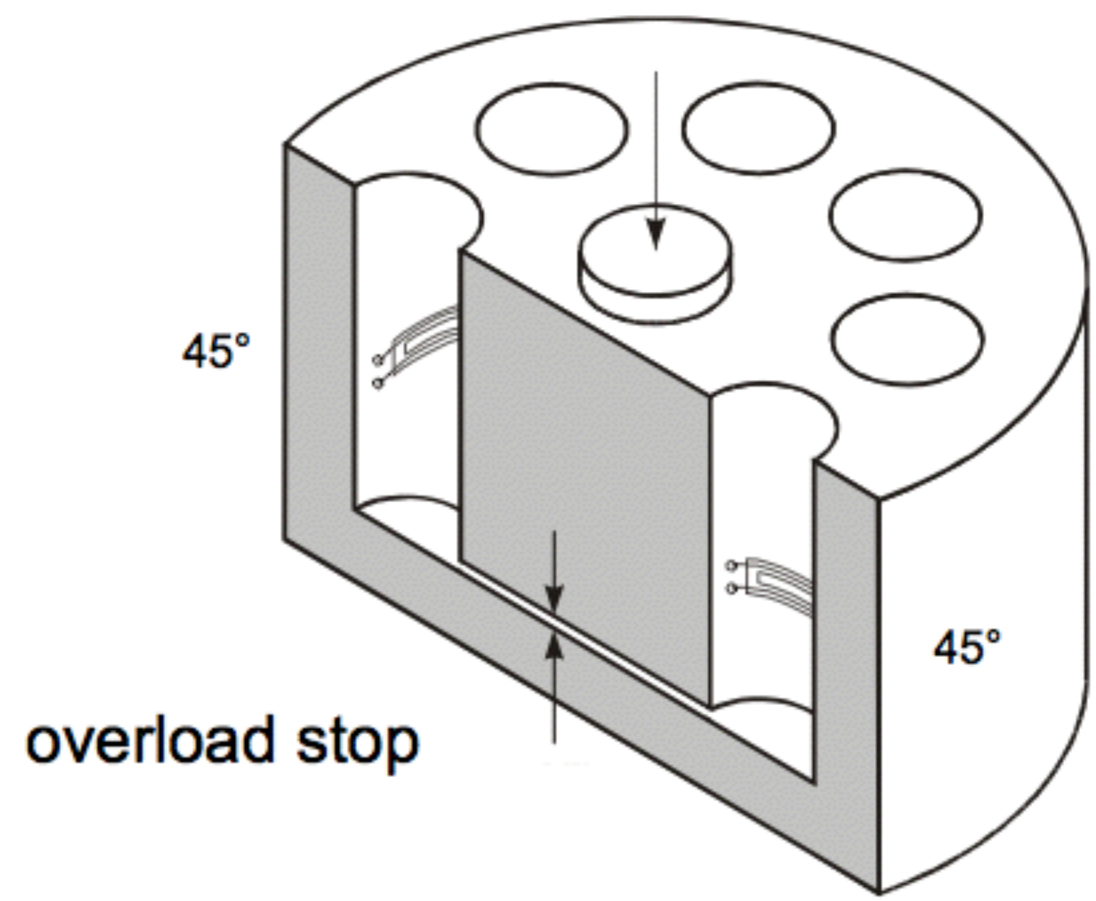
for small forces (up to some kN)

How to measure a large force

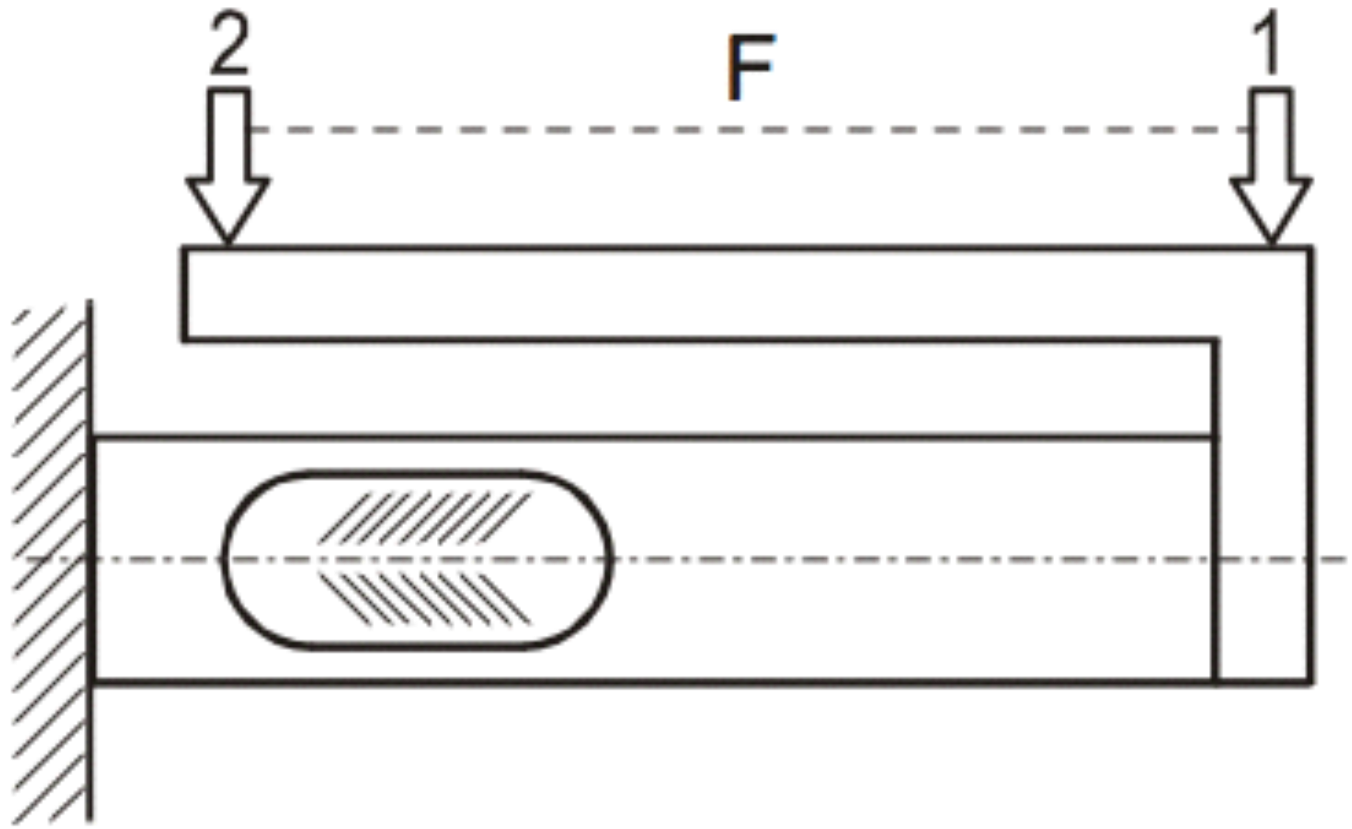
S-type load cell



Shear-web force transducer

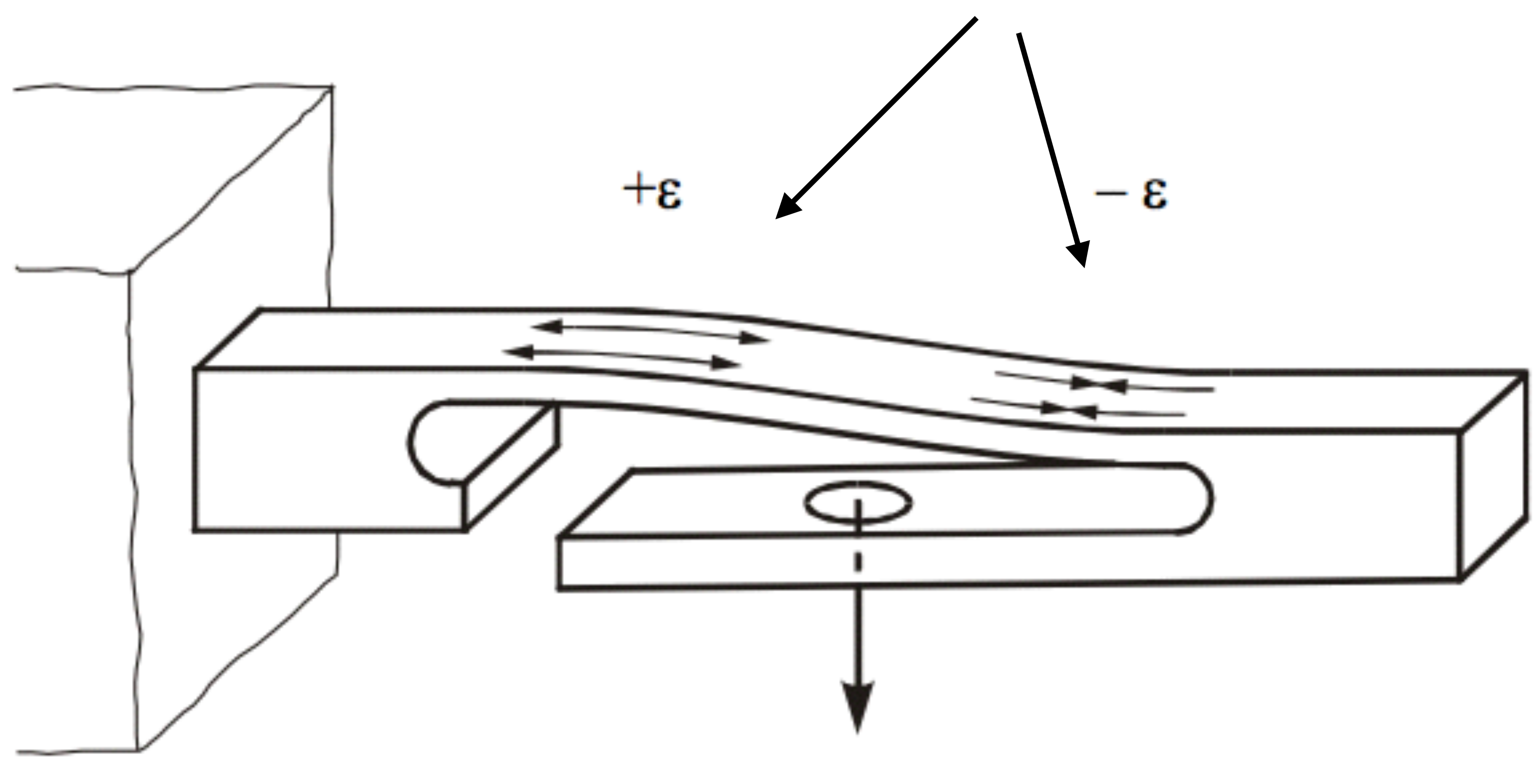


How to measure shear

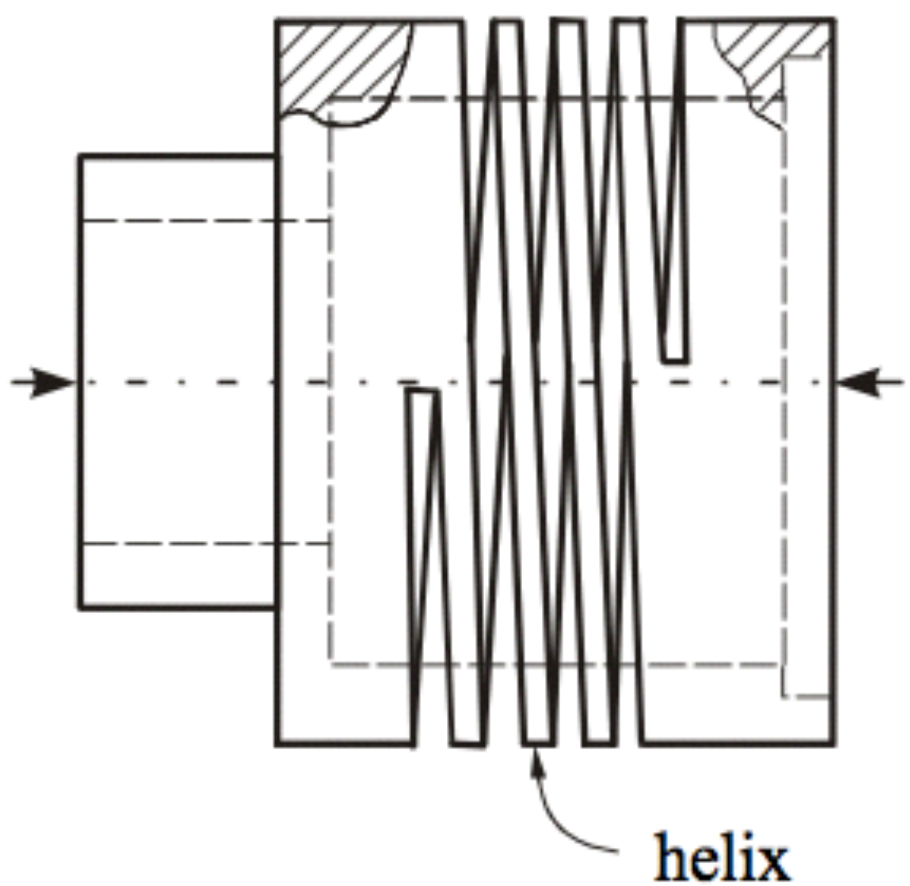


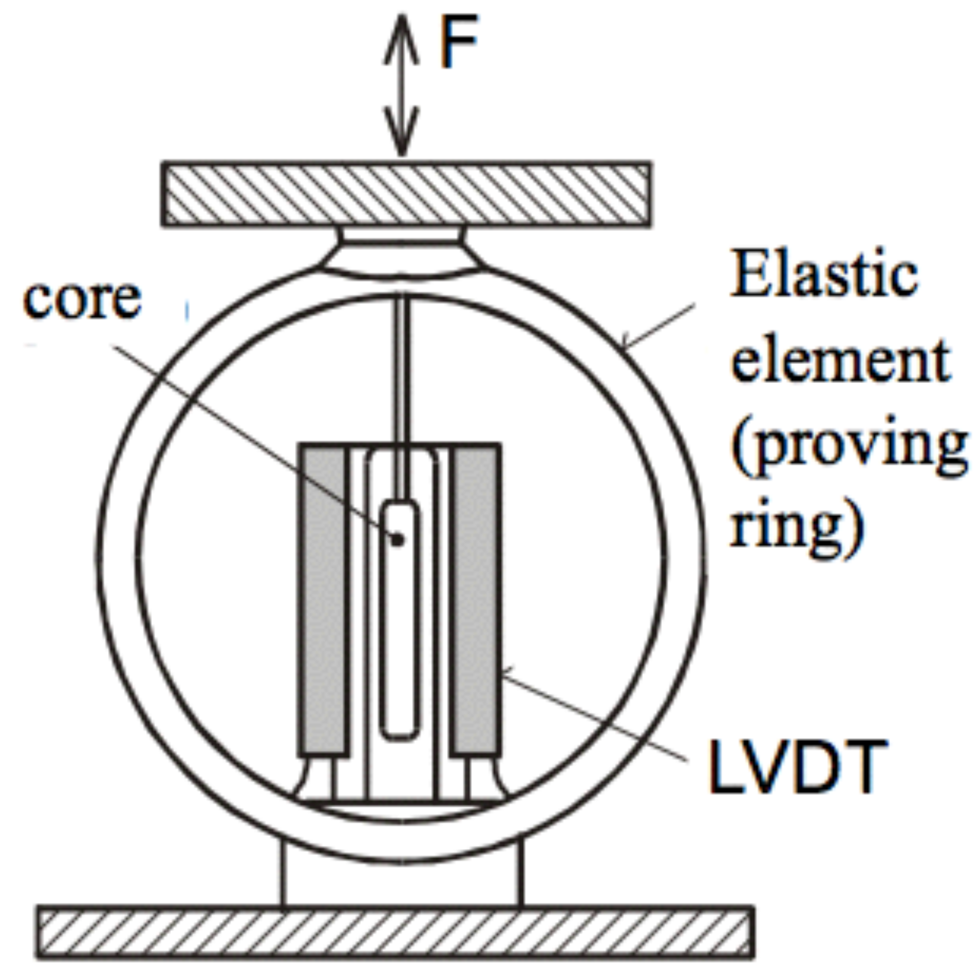
Folded cantilever

extension and compression are the same

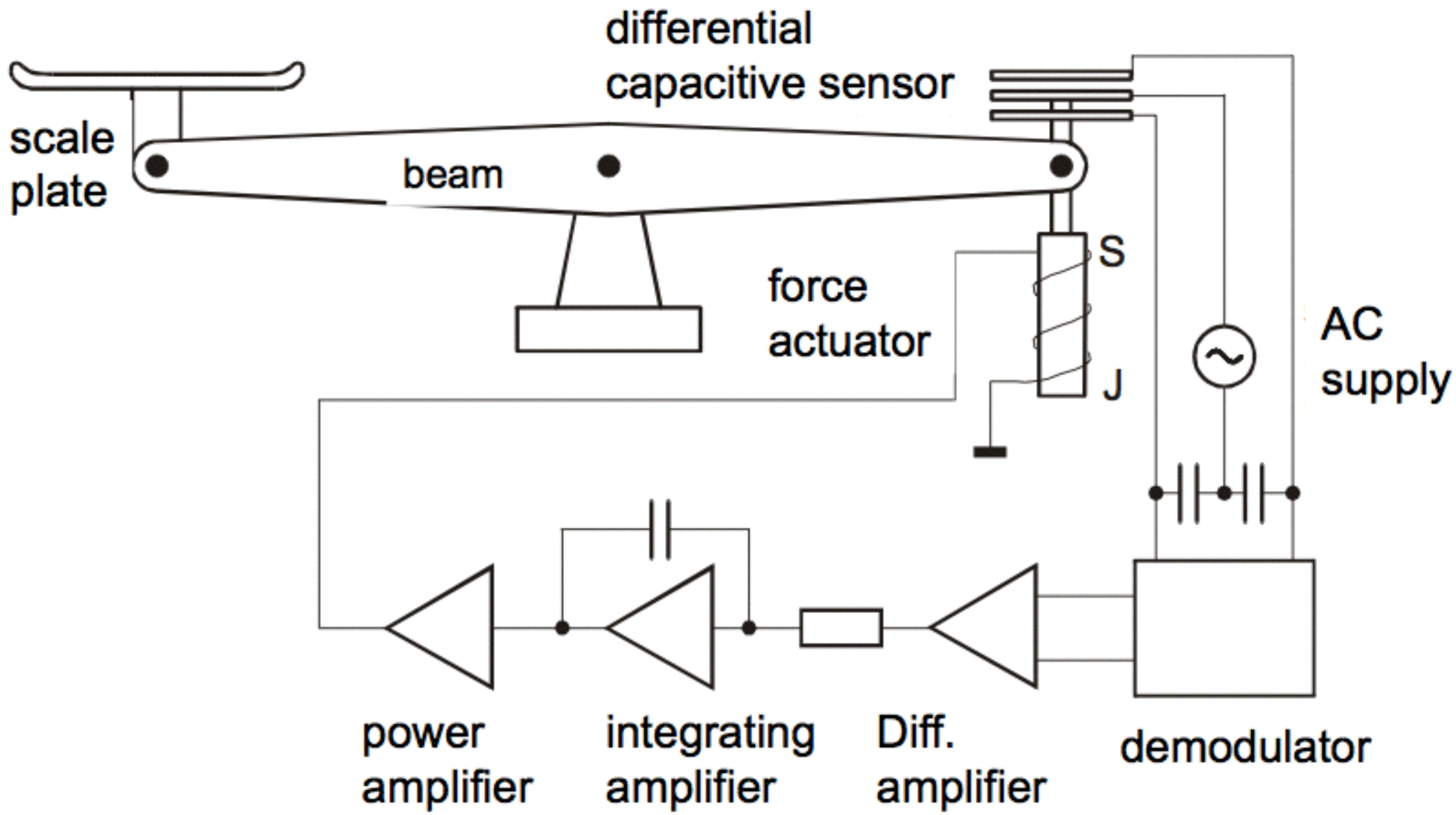


Sensors of force based on displacement

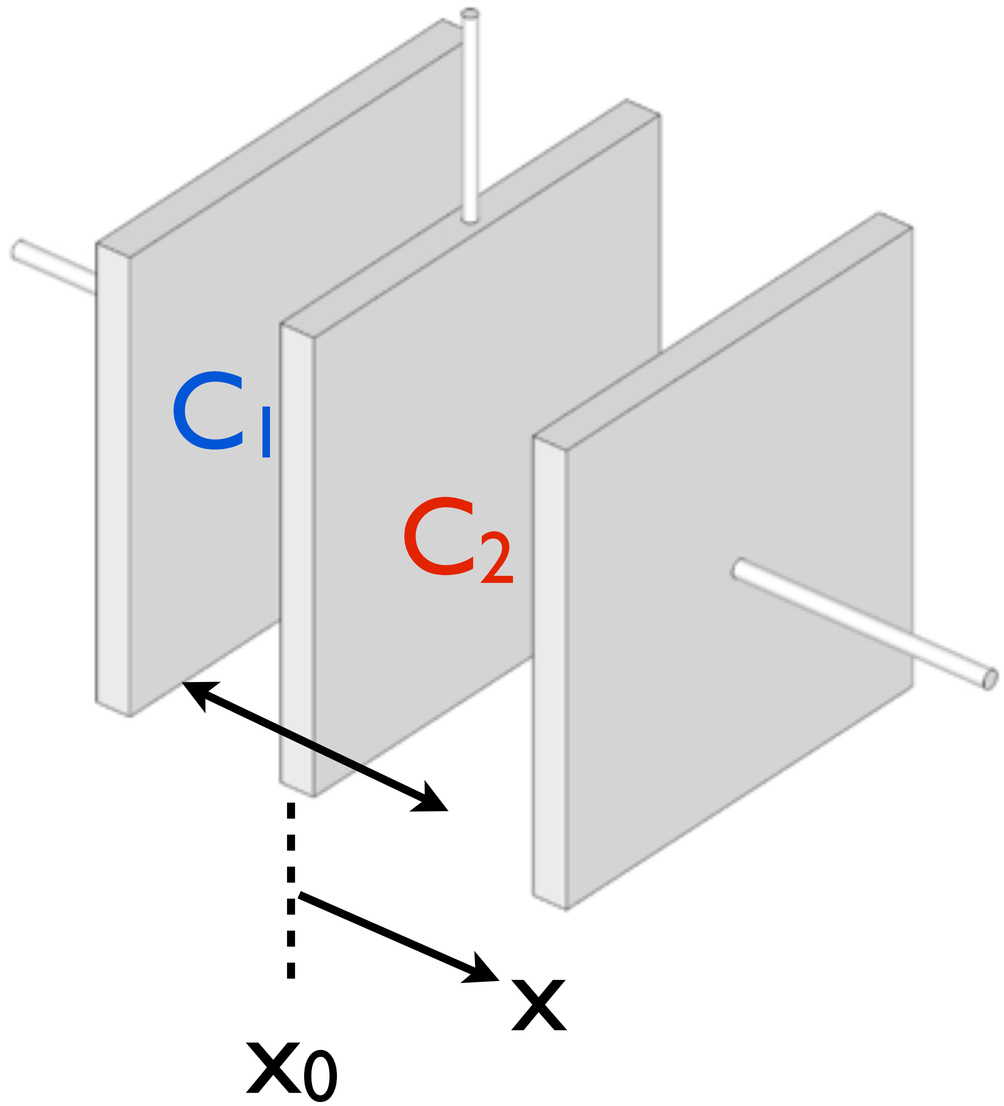


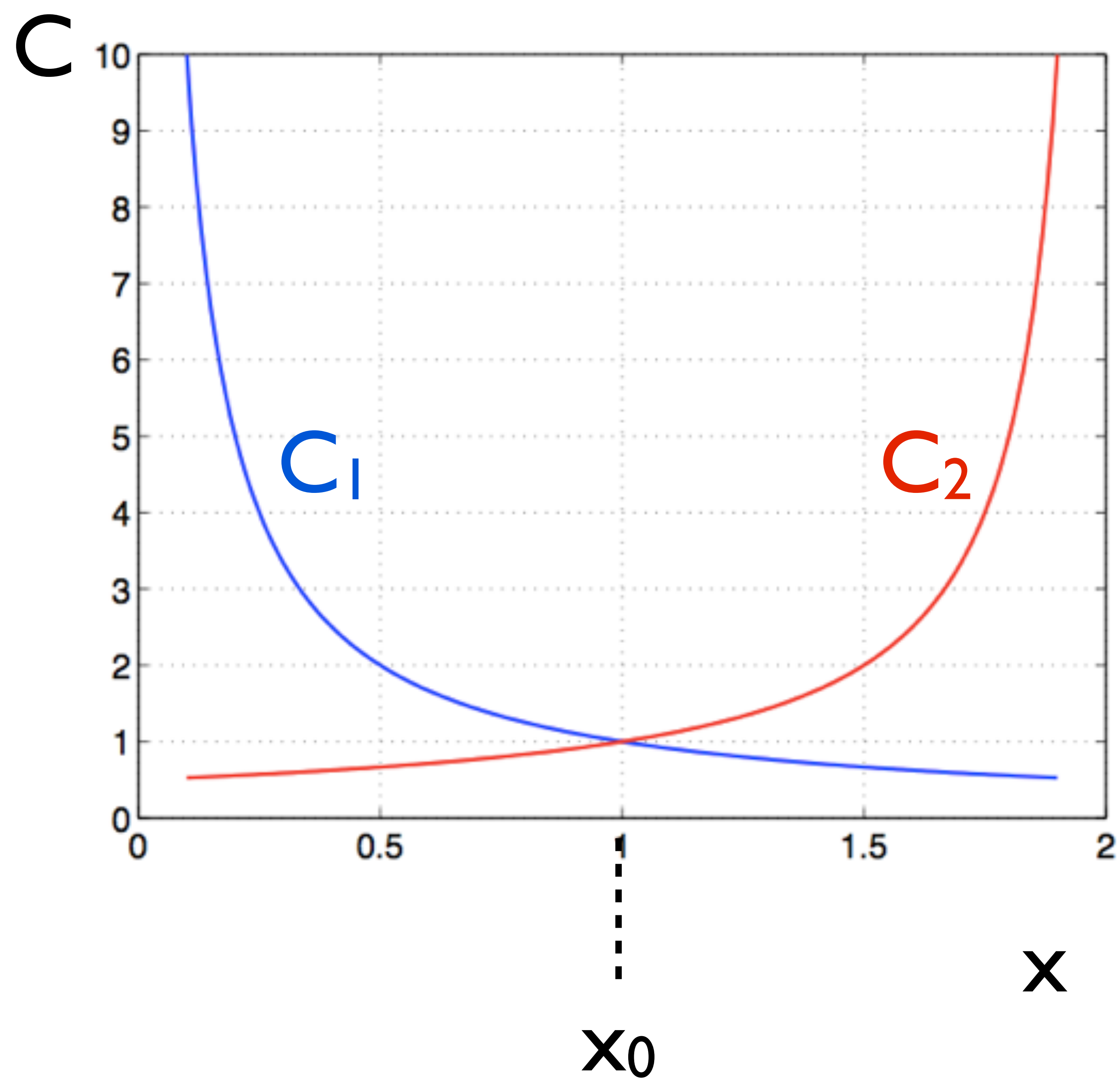


Sensors with electromechanical feedback



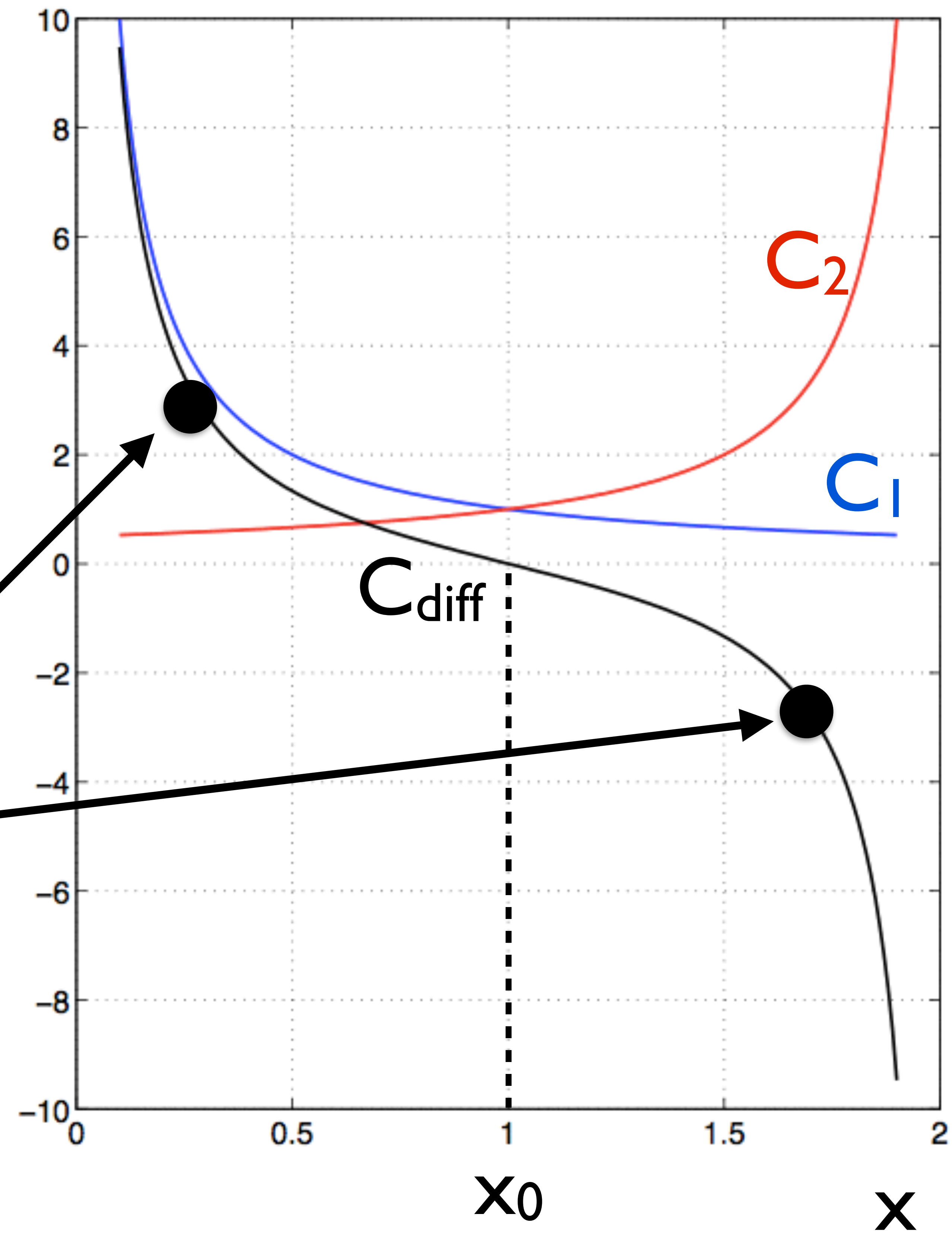
Why should we use feedback?
Can't we simply read the difference of capacity?



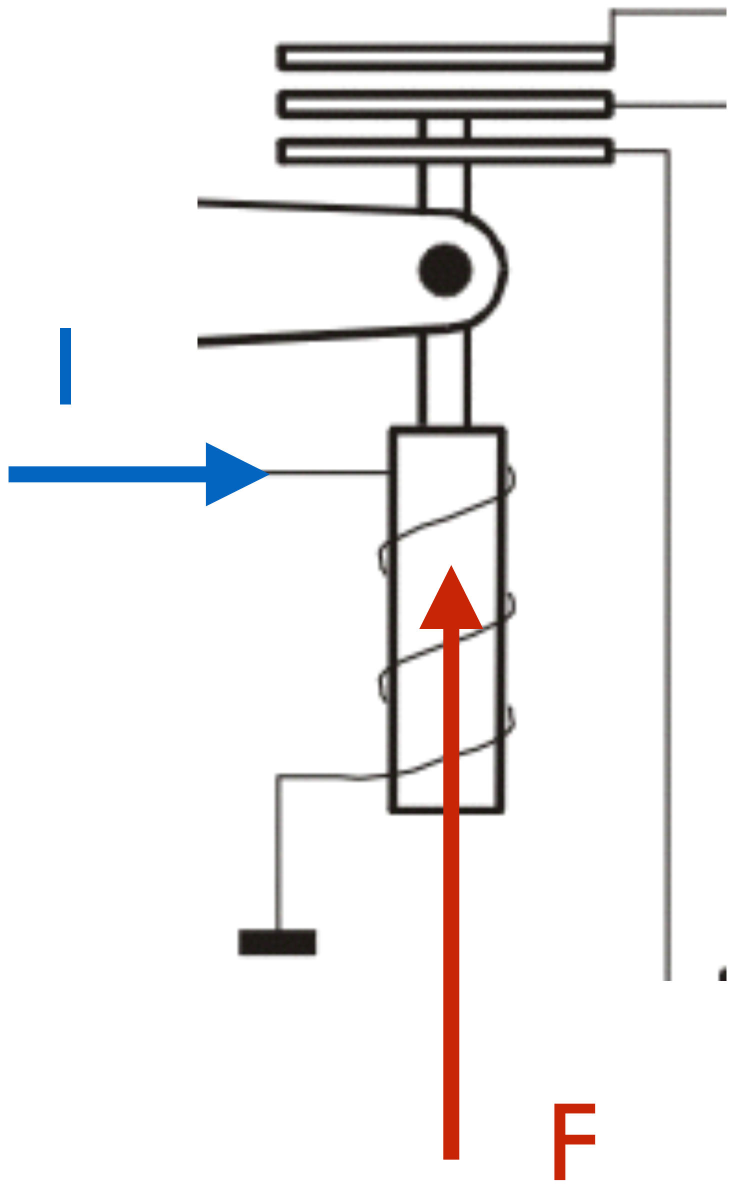


Why should we use feedback?
Can't we simply read the difference of capacity?

C_{diff} is more linear than C_1 and C_2 but in this working points is also non-linear



How feedback works

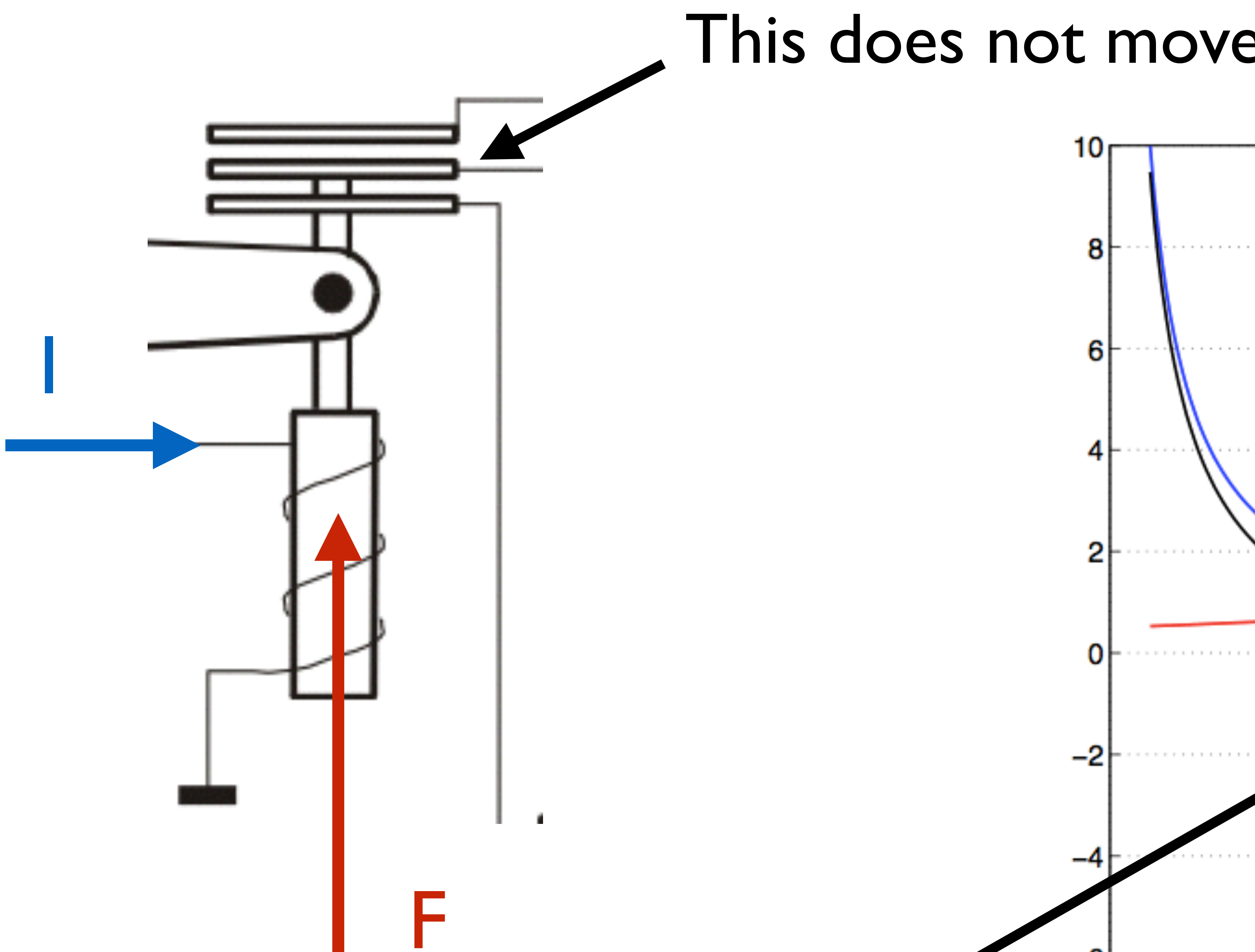


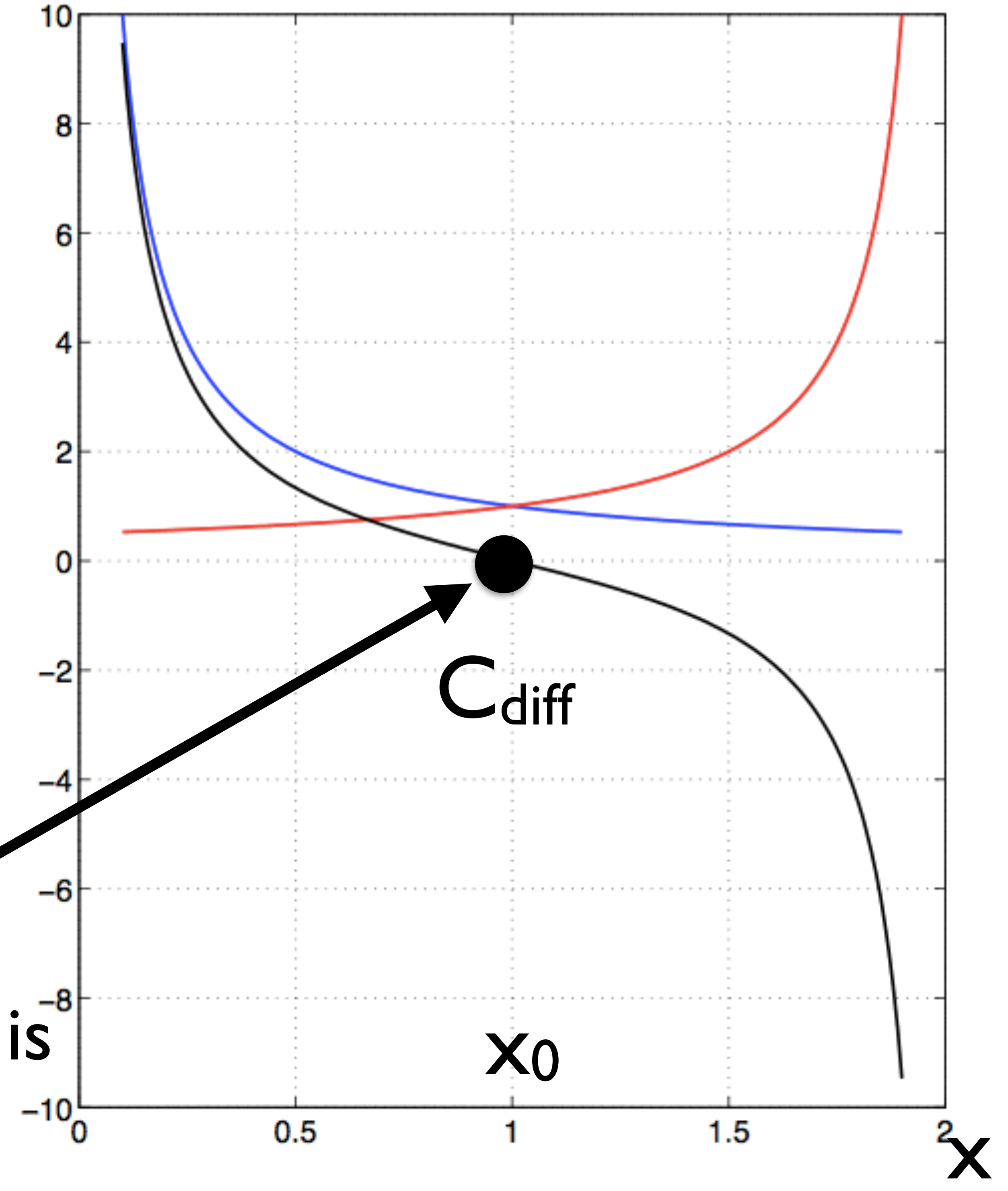
The current I in the solenoid creates a force F

F=kI

so that the differential capacitor is always in the central position

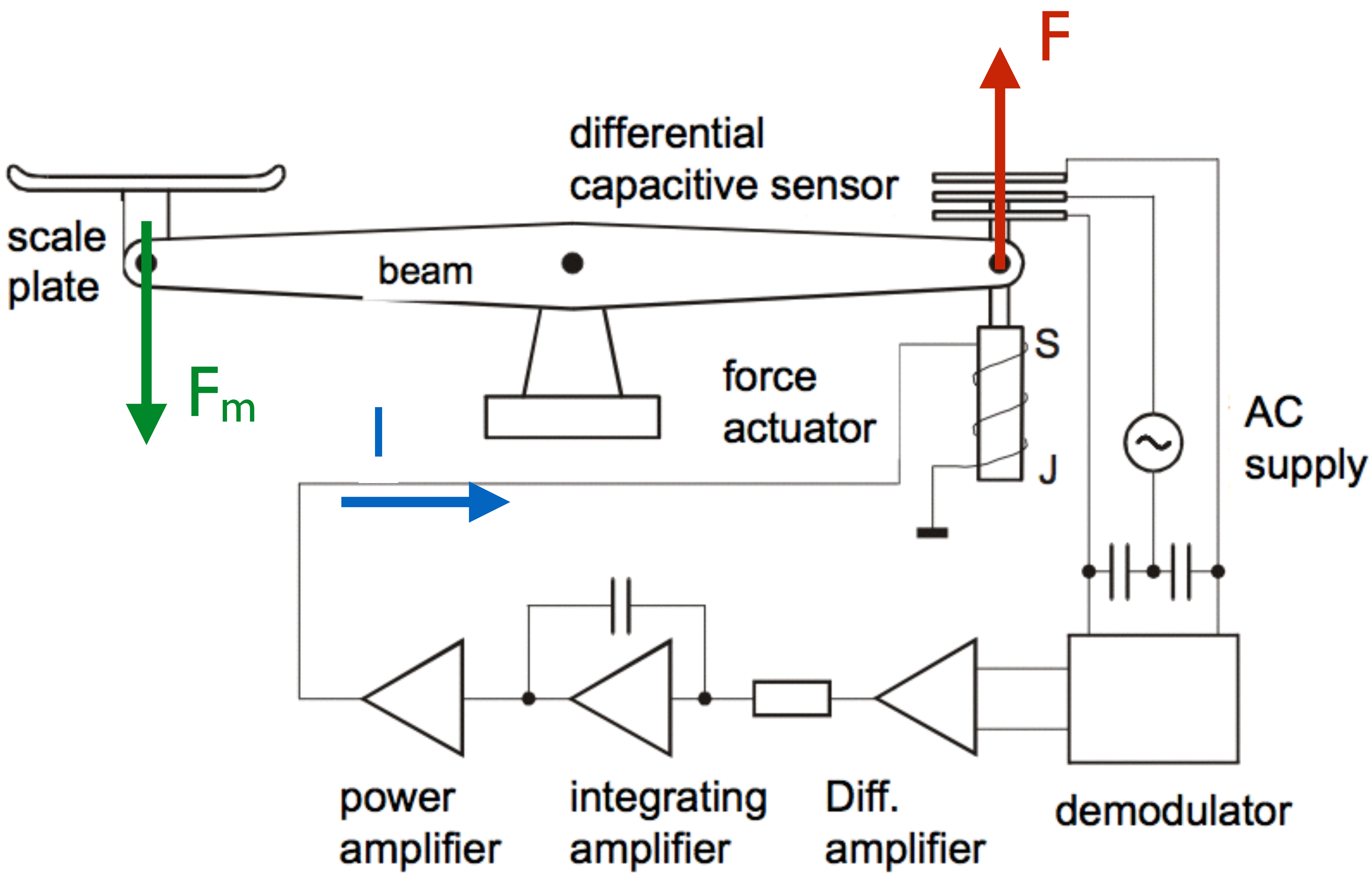
How feedback works





The working point of the capacitor is always in zero

The output signal is not capacity anymore.
The output signal is the current used to produce the balancing force.



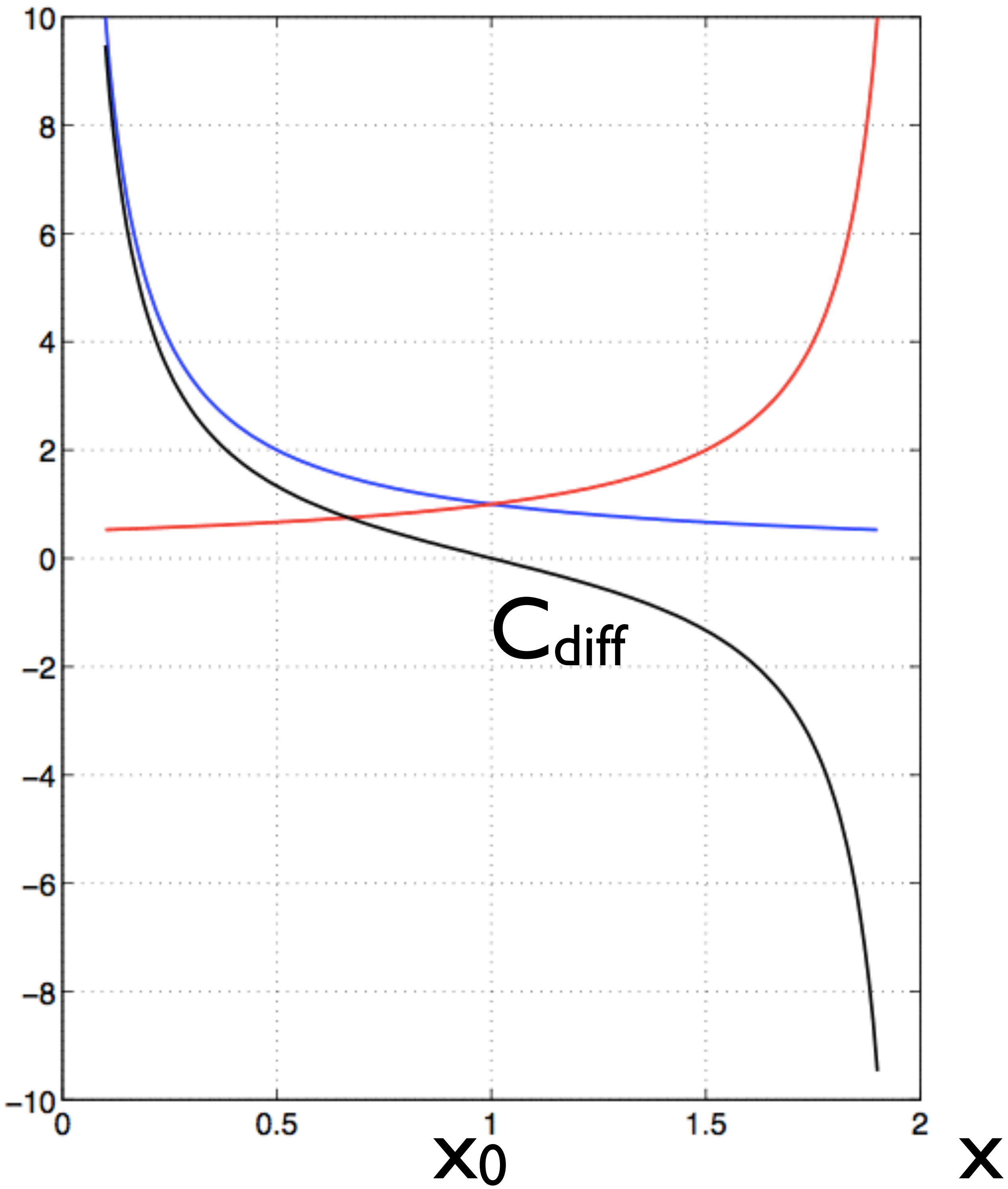
If Cdiff= 0 then

$F_m = F = kI$

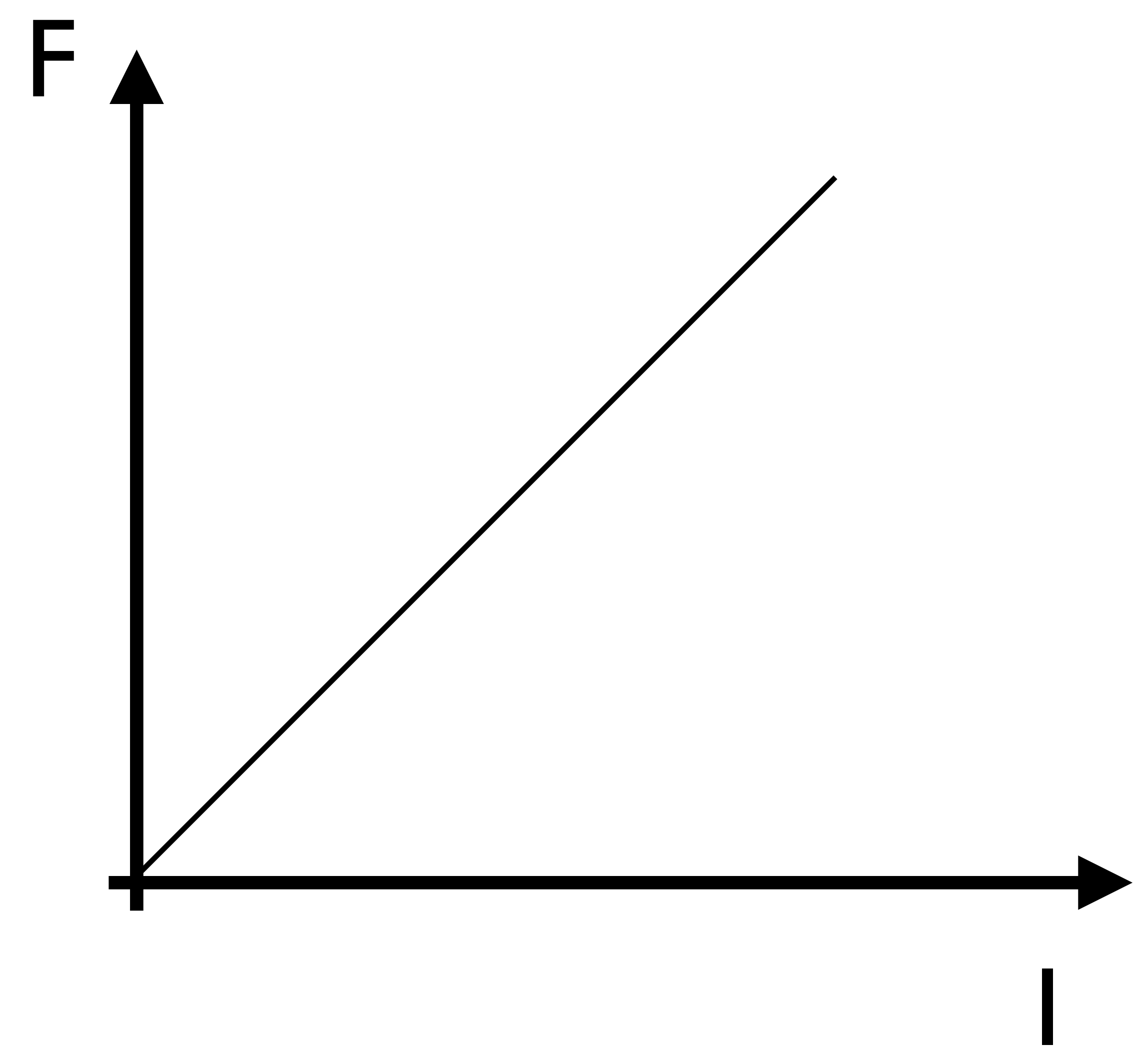
So, finally

$F_m = kI$

If I measure the capacity I get a non-linear dependence of the output quantity Cdiff on displacement (and then force F_m)



If I measure the current I, I obtain a linear dependence of the output current on the measured foce F_m)



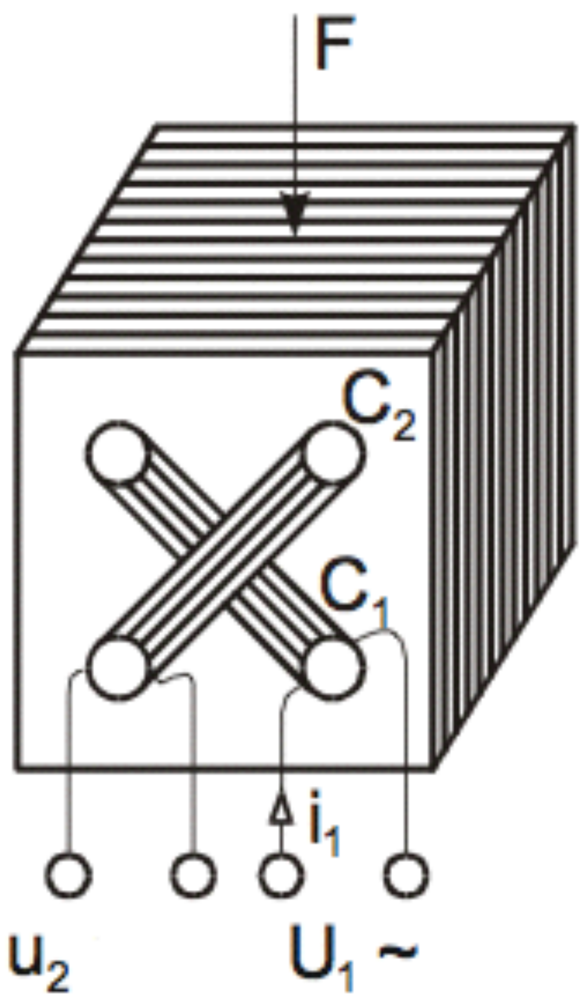
No feedback:

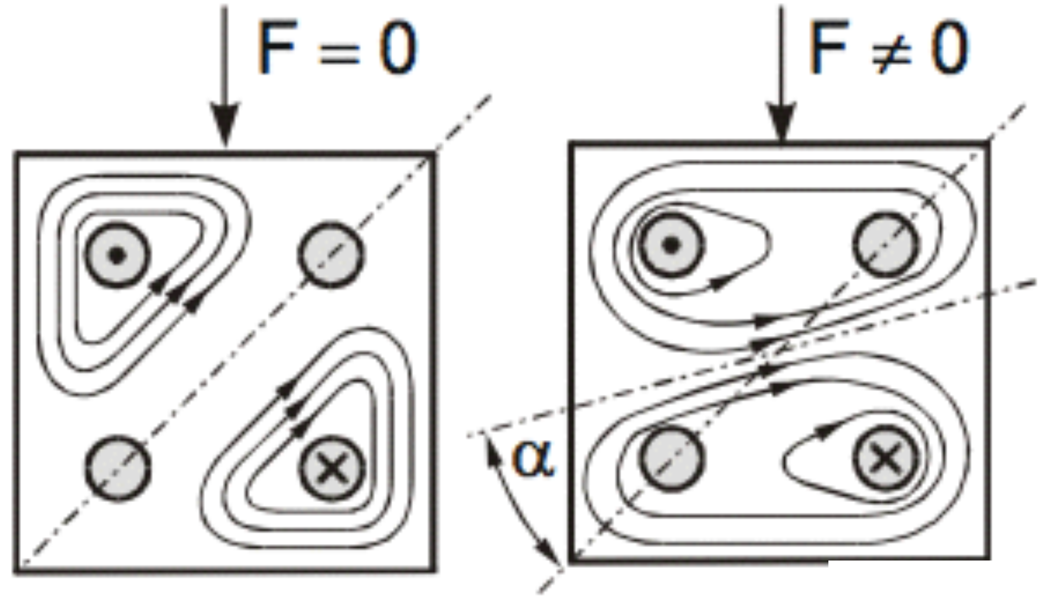
$$F_m \longrightarrow \text{displacement} \xrightarrow{\text{non-linearity}} C_{diff}$$

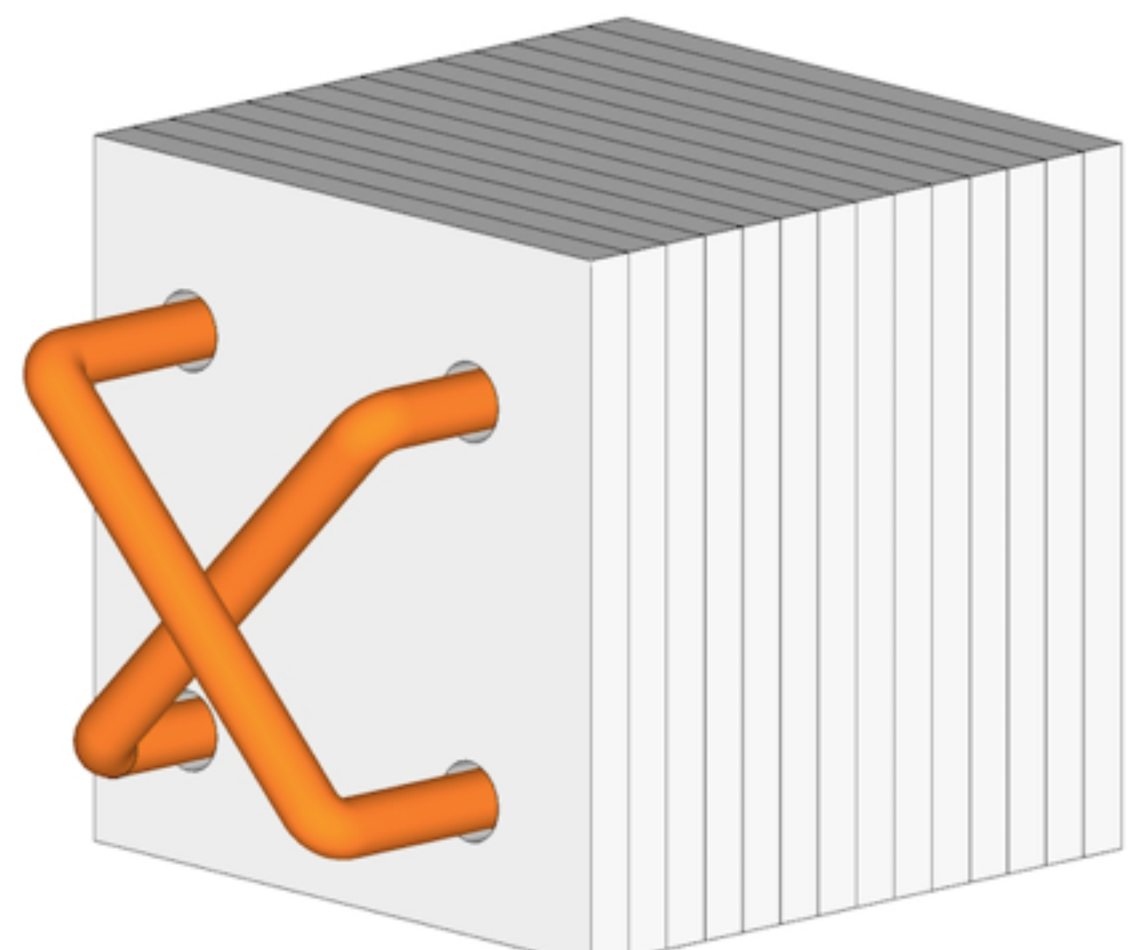
With feedback:

$$F_m \xrightarrow{=} \underset{\text{balancing}}{F} \xleftarrow[]{\substack{\text{linearity} \\ F=kI}} I$$

Magnetoanisotropic sensor of force

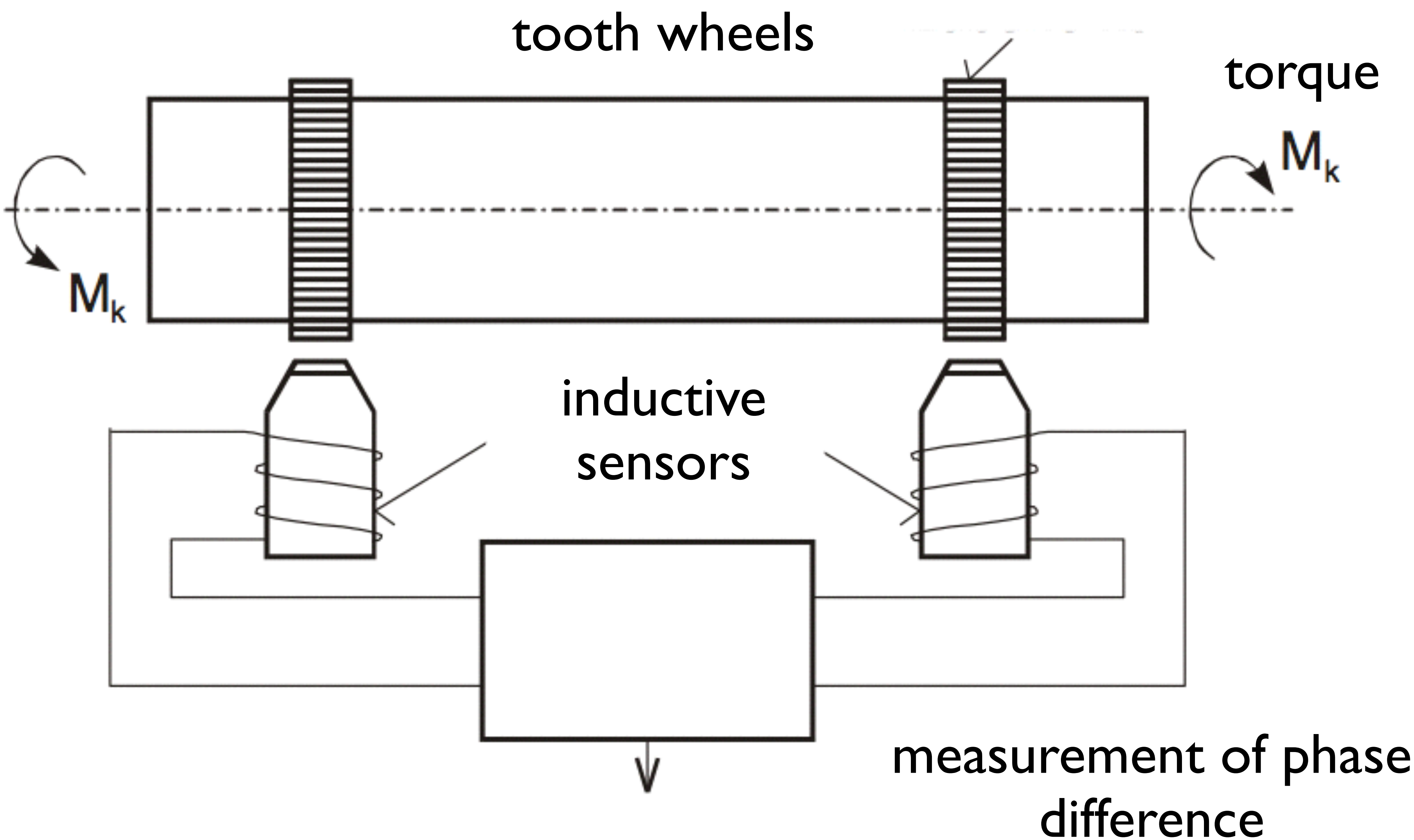






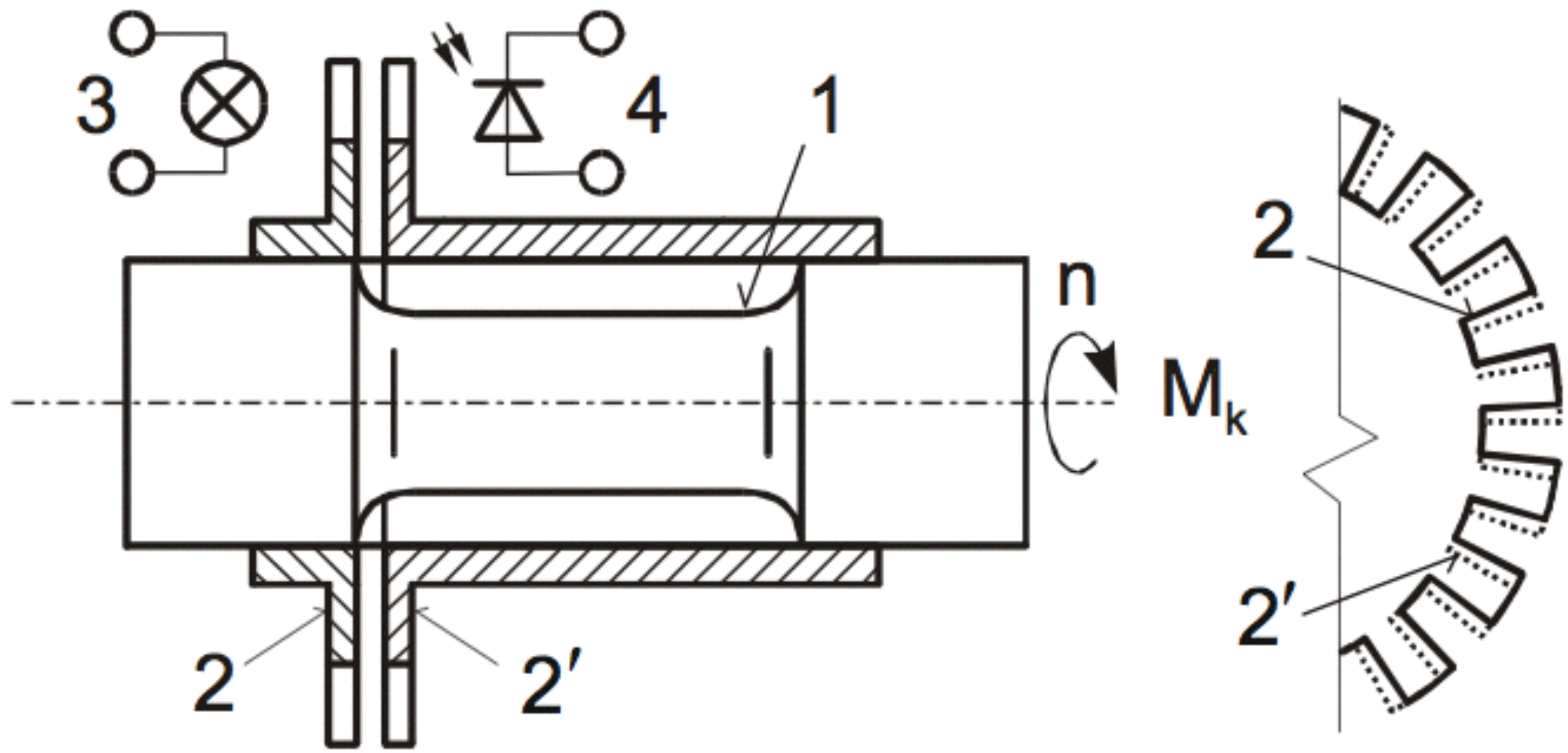
Measurement of torque

sensor of torque based on angular displacement:

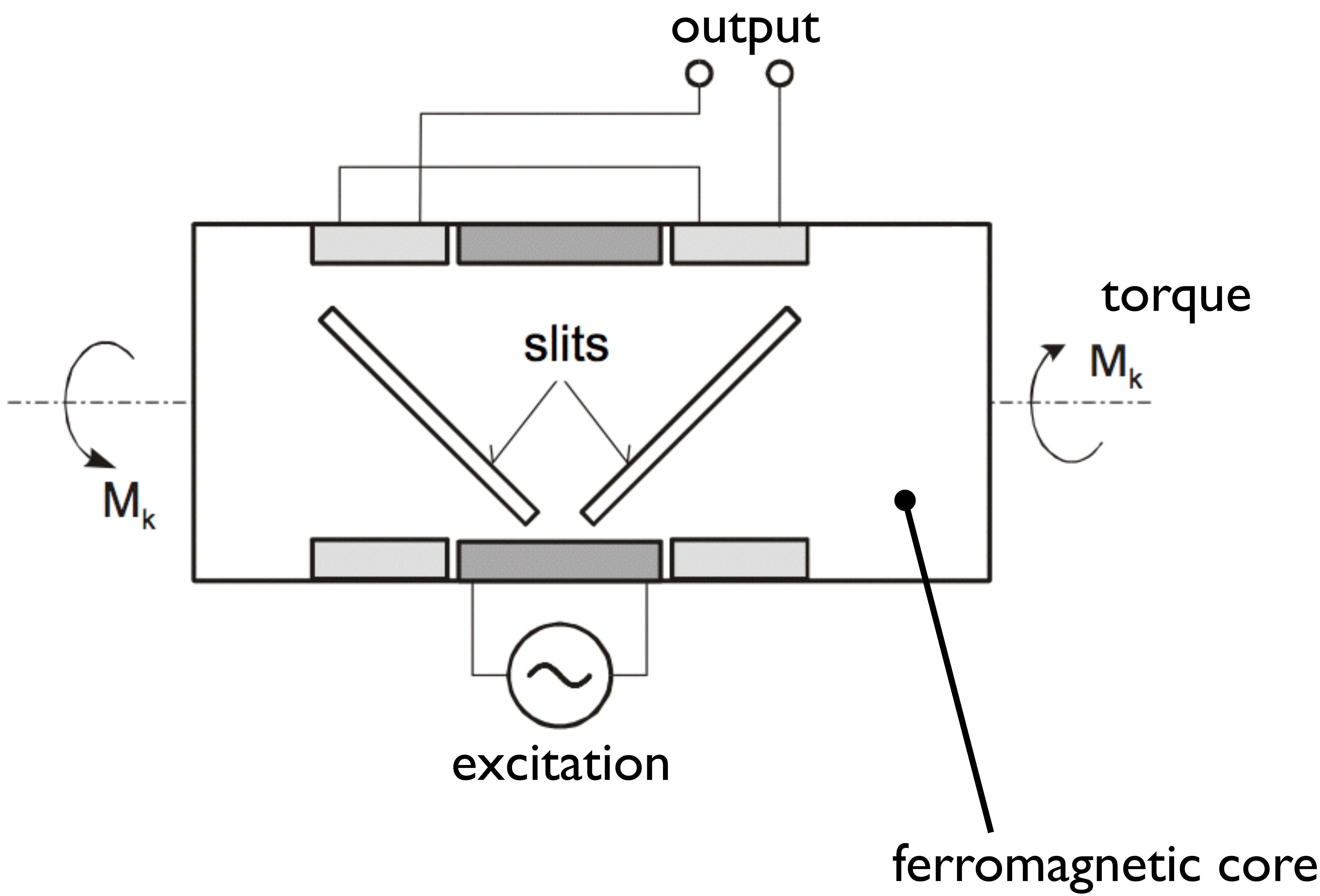


Measurement of torque

optolectronic sensor based on overlapping of shades 2-2’



Magnetic (variable reluctance) sensors of torque



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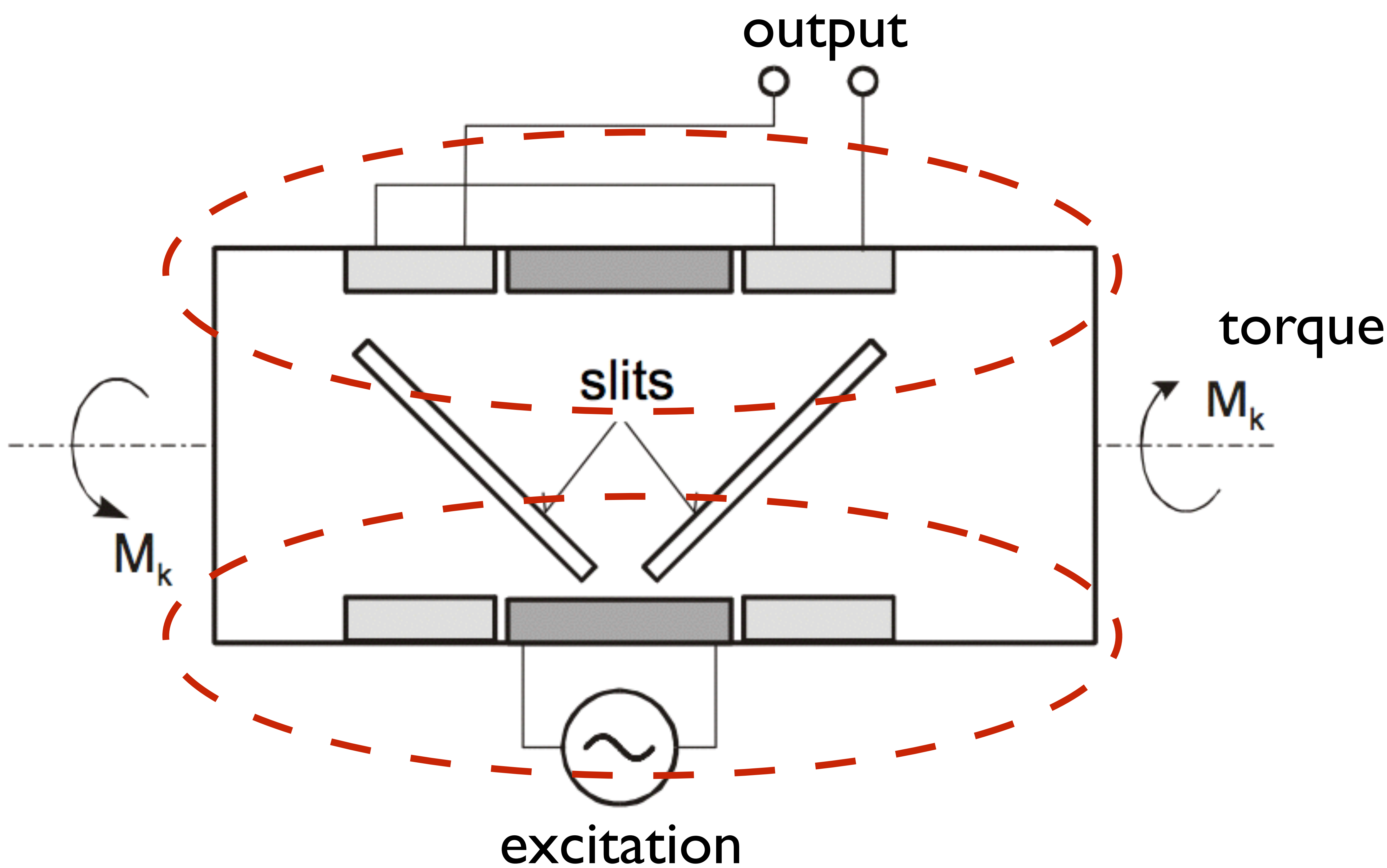

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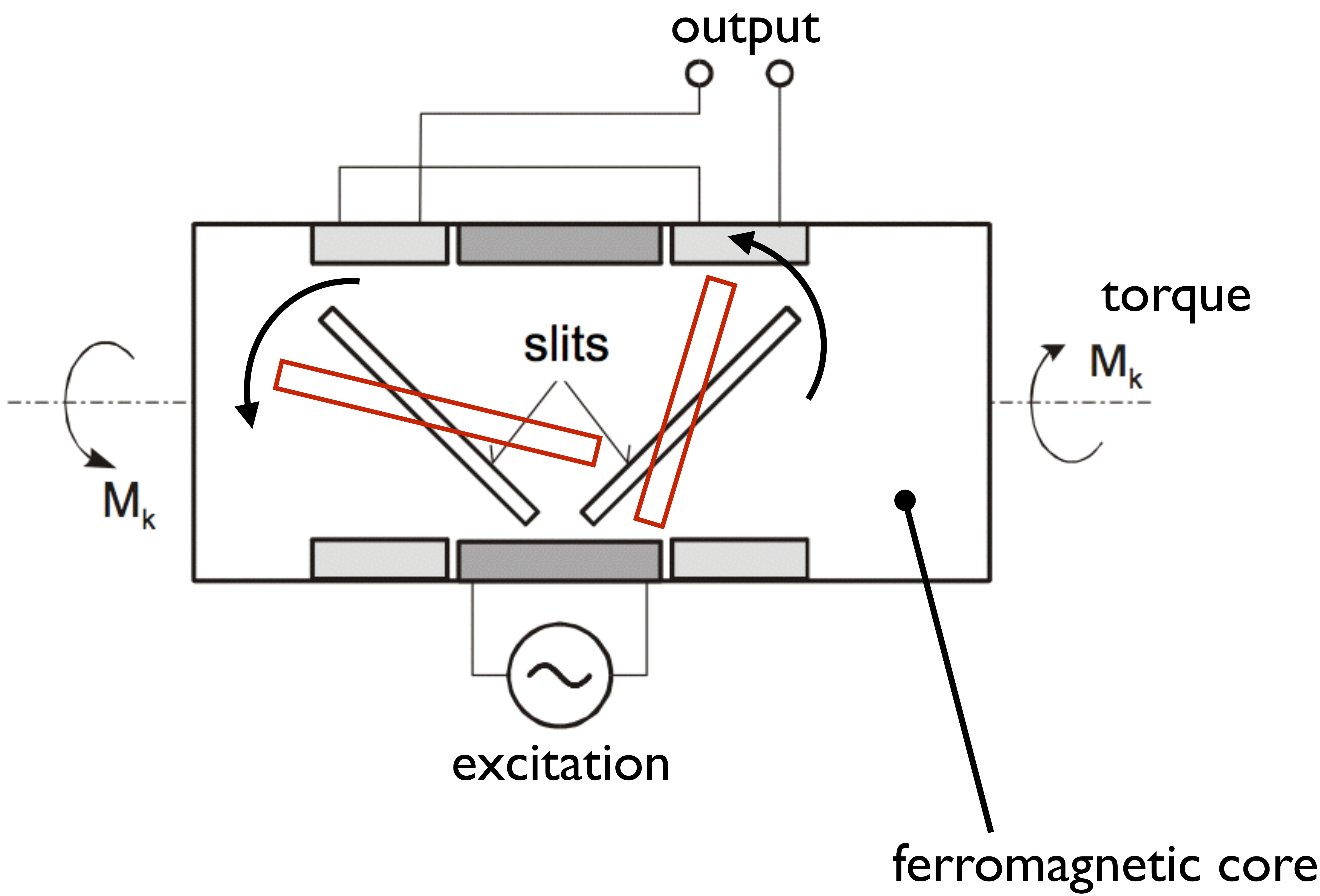
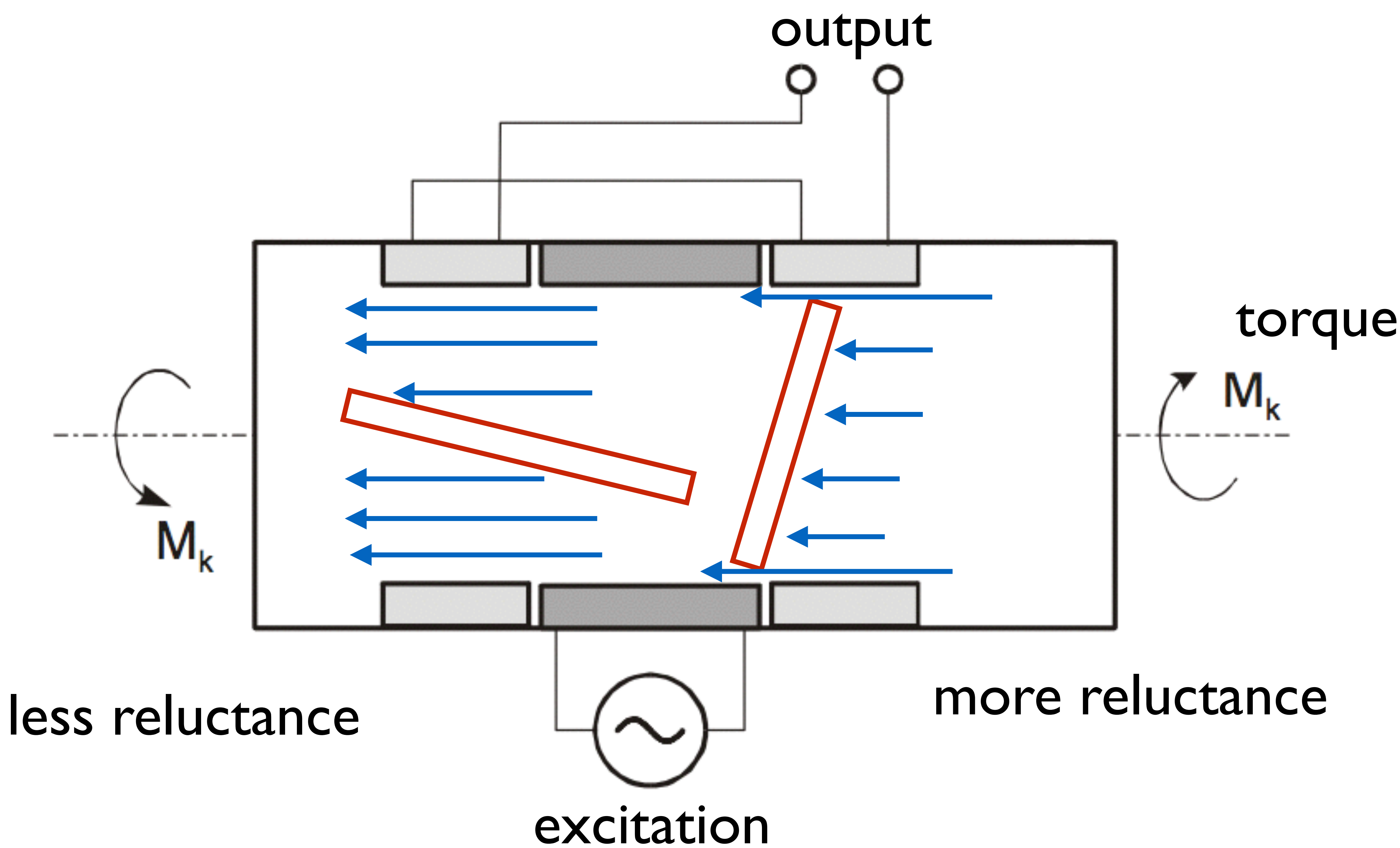
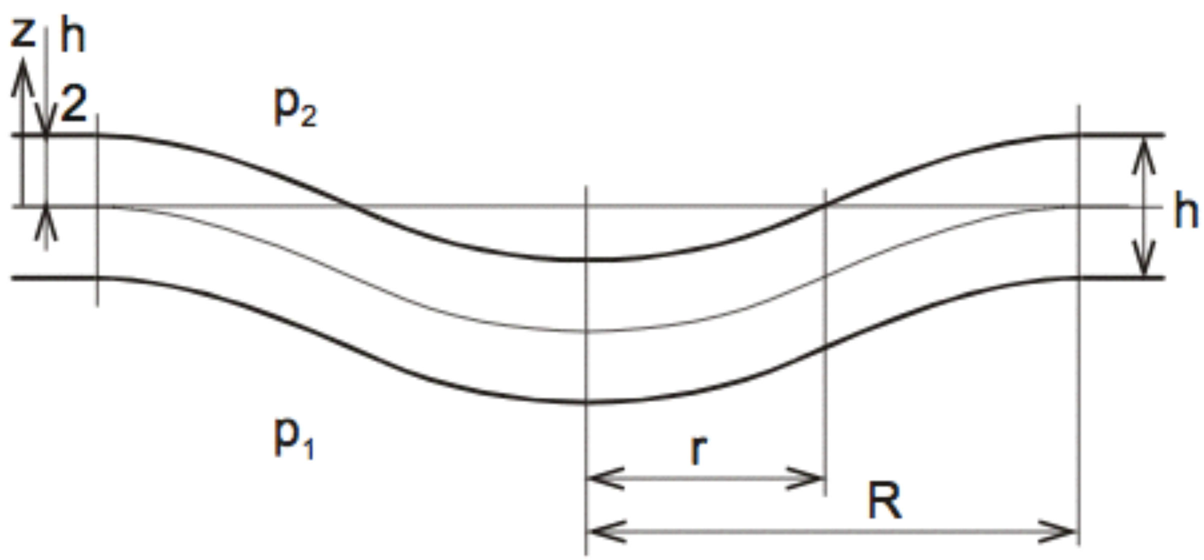


Magnetic (variable reluctance) sensors of torque

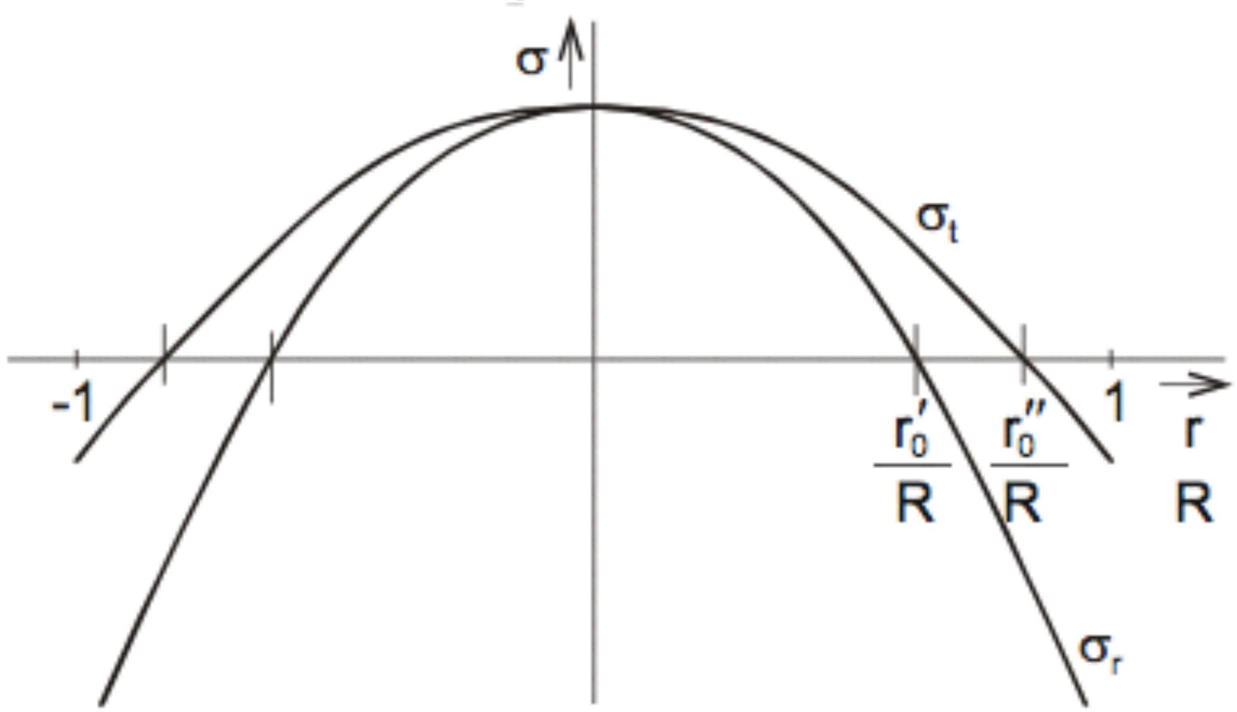


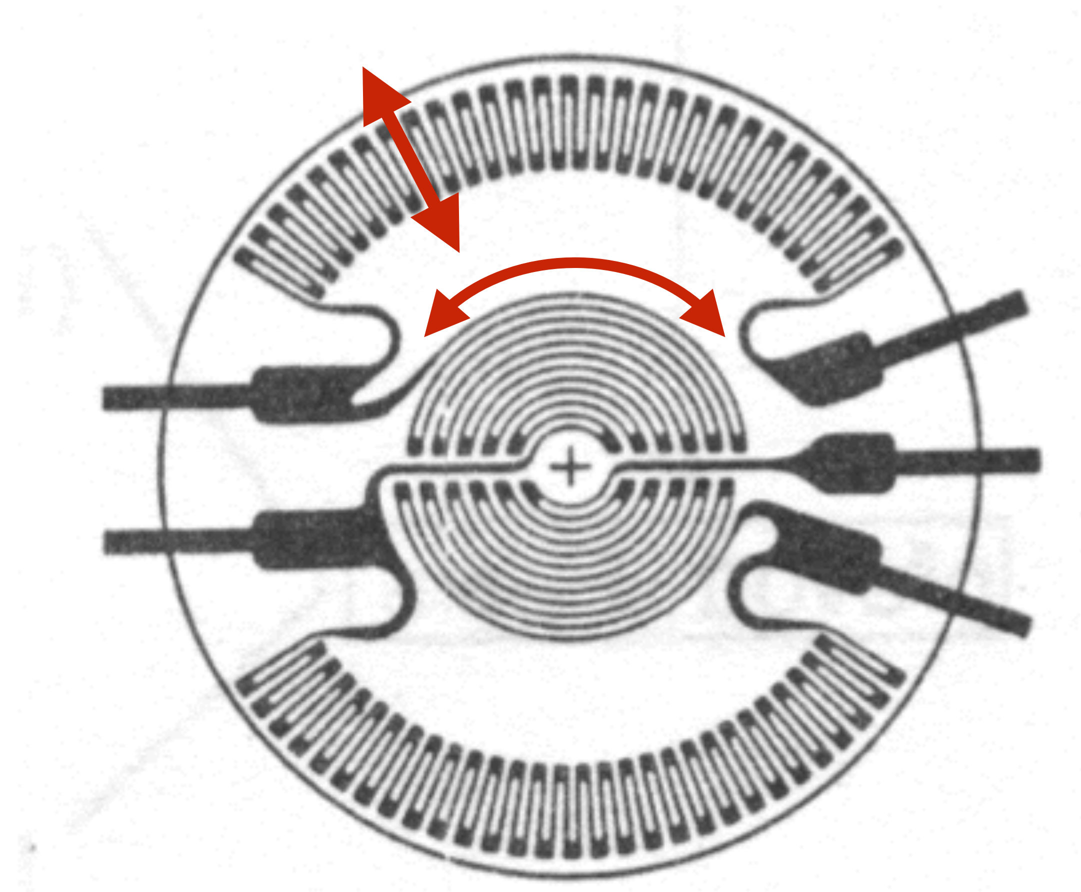
Measurement of pressure

Membrane with rossete strain gauges

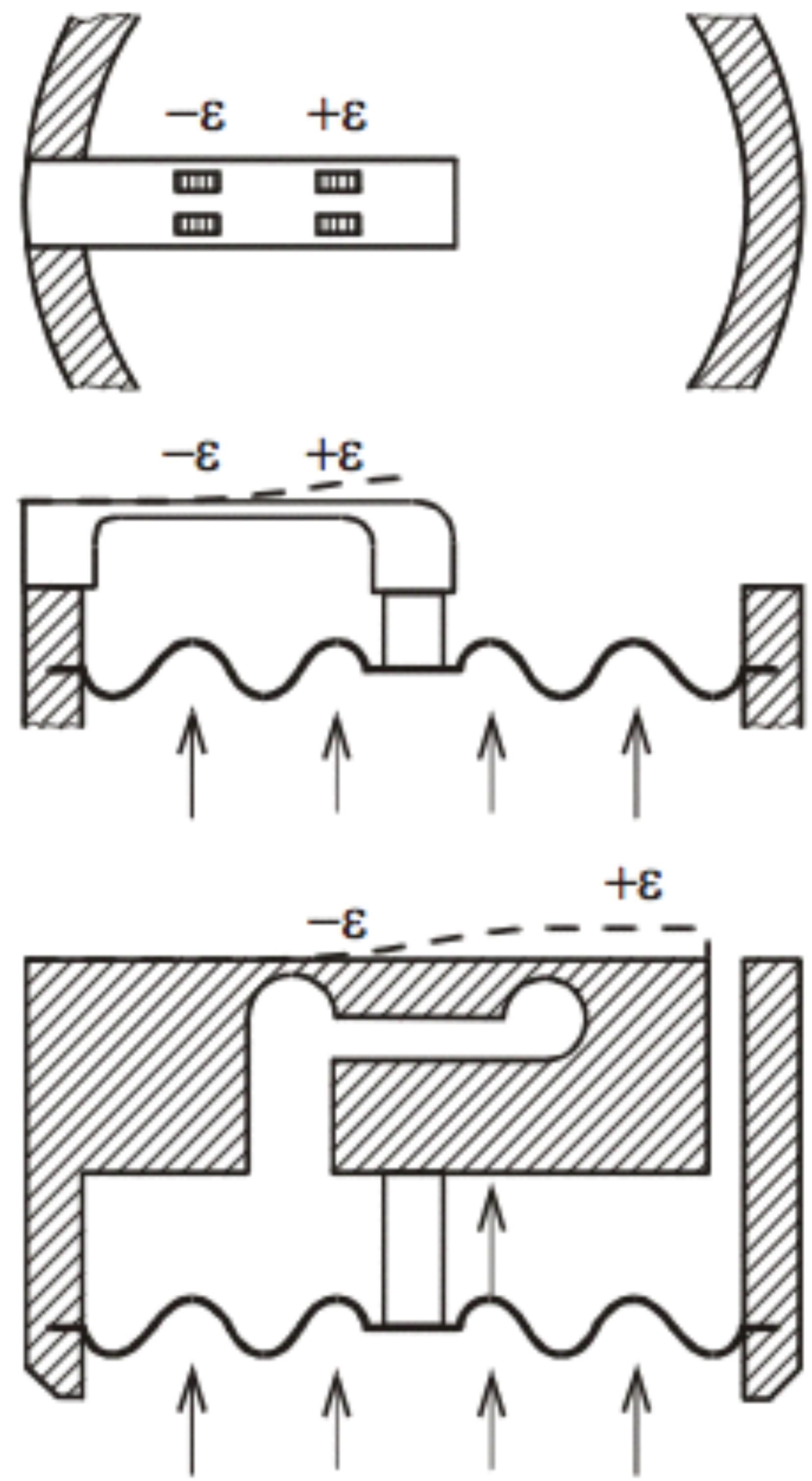


Distribution of radial and tangential strain under pressure-deformation

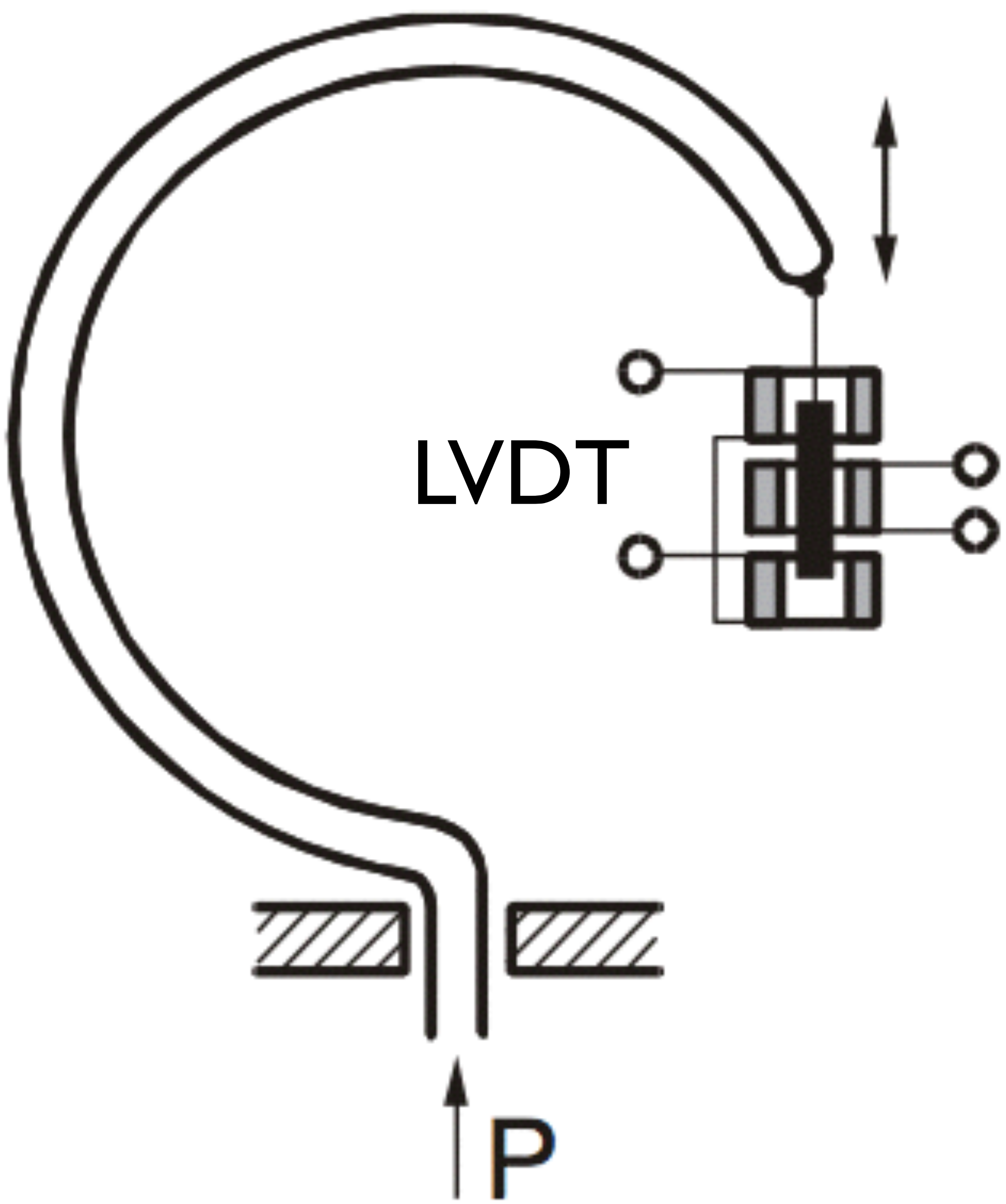


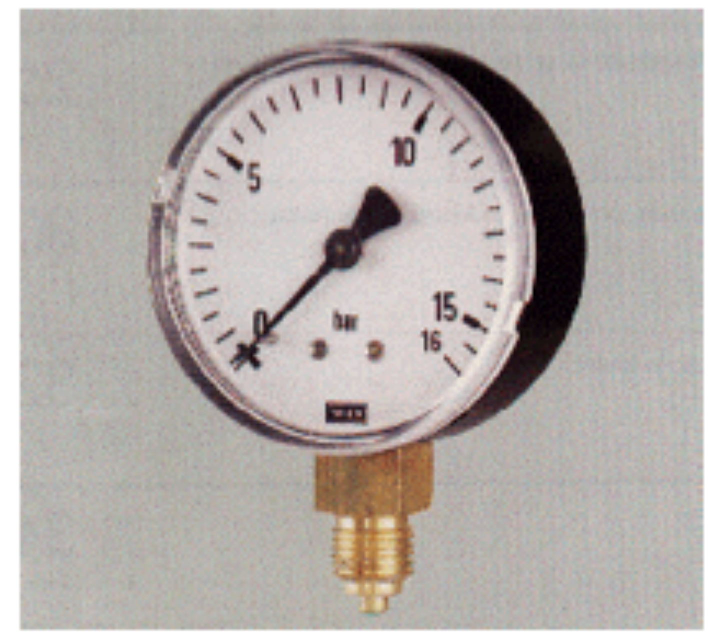


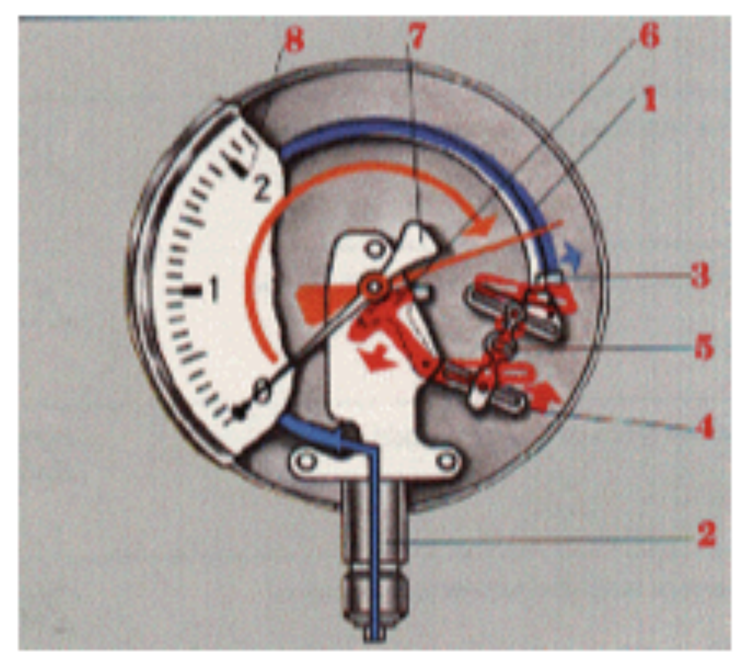
Deformation elements with cantilever and bellows



Bourdon tube







Differential capacitor with separating liquid