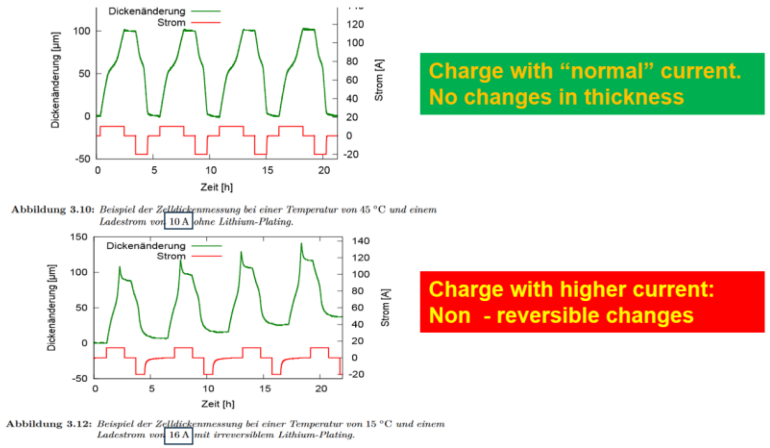
HBK Technology Days – Virtual Seminar Series

Tuesday, November 8, 2022

Introduction / Force Measurements at batteries – why?



Measuring capacity fading due to charge/ discharge cycles using force transducers

Presented by Mr. Thomas Kleckers,
Product and Application Manager, HBK

Measuring capacity fading due to charge/ discharge cycles using force transducers

Abstract

Electric cars play an important role in decarbonization strategy of many countries. The technology has been improved in the last years, but besides the range of the car, the time required to charge an electric vehicle is also important as shorter charge stops would make them much more attractive to a wider audience. A shorter time with the same capacity entails operating with higher currents. Current, temperature and number of cycles are the most important factors that influence capacity fading, meaning the decrease of the capacity of a lithium-ion battery. Traditionally, battery tests are performed by measuring voltage and current. A more innovative method is to measure the force of a lithium-ion pack while charging or discharging processes in a fixed position. Using a suitable load cell, the test can be performed at various temperatures, and long-term tests are possible as well. The requirements the force transducer must meet are given by the nature of the testing procedure: The long duration requires a low drift, and possible harsh environments make a hermetically sealed load cell necessary. Recent load cells are extremely accurate sensors, but as with every measurement, a certain measurement uncertainty occurs with a battery test as well. This lecture will discuss the most important technical aspects for choosing a suitable load cell for a “punch cell test”, and you will also learn how to do an easy calculation to get a good estimation of the measurement uncertainty.

About the presenter, Mr. Thomas Kleckers, Product and Application Manager, HBK

Thomas Kleckers studied at the university for applied science in Duisburg and holds a diploma in physical engineering. He started working for HBM in 1992 as a development engineer for strain gauges with a focus on experimental stress analysis. Since 2009 Thomas has been the responsible Product Manager for force sensors at HBK. With more than 25 years of experience in the field of measurement of mechanical quantities, Thomas brings much experience with the application of strain gauges and strain gauge based sensors. He has published several articles about transfer standards for force in the IMEKO organization and worked actively on the standard for characterization of strain gauges.

Mechanical Battery Testing

Thomas Kleckers

Thomas Kleckers

- **Product manager for force sensors at HBK**
- Engineer for physical technology
- 16 years experience in sensor development
- > 10 Years experience in force measurement technology
- **E-Mail:** Thomas.Kleckers@hbkworld.com
- Hobbies: Hiking, race bikes, motor cycles and grandson Felix

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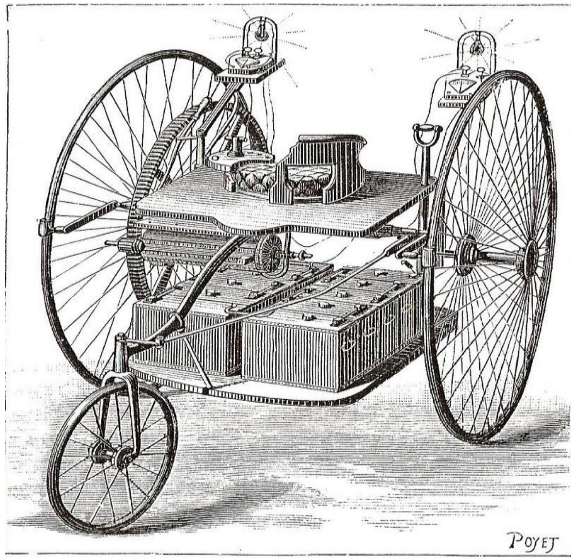
Agenda

- Introduction / Force Measurements at batteries – why?
- The measurement task
- Which load cell? Criteria's to choose the right sensor for a measurement chain
- Measurement uncertainty in battery testing. What is the accuracy I can achieve?

1882 Ayrton & Perry Electric Tricycle

- Speed control: Connect and disconnect of battery cells (10 in total)
- Battery capacity:1.5 kWh
- Engine: 0.5 HP
- Range: 40 km
- Max. Speed: 14 km/h



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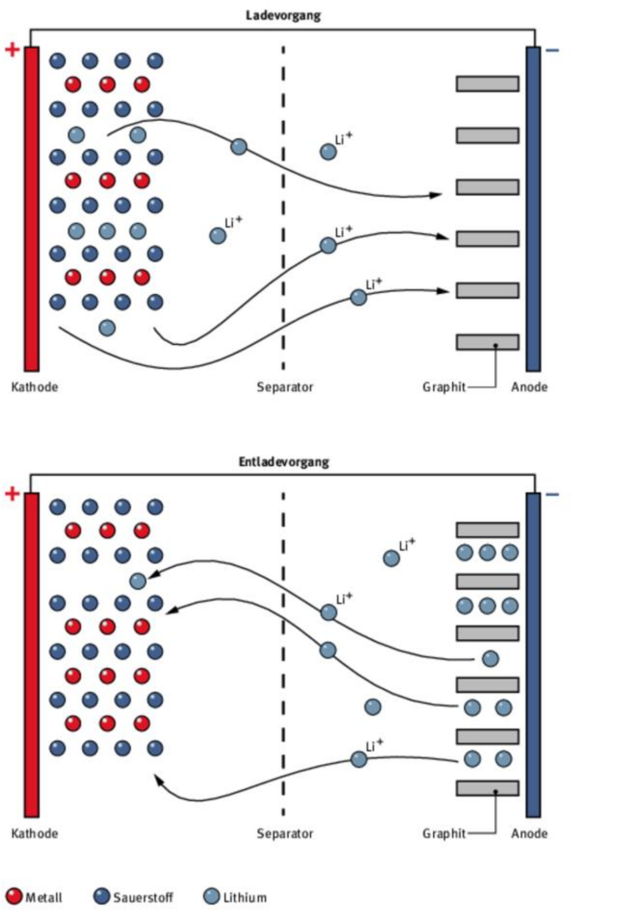
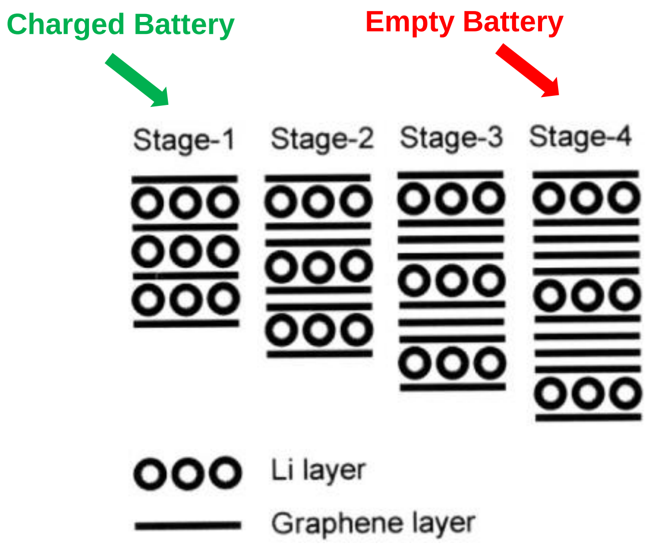


Lithium Ions in Graphite (C_6) =>
Change in volume
If they cannot expand pressure
will occur.



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Introduction / Force Measurements at batteries – why?

Results from a students work at the university Oldenburg. Author: Florian Grimsmann(2014)

https://www.microcharge.de/forum/downloads/Auswirkungen_des_Ladeprofils_auf_das_Lithium-Plating-Verhalten_von_Lithium-Ionen-Zellen.pdf

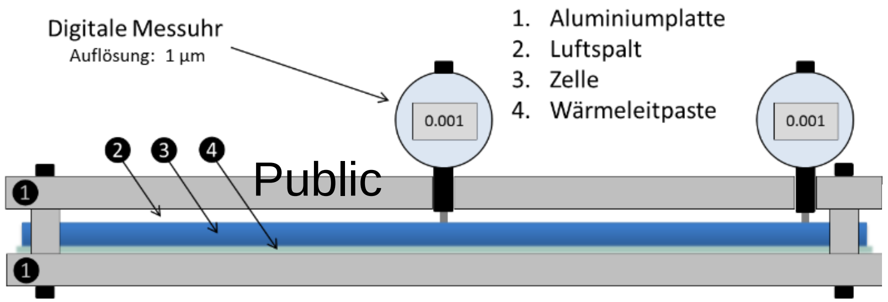

Abbildung 3.1: *Skizze des Aufbaus zur Messung der Zelldicke mit einer Auflösung von 1 µ*

Mr. Grimsmann showed with quite easy tools the mechanical effects on Lithium – Ion cells while charging and discharging

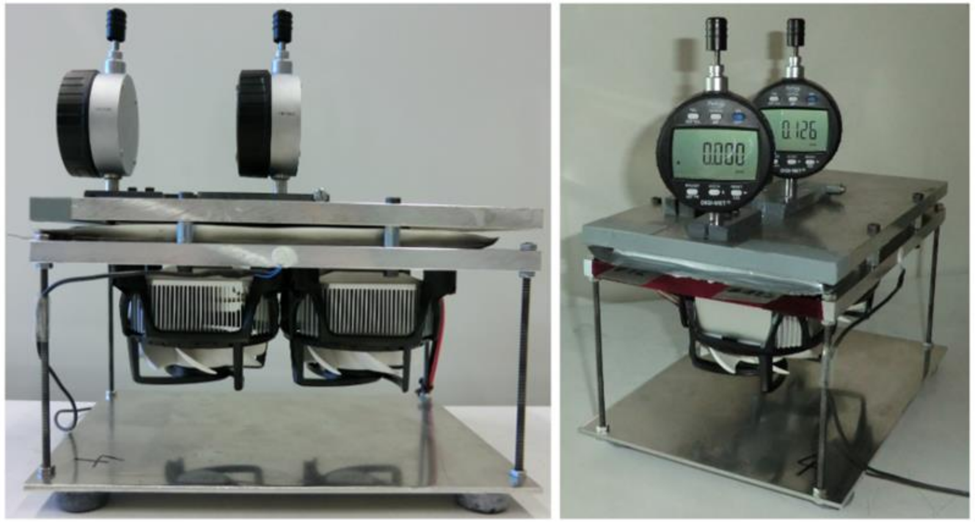

Abbildung 3.3: *Seiten- und Diagonalansicht des verwendeten Messaufbaus.*

Introduction / Force Measurements at batteries – why?

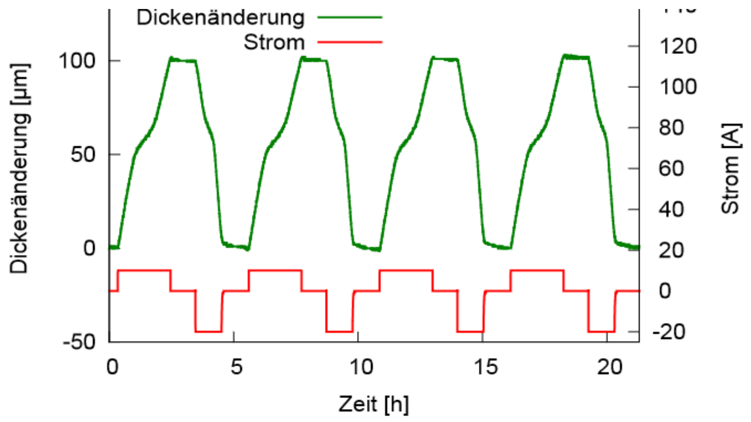

Abbildung 3.10: *Beispiel der Zelldickenmessung bei einer Temperatur von 45 °C und einem Ladestrom von* 10 A *ohne Lithium-Plating.*

Charge with “normal” current.
No changes in thickness

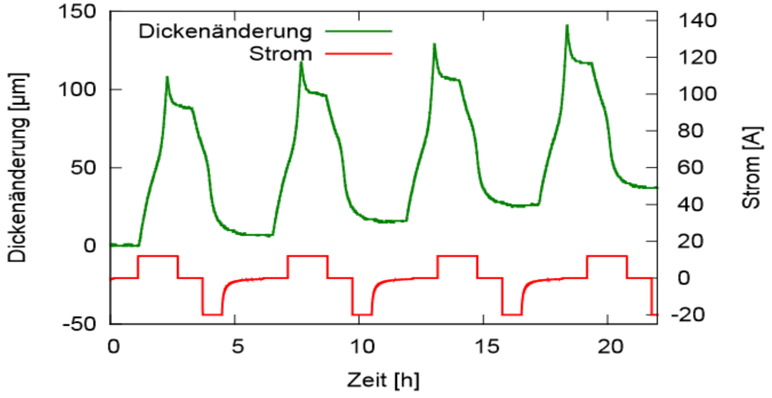

Abbildung 3.12: *Beispiel der Zelldickenmessung bei einer Temperatur von 15 °C und einem Ladestrom von* 16 A *mit irreversiblem Lithium-Plating.*

Charge with higher current:
Non - reversible changes

Introduction / Force Measurements at batteries – why?

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journal homepage: www.elsevier.com/locate/jpowsour

ELSEVIER

Stress evolution and capacity fade in constrained lithium-ion pouch cells

CrossMark

John Cannarella, Craig B. Arnold[*,1]

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https://spikelab.mycpanel.princeton.edu/papers/103.pdf

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Journal of The Electrochemical Society

The Electrochemical Society
Advancing solid state & electrochemical science & technology

OPEN ACCESS

Battery Capacity Fading Estimation Using a Force-Based Incremental Capacity Analysis

To cite this article: Nassim A. Samad *et al* 2016 *J. Electrochem. Soc.* **163** A1584

https://iopscience.iop.org/article/10.1149/2.0511608jes/pdf

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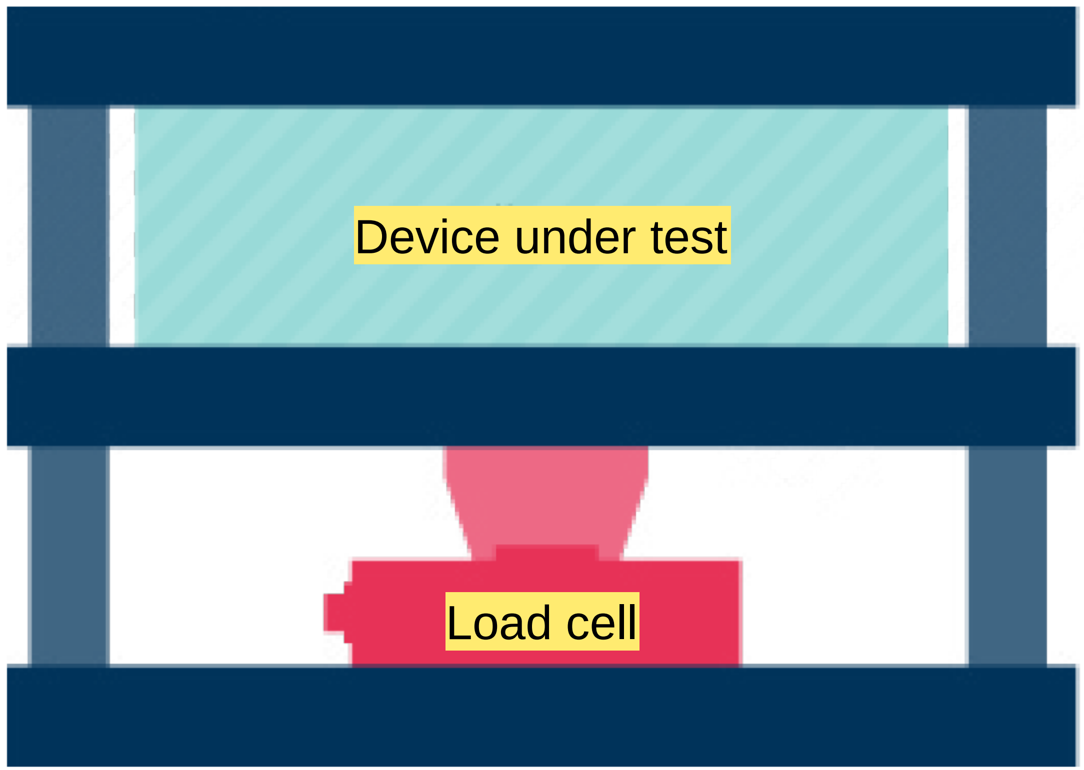
Measurement task



Too high stack pressure:

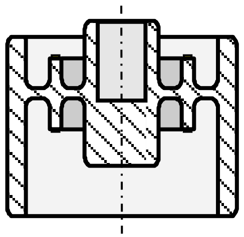
- More capacity fade
- Plastic deformation may occur
- Risk of delamination

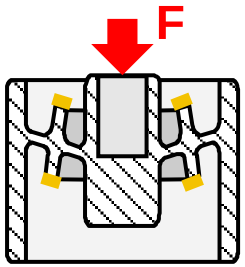
Too low stack pressure

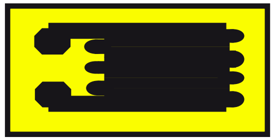
- Too much movement

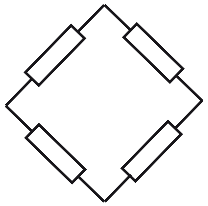
Which load cell?

Force sensors based on strain gauges- how does it work?









Spring Body
Public

If a force is introduced a strain occurs on the surface of the material.
Strain gauges change the strain into a change of resistance.

The wheatstone bridge converts this change in resistance into a measurable strain.

In most cases the strain is1000 µm/m:

$$\frac{U}{U_0} = \frac{k}{4} \cdot (\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)$$

$$\frac{U}{U_0} = \frac{2}{4} \cdot (1000 \cdot 10^{-6} - (-1000 \cdot 10^{-6}) + 1000 \cdot 10^{-6} - (-1000 \cdot 10^{-6}))$$

$$\frac{U}{U_0} = 2mV/V$$

Requirements

Long time stability: Some tests are performed over many charging / discharging cycles

Stiffness: The stiffness of the load cell has an huge impact on the test result

Temperature influence: If the tests are performed under changing and/ or higher temperature, this is important

Temperature gradients: Heat of the battery may leak into the load cell => Temperature gradients

Unsensitive against moisture: In case of temperature changes / hard test conditions this is important

Which load cell?

Shear type load cells turned out to be very suitable for this measurement

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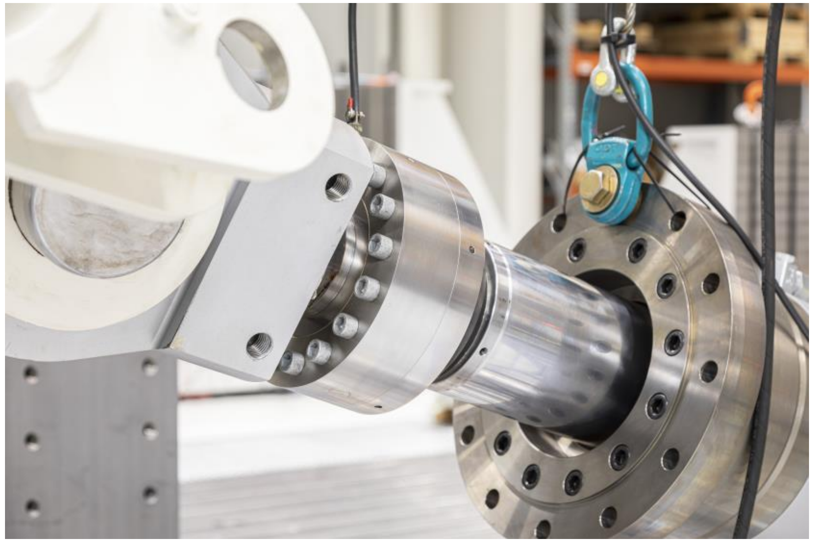
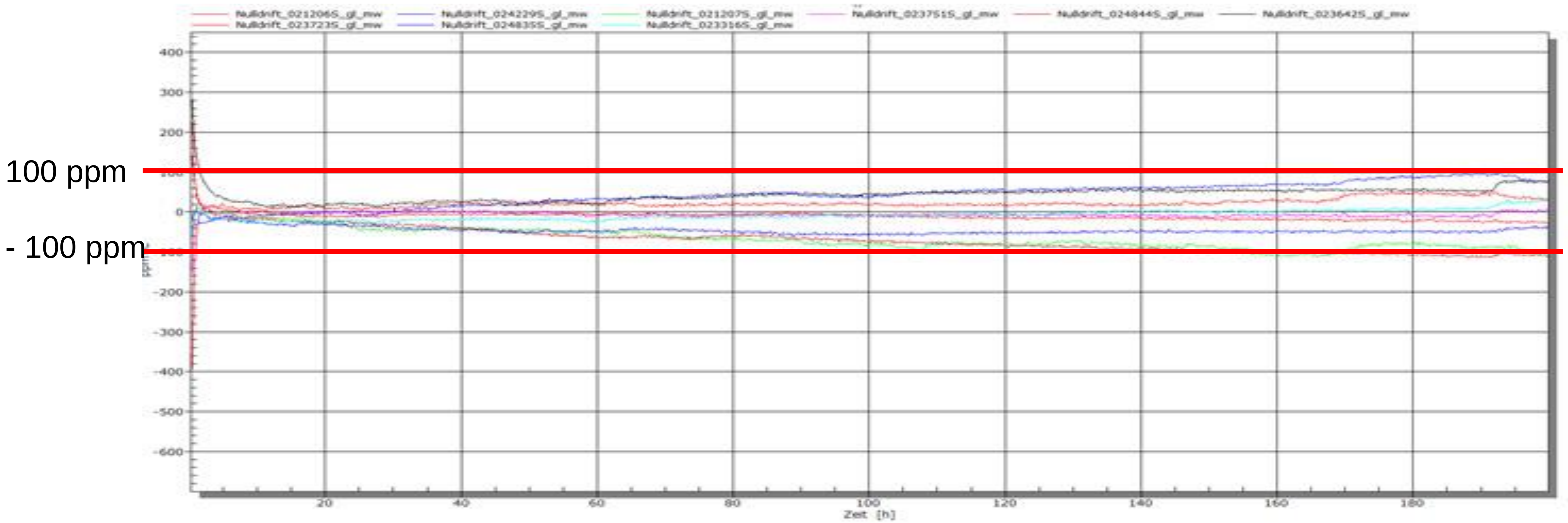
Which load cell?

General characteristic of shear type force sensors:

Low height
High output signal > 4 mV/V (Standard: 2 mV/V)
HBK - Accuracy class 0.02 … 0.05 (depending on capacity)
Suitable for dynamic and static measurements
Available as load cell for compressive forces or as universal load cell for tensile and compressive forces
Capacities from 1.25 kN to 5MN



Drift of C10 load cells (2000 h = 84 days) at 40 °C



The load cells are suitable for long term measurements.
Conservative estimation: 0.1 % of FS drift in one year as typical value

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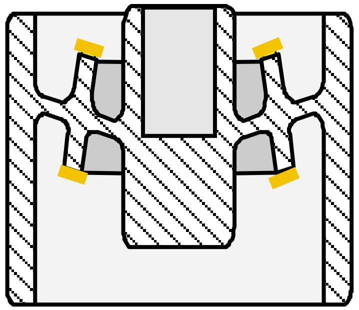
Stiffness



Every load cell shows a certain deflection when loaded
(piezoelectric sensors as well)

C10 deflection under full load

2.5 kN – 10 kN	0.04 mm
25 kN – 125 kN	0.06 mm
250 kN	0.08 mm
500 kN	0.10 mm
1 MN	0.12 mm

The stiffness of radial symmetric load cells is high. Mostly higher than the stiffness of the load frame or the object under test. The deflection has no huge influence on the result.

$$D = \frac{F}{s}$$

Stiffness of a C10/125 kN:
120 000 N/ 0.06 mm = **200 000 N/mm**

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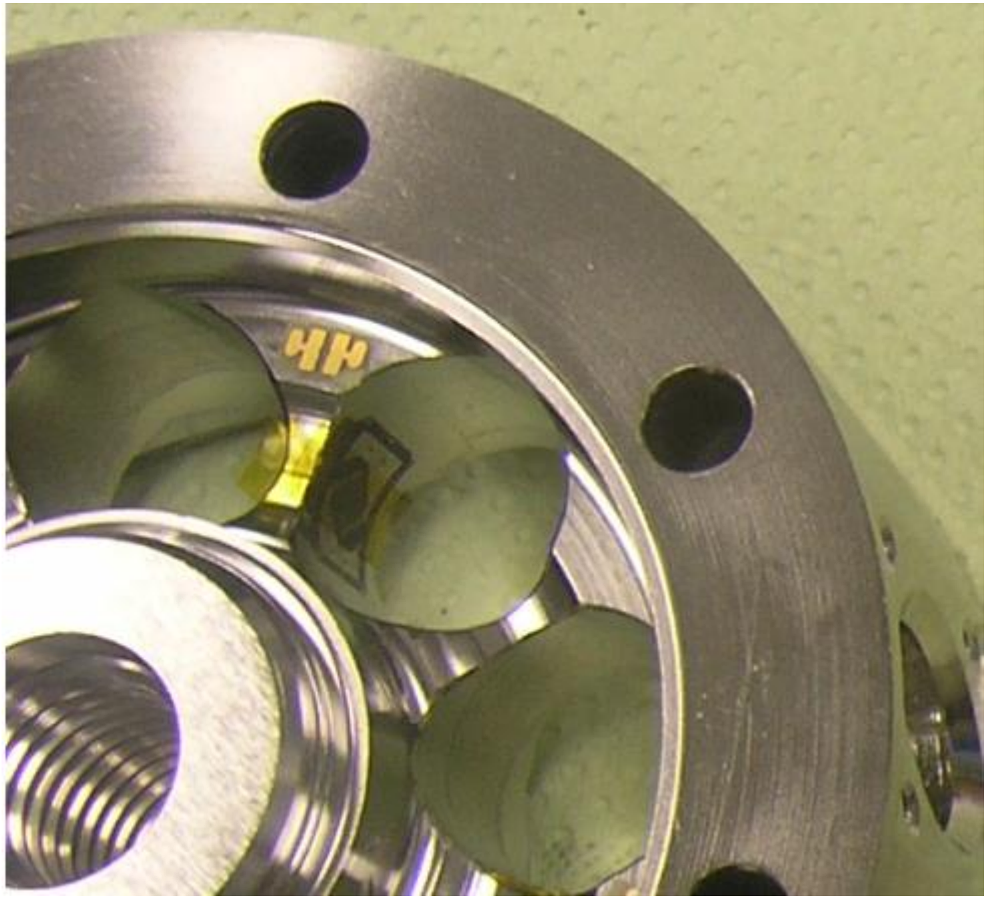
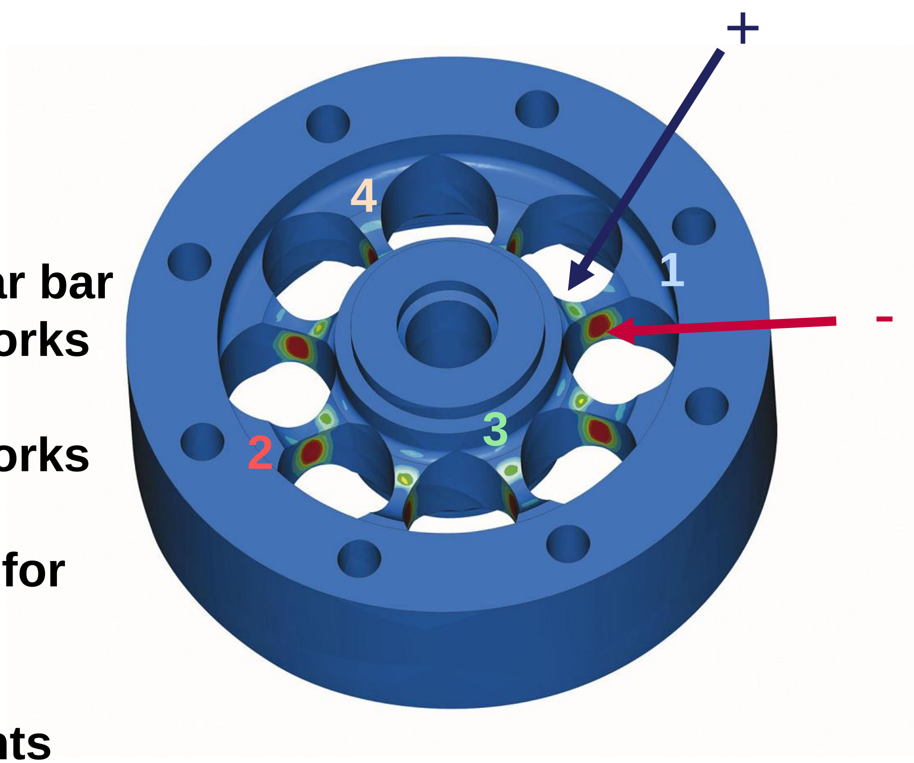
Temperature, Temperature Gradients



- Always two strain gauges on one shear bar
- One strain gauge works negative
- One strain gauge works positive
- Best compensation for every shear bar
- => Not sensitive to temperature gradients



TCZero: 75 ppm/10K
TCSpan: 150 ppm/ 10K

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Humidity / relaibility

Radial symmetric shear beams can be hermetically sealed
This is the case with C10 sensors
⇒ Long term stability
⇒ Tests under humidity possible
⇒ No problem if the dew point is passed while testing

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Which load cell?

Long time stability: Proven in tests. Typical zero point dirft: 0.1% of FS

Stiffness: 200 000 N/mm for C10/125kN. Deflection of the load cell is low with respect to other components

Temperature: Most important: TCZero. Adjusted to 75 ppm/10k (maximum, not typical)

Temperature gradients: Compensated with two strain gauges (one positive, one negative) close to each other

Unsensitive against moisture: Hermetically sealed housing, degree of protection IP68

Uncertainty: What do we have to take into account?

Linearity

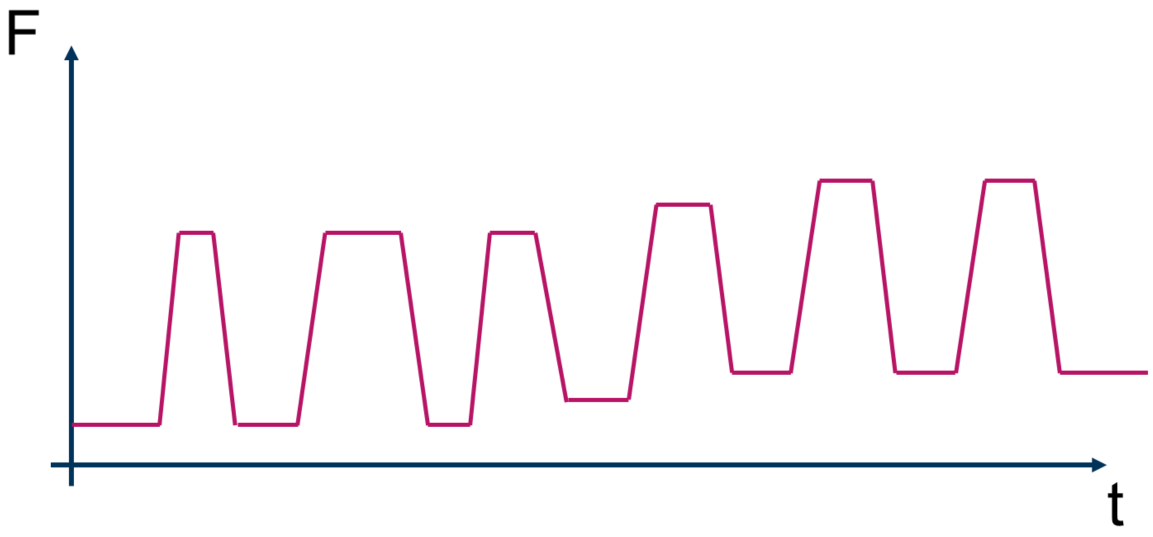
C10/125KN: 0.035 % rel. to FS

Hysteresis

C10/125KN: 0.04 % rel. to FS

TCZero

C10/125KN: 0.0075 % rel. to FS /10K



Uncertainty: What do we have to take into account?

TCSpan

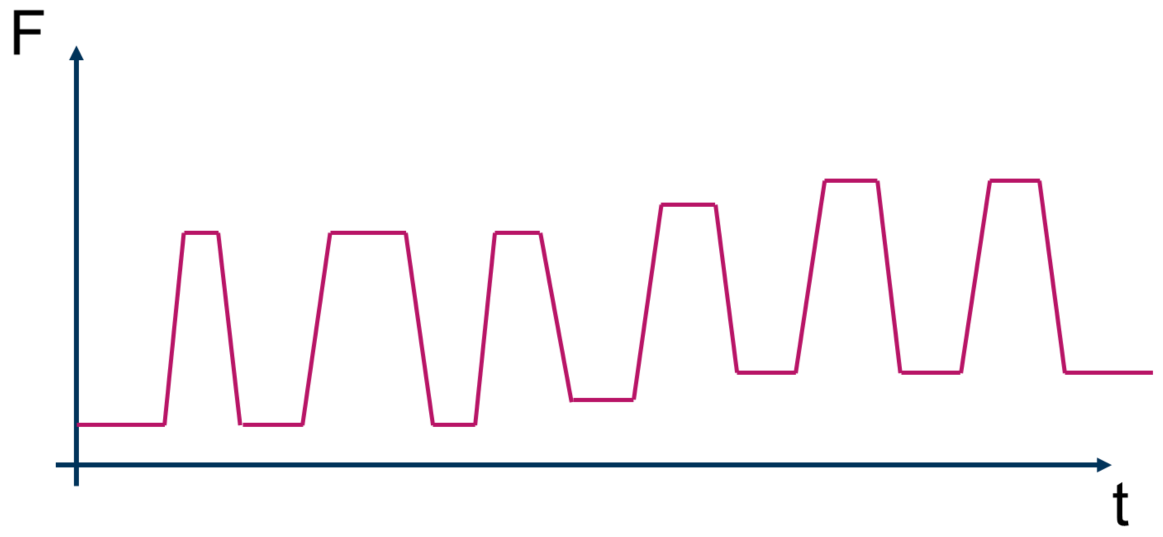
C10/125KN: 0.015 % rel. to MV

Drift

C10/125KN: 0.1 % rel to FS / a

Creep error

C10/125KN: 0.02 % rel to MV



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Measurement uncertainty

Assumptions:

- C10/125KN load cell.
- Measurement value: 50 kN
- Temperature: constant 40 ° C
- Measurement taken after 100 days (without zero setting)

Linearity

0.035 % rel. to FS
=> 0.035 % of 125 000 N = **43,75 N**

Hysteresis

0.04 % rel. to FS
=> 0.04 % of 125 000 N = **50 N**

TCZero

0.0075 % rel. to FS /10K
=> (0,0075% of 125 000)/5 = **1,875 N**

TCSpan

0.015 % rel. to MV
=> (0,015% of 50 000N)*(17/10) = **12,75N**

Drift

0,1 % rel to FS / 100 days
=> (0,1 % of 125 000)= **125 N**

Creep error

0.02 % rel to MV
0,02 % of 50 000 N = **10 N**

$$U_{\text{ges}} \approx \sqrt{(43.75\ \text{N})^2 + (50\text{N})^2 + (1.875\text{N})^2 + (12.75\text{N})^2 + (125\text{N})^2 + (10N)2}$$

Measurement uncertainty

$$U_{\text{ges}} \approx \sqrt{(43.75\text{ N})^2 + (50\text{N})^2 + (1.875\text{N})^2 + (12.75\text{N})^2 + (125\text{N})^2 + (10N)^2} \approx 142{,}49\ N$$

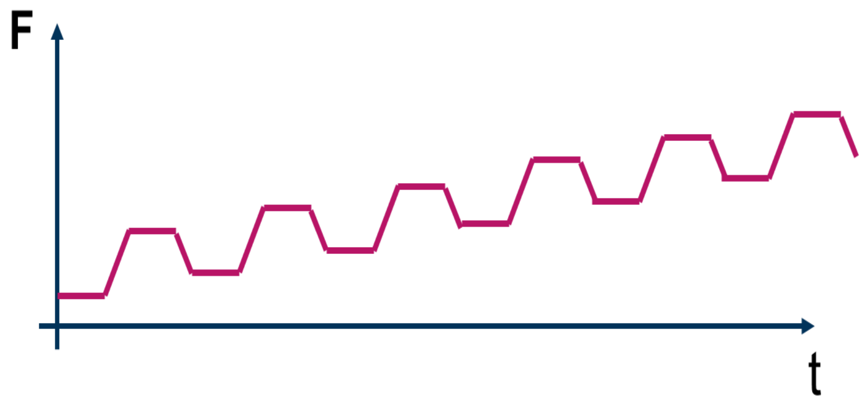
= 0.28 % of 50 000 N (our measurement value)

Remarks:

- Simplified method, conservative approach
- Meaning: If you take 100 measurements, 64 % will be in the error range (K=1)
- 0.96 % for K = 2

Measurement uncertainty

In case of growing force levels:



Measurement temperature 60 °C
Measurement time: 500 days
All other assumptions like before

Time(d)	Force (KN)	Drift (%)	Error (%)	Error (N)
0	0,1	0	57,8	578
50	10	0,05	1,05	105
100	20	0,1	1,08	217
150	30	0,15	1,04	312
200	40	0,2	1,03	413
250	50	0,25	1,03	514
300	60	0,3	1,03	616
350	70	0,35	1,03	718
400	80	0,4	1,03	820
450	90	0,45	1,02	922
500	100	0,5	1,02	1024

Questions?

Thank you!

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Abbildung 3.10: *Beispiel der Zelldickenmessung bei einer Temperatur von 45 °C und einem Ladestrom von 10 A ohne Lithium-Plating.*

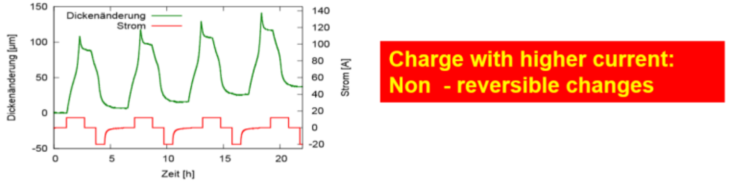

Abbildung 3.12: *Beispiel der Zelldickenmessung bei einer Temperatur von 15 °C und einem Ladestrom von 16 A mit irreversiblem Lithium-Plating.*

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