How to estimate uncertainties of force measurements

The presentation starts at 4 pm CET / 10 am Eastern

Thomas Kleckers – Product Manager

Organizational Information

- All participants' **microphones** are **muted** during the webinar.
- Please do not forget to **activate** your PC **speakers** to enable **audio** or connect **headphones** to your PC. You may have to take the step of joining the audio conference to hear sound.
- Please type any questions you have into the WebEx Q&A dialog
- You can open the Q&A window by selecting the "Q&A" icon in the WebEx toolbar at the top of your screen:

- Today's presentation will be E-mailed to all attendees. The webinar will also be posted on our website: http://www.hbm.com/en/3157/webinars/
- If you have additional technical questions, feel free to contact our technical support team at support@usa.hbm.com

HBK HOTTINGER BRÜEL & KJÆR

Today´s speaker

Thomas Kleckers

- **Product manager for force sensors at HBK**
- Engineer for physical technology
- 16 years experience in sensor development
- > 10 Jears experience in force measurment technology
- **E-Mail:** Thomas.Kleckers@hbkworld.com
- Thomas likes hiking, race bikes and motor cycles

HBK HOTTINGER BRÜEL & KJÆR

Agenda

1. Definitions / general hints
2. Systematic errors
3. Estimation of the measurement uncertainty
4. Example
5. Not precise enough?

Definitions / general hints

The educated does not drive the accuracy
behind the nature of the things

Prof. Werner Richter:

„A measurement result without an uncertainty calculation is so much disputable that it should not be mentioned

Kleckers

It is important to know

- what the value of my measurement uncertainty is
- how can I improve my accuracy?

Definitions / general hints

HBK
HOTTINGER BRÜEL & KJÆR

Definitions / general hints

This measurement device has a resolution of 1 mm

A DMP41 can show 2 Mio digits.
Resolution: 2,5mV/V/1Mio=0,0025 µV/V

Definitions / general hints

Accuracy class ?

Strain gauge full bridge, 5 or 10 mV/V measuring range, bridge excitation AC / carrier frequency		
Accuracy class		0.05
Carrier frequency (sine)	Hz	4800 ±1.5
Bridge excitation voltage (effective)	V	1 and 2.5 (±5 %)
Transducers that can be connected		strain gauge full bridges
Permissible cable length between MX840B and transducer	m	< 100

?

Type			S2M						
Nominal (rated) force	F_{nom}	N	10	20	50	100	200	500	1000
Accuracy									
Accuracy class			0.02						
Relative reproducibility and repeatability errors without rotation	b_{rg}		0.02						
Relative reversibility error	v		0.02						
Non-linearity	d_{lin}	%	0.02						
Relative creep over 30 min	[illegible]		0.02						

Definitions / general hints

Accuracy class ?

Everybody can do whatever he wants!

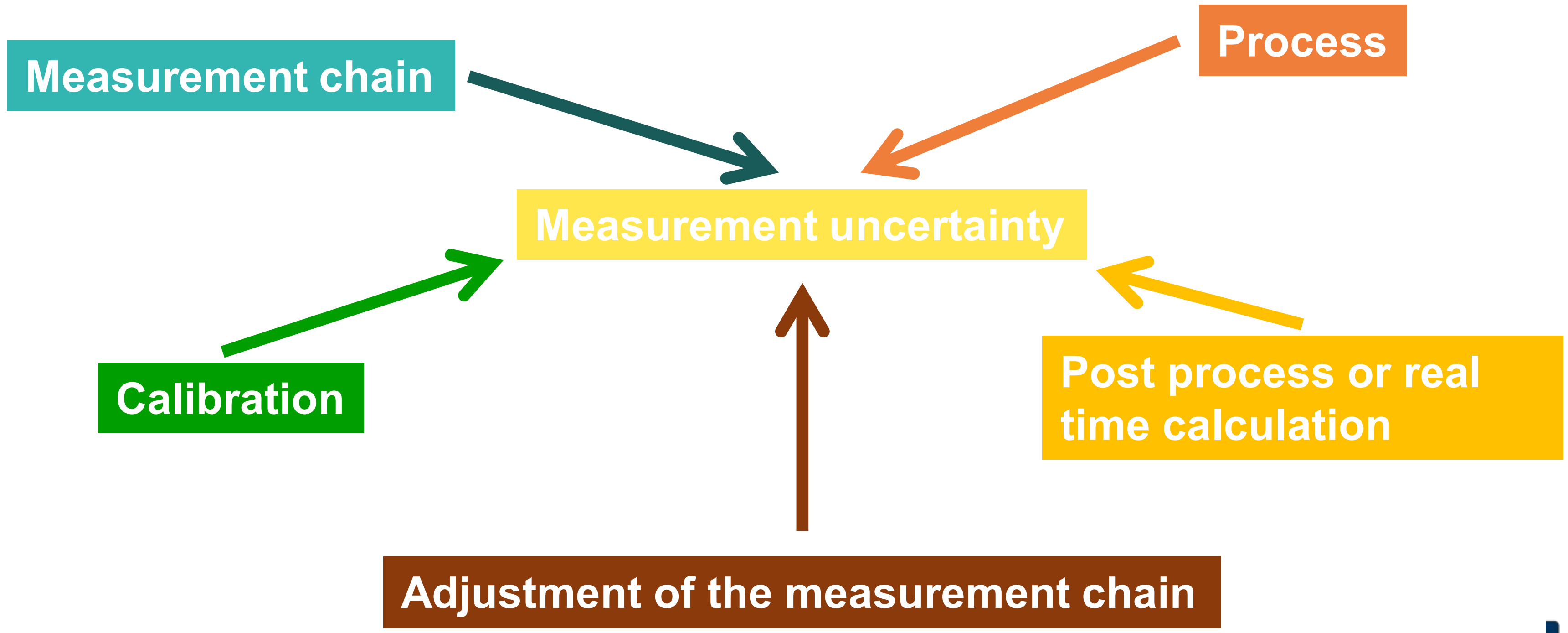
- No standard existing
- % of full scale
- Do not mix up with
  - Measurement uncertainty
  - Accuracy class according ISO376

- You can not compare sensors from different suppliers
- You can not calculate any errors or uncertainties with the accuracy class
- BUT: Choosing a DAQ-System that fits to the sensor- this works!

Definitions / general hints

What is the accuracy of my measurement chain?

Sorry, depends on ….



HBK
HOTTINGER BRÜEL & KJÆR

Systematic errors

Systematic deviations

It is known if the difference is positive or negative as well as the value of the deviation

➔ have to be corrected

Example

The weight of load introduction parts:

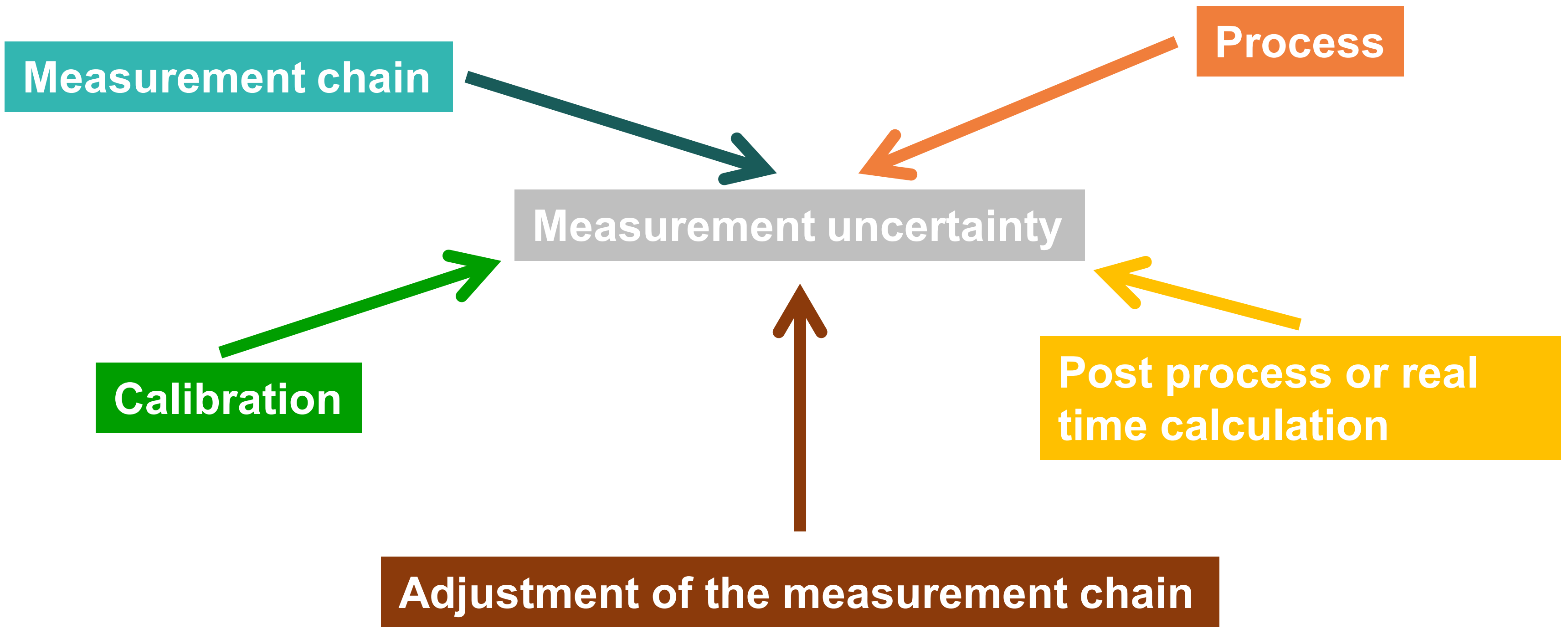
➔ Tare your measurement chain

Estimation of the measurement uncertainty

Other measurement errors (not systematic)

It is **not** known if the error is positive or negative as well as the value

➔ Measurement uncertainty



Estimation of the measurement uncertainty

GUM =„***G**uide to the Expression of **U**ncertainty in **M**easurement*"

- For highest scientific demands
- Requires some special knowlegde
- Some effort

„The determination of the measurement uncertainty is not a routine job or a math's problem- a detail knowledge about the measurement task is required"

HBK
HOTTINGER BRÜEL & KJÆR

Estimation of the measurement uncertainty

Measurement chain

Hysteresis
Linearity
TCZero
TCSpan
Bending moment
Sensitivity…

Process

Temperatures
Side load existing?
Humidity?
…

Post process or real time calculation

Used filter
Rounding error
…

Measurement uncertainty

Adjustment of the measurement chain

According datasheet?
According test certificate?
According individual Calibration?
…

Calibration

Daks-Calibration?
Calibration in mounting position?

Estimation of the measurement uncertainty

Methods according GUM-standard

Method A

- Get a suitable number of individual measurements
- Calculate the mean value
- The measurement uncertainty can be calculated by calculating the standard deviation of the results

Method B

- Use of existing information on influences that have an impact on the measurement uncertainty
- Calculating the resulting measurement uncertainty by using the single results above

Method B is the better choice for force measurements in most case.

HBK HOTTINGER BRÜEL & KJÆR

Estimation of the measurement uncertainty

Strategy with measurement uncertainty:

- Calculation of the individual errors
- ~~Statistical characteristic of the individual properties~~
- Geometrical addition
- ~~Taking care for the range of uncertainty~~

We need to state: No single error is depending on another one!

This is a more or less rough estimation

HINT: HBM Seminar “Uncertainty of measurement chains”

Example

Tension measurement for a component test

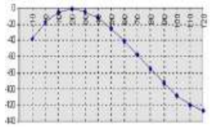
• Load cell U2B/5KN	Capacity 5 kN
• Range of force (Sinus)	between 0 and 1 kN
• Temperature range	23°C up to 45°C
• Frequency	15 Hz
• Testing duration	30 min
• Zero-point setting	before every test
• Adjustment according datasheet	5 kN = 2 mV/V

HBK HOTTINGER BRÜEL & KJÆR

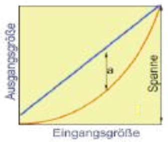
Example: What is relates to full scale, what to actual value?

Related to full scale	Related to actual value	Related to actual value, but depending of history

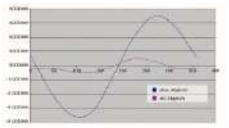
TCZero



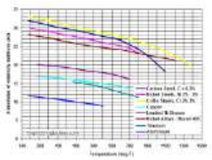
Linearity



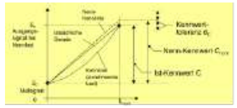
Bending moment



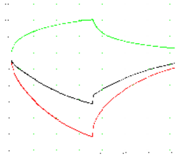
TCSpan



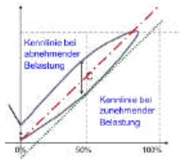
Tolerance of calibration



Creep



Hysteresis



<u>All errors related to full scale have a big impact on measurement of low forces!</u>

Example: S9M/1kn, 100N are measured:

TCZero: 200ppm/10K relative to 1000N. This is 2000ppm/10K relative to 100N with the same load cell and the same change in temperature.

Example

Data sheet of the U2B:

- Tolerance of rated output: ± 0.2% (related to MV)
- Linearity deviation.: ± 0,1% (related to FS)
- Hysteresis ± 0,15 % (related to FS)
- TCSpan: ± 0,1% (related to MV)
- TCZero: ± 0,05% (related to FS)
- Creep (30 min): ± 0,06% (related to MV)

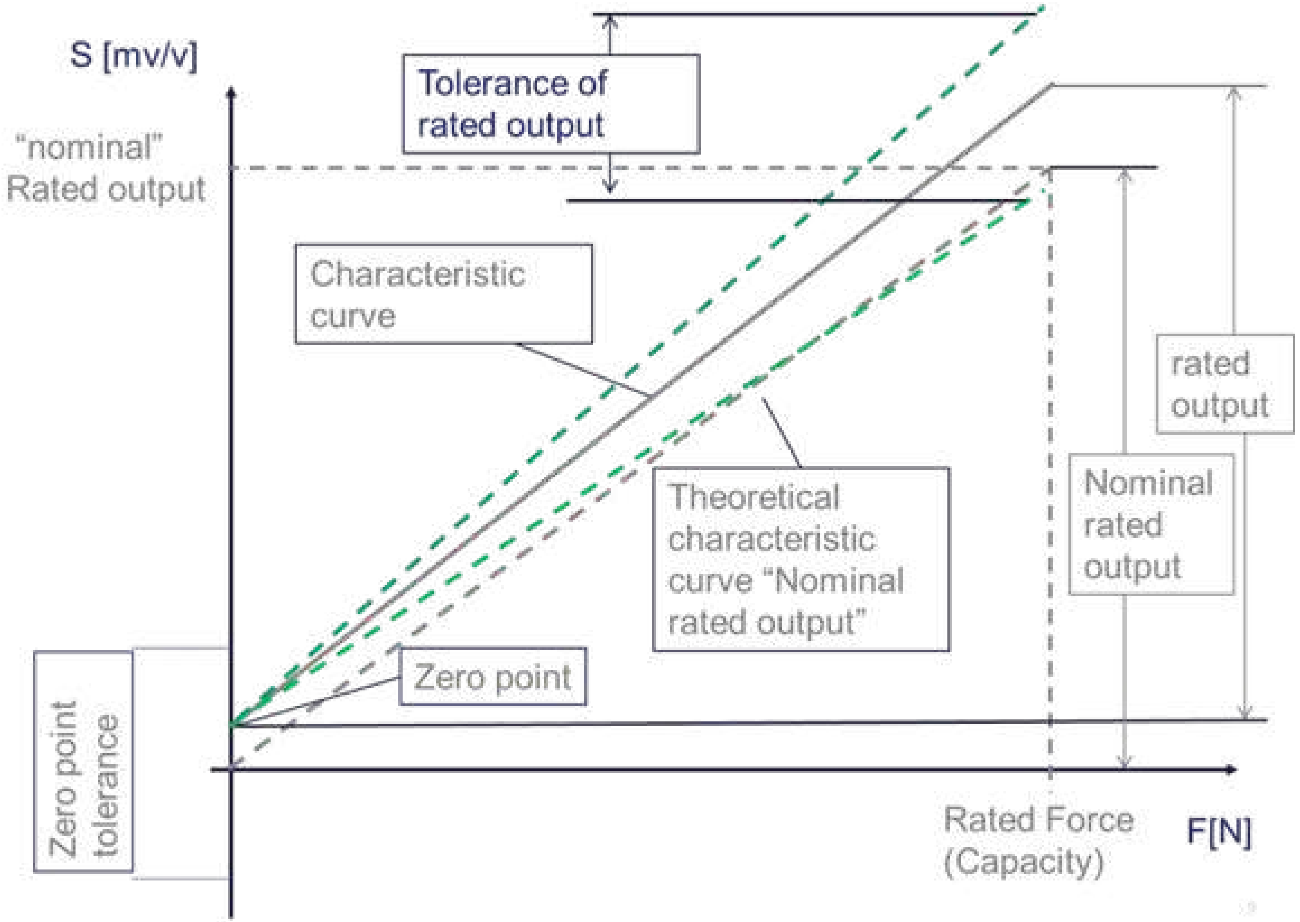
MV = rel. to measurement value FS = relative to full scale

Example

- **Tolerance of the rated output**

  (Related to actual value)

$\Delta_{d\ C}$ = 0.2 % of 1 kN = **2 N**

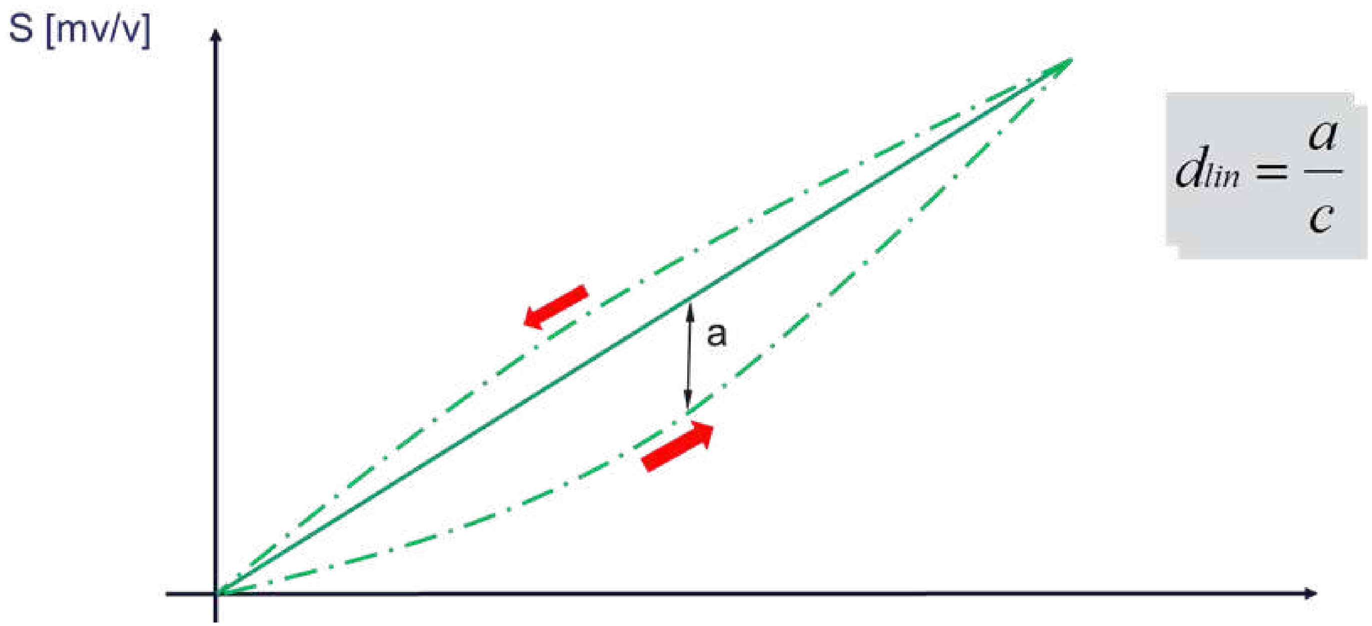


Example

- **Linearity deviation**

  (Related to full scale)

$\Delta_{d\ lin}$ = 0,1 % of 5 kN = **5 N**

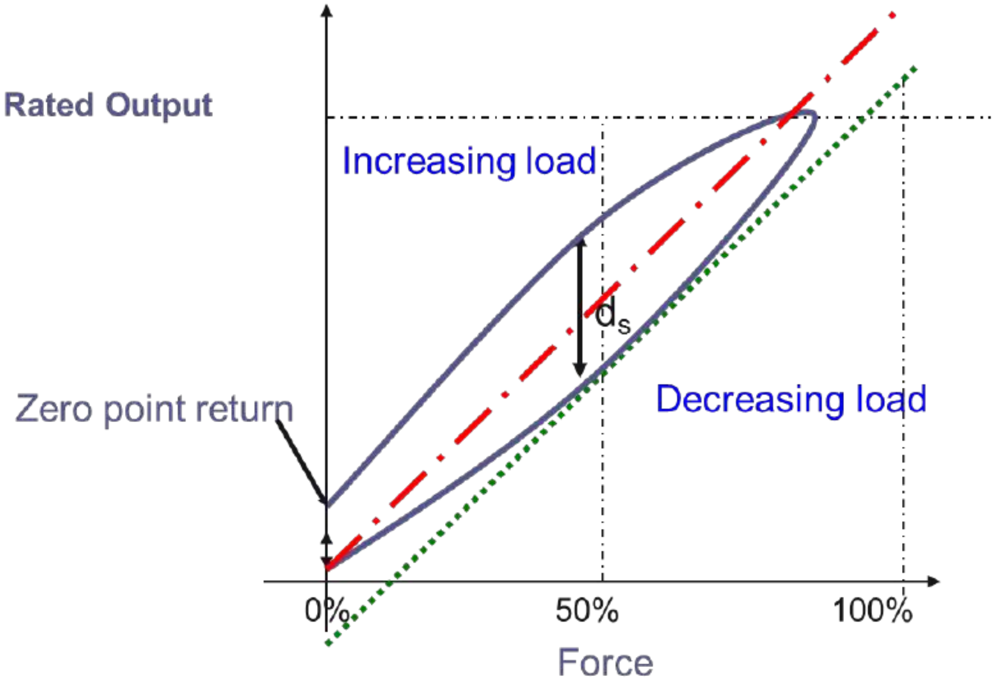


Example

- **Hysteresis**

(Related to full scale)

Δ_{hys} = 0.15 % of 5 kN = **7,5 N**



$$\upsilon = \frac{d_s}{C}$$

Typical values:

S2M: 0,02%
U10M: 0,02...0.05%
C9c: 0,2%

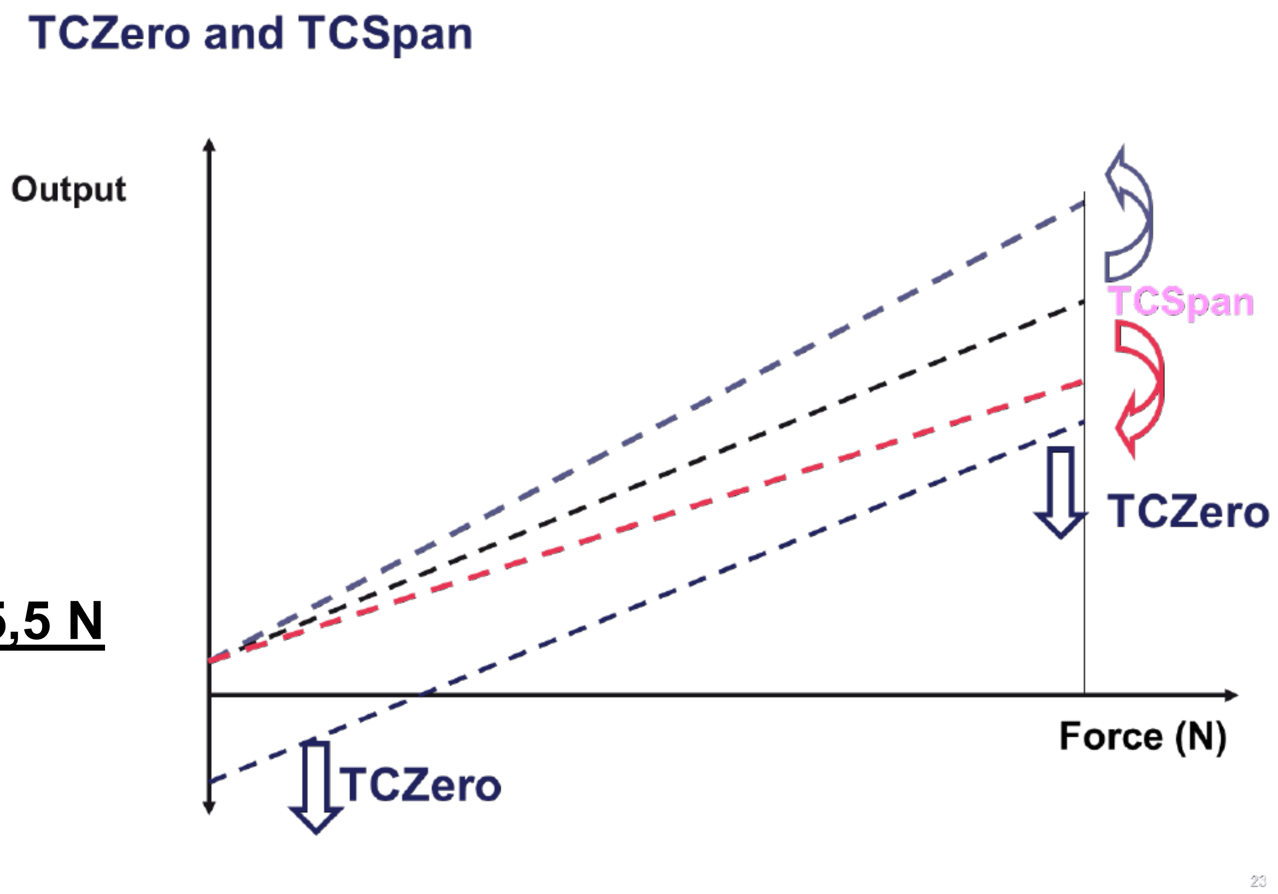
13

Example

- **TCZero**

(Related to full scale)

Δ_{TK0} = 0,05 % of 5 kN $\cdot$(45°C-23°C)/10K = **5,5 N**



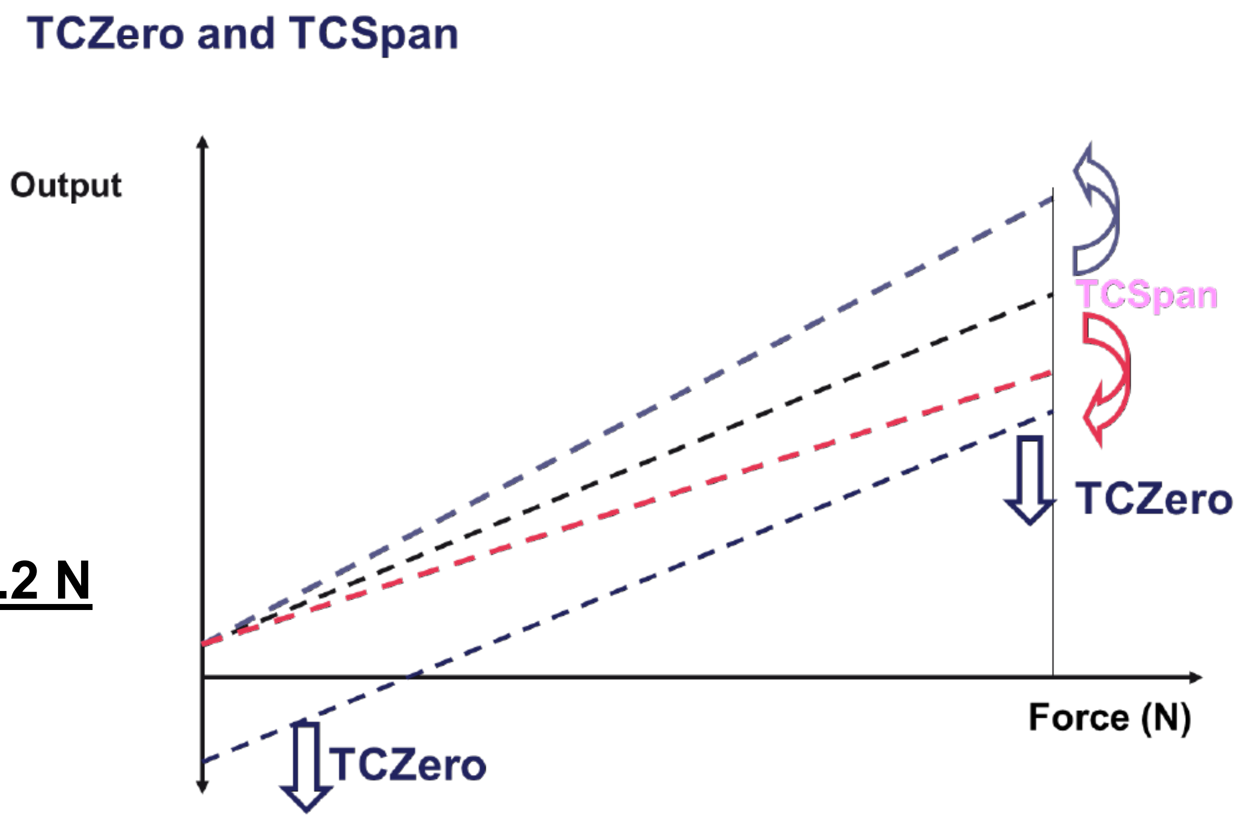
HOTTINGER BRÜEL & KJÆR

Example

- **TCSpan**

(Related to actual value)

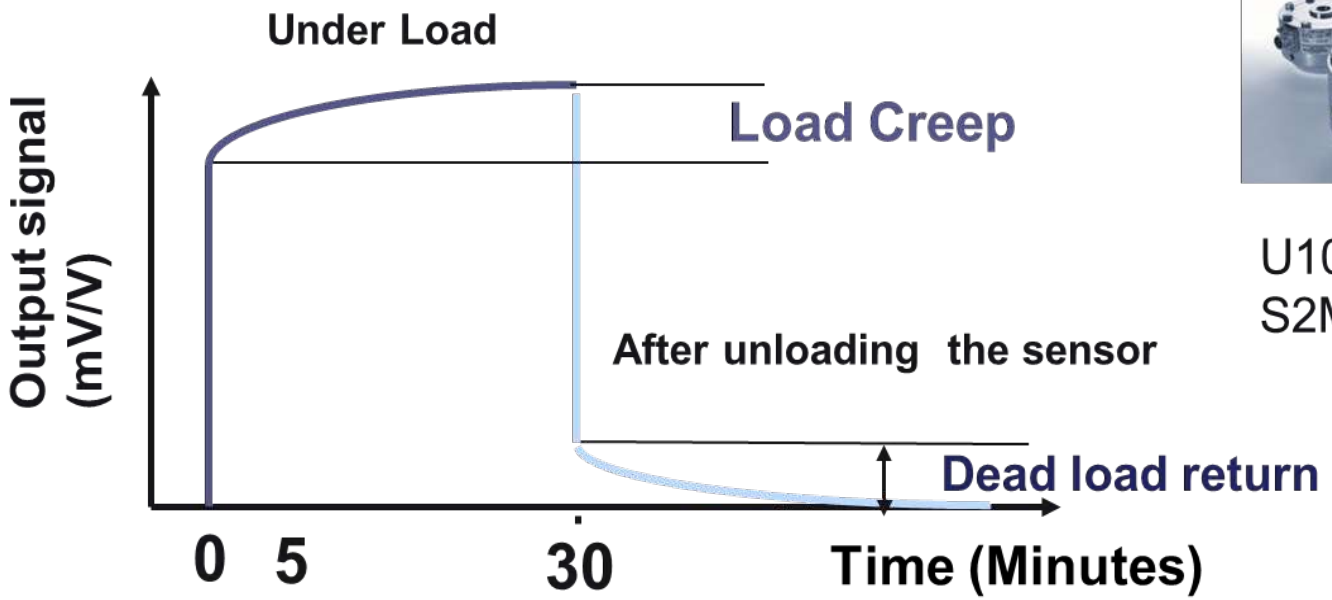
Δ_{TKC} = 0,1 % of 1 kN ·(45°C-23°C)/10K = **2.2 N**



Example

- **Creep**

  (Related to actual value)



U10M: 0,02 %
S2M: 0.02 %

Δ_{cr} = 0,06 % of 1 kN = **0.6N**

Example

- **Tolerance of the rated output** (Related to actual value)
  $\Delta_{d\,C}$ = 0.2 % von 1 kN = **<u>2 N</u>**
- **Linearity deviation** (Related to full scale)
  $\Delta_{d\,lin}$ = 0,1 % von 5 kN = **<u>5 N</u>**
- **Hysteresis** (Related to full scale)
  Δ_{hys} = 0.15 % von 5 kN = **<u>7,5 N</u>**
- **TCSpan** (Related to actual value)
  Δ_{TKC} = 0,1 % von 1 kN ·(45°C-23°C)/10K = **<u>2.2 N</u>**
- **TCZero** (Related to full scale)
  Δ_{TK0} = 0,05 % von 5 kN ·(45°C-23°C)/10K = **<u>5,5 N</u>**
- **Creep** (Related to actual value)
  Δ_{cr} = 0,06 % von 3 kN = **<u>0.6N</u>**

HBK HOTTINGER BRÜEL & KJÆR

Example / How to improve

$$U_{\text{ges}} \approx \sqrt{\Delta_{dC}^2 + \Delta_{d\,lin}^2 + \Delta_{hys}^2 + \Delta_{TKC}^2 + \Delta_{TK0}^2 + \Delta_{cr}^2}$$

$$= \sqrt{(2\,\mathrm{N})^2 + (5\,\mathrm{N})^2 + (7.5\,\mathrm{N})^2 + (2.2\,\mathrm{N})^2 + (5.5\,\mathrm{N})^2 + (0.6\,\mathrm{N})^2}$$

$$\approx \underline{\underline{10{,}98\,\mathrm{N}}}$$

Error: 1,1% (K=1) ....too big??

- **Lower capacity**
  (lower influence of all parameters that related to full scale)
- **More stable temperature conditions**
  (lower influence of TCZerol/TCSpan)
- **Calibration at HBM**
  (Lower linearity deviation, lower tolerance of sensitivity)

How to improve

Accuracy Class 0,02

Accuracy Class 0,02

Accuracy Class 0,03

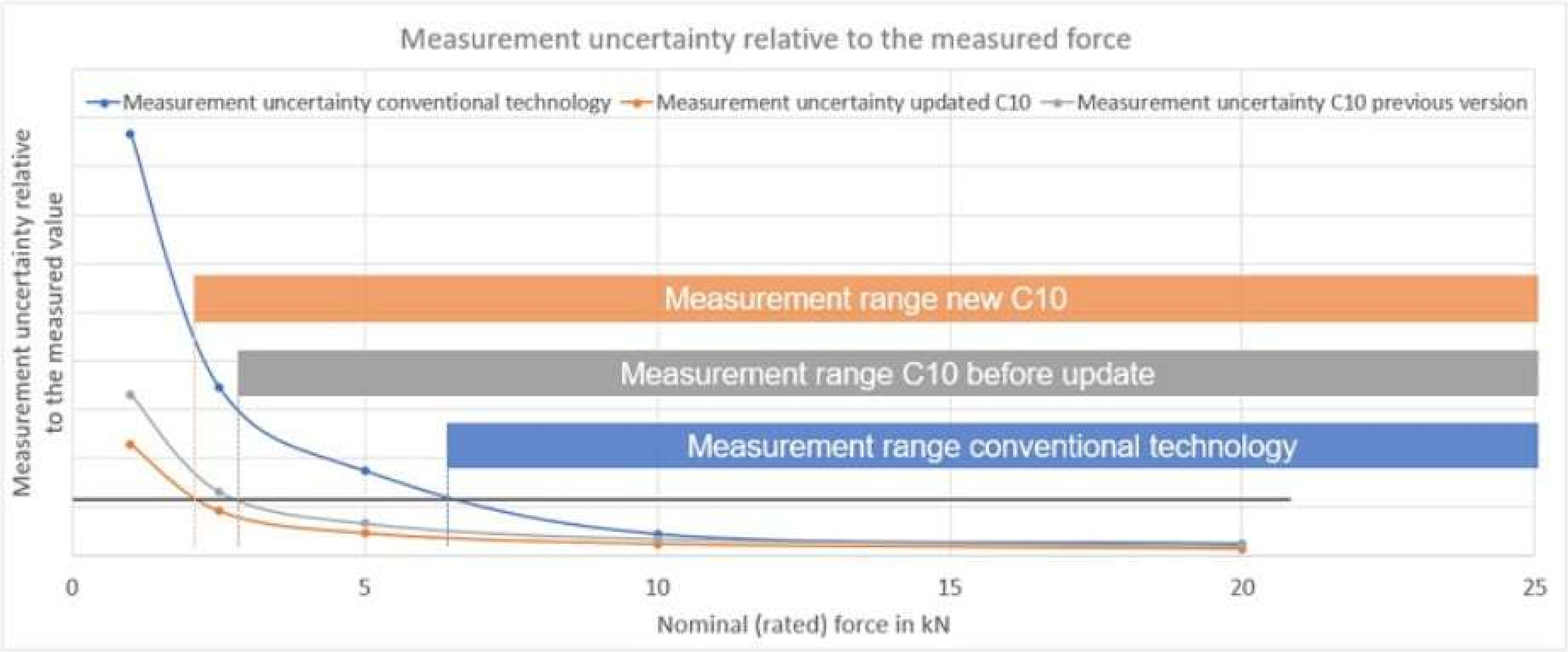
How to improve

- **Tolerance of the rated output** (Related to actual value)
  $\Delta_{d\ C}$ = 0.01 % von 1 kN = **0,1 N**
- **Linearity deviation** (Related to full scale)
  $\Delta_{d\ lin}$ = 0.03 % von 5 kN = **1,5 N**
- **Hysteresis** (Related to full scale)
  Δ_{hys} = 0.03 % von 5 kN = **1,5 N**
- **TCSpan** (Related to actual value)
  Δ_{TKC} = 0,015 % von 1 kN ·(45°C-23°C)/10K = **0.33 N**
- **TCZero** (Related to full scale)
  Δ_{TK0} = 0,015 % von 5 kN ·(45°C-23°C)/10K = **0.825 N**
- **Creep** (Related to actual value)
  Δ_{cr} = 0,04 % von 3 kN = **0.4 N**

Error: 2,33 N (=0,233 %) for k=1

HBK
HOTTINGER BRÜEL & KJÆR

Another effect of precision: Larger measurement range



Questions?

- Please type any questions you have into the WebEx Q&A dialog
- You can open the Q&A window by selecting the “Q&A” icon in the WebEx toolbar at the top of your screen:

- Today’s presentation will be E-mailed to all attendees. The webinar will also be posted on our website: http://www.hbm.com/en/3157/webinars/

- If you have additional technical questions, feel free to contact our technical support team at support@usa.hbm.com

HBK HOTTINGER BRÜEL & KJÆR

Thank You

HOTTINGER BRÜEL & KJÆR