Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

TU BRAUNSCHWEIG

Calibration of a 30 MN Material Testing Machine According to ISO 7500-1 Using a Force-Transducer Build-Up System

within the scope of the EMRP SIB 63 project

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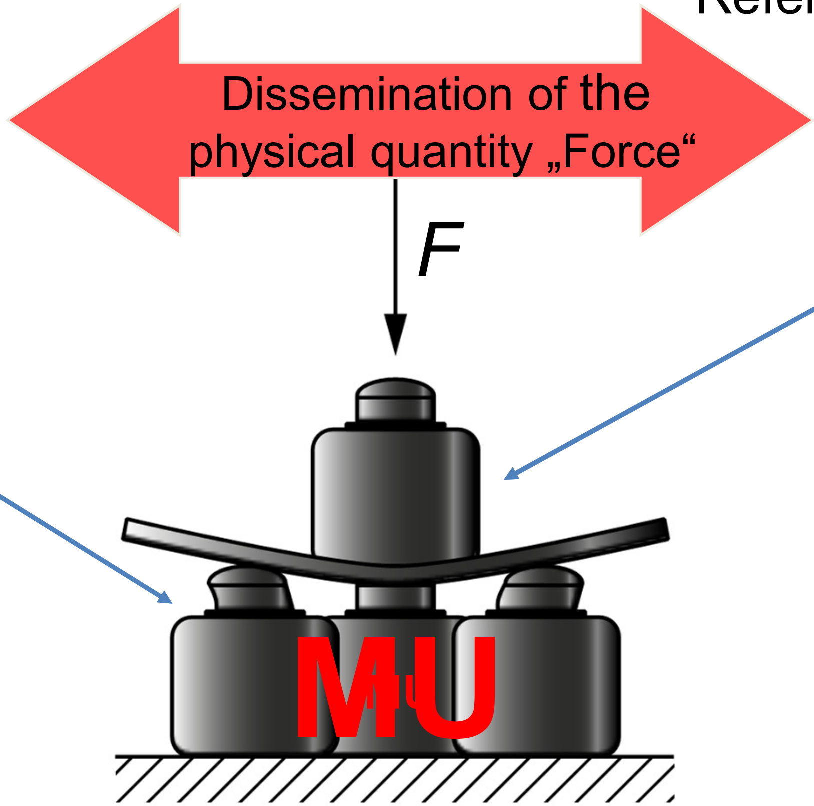
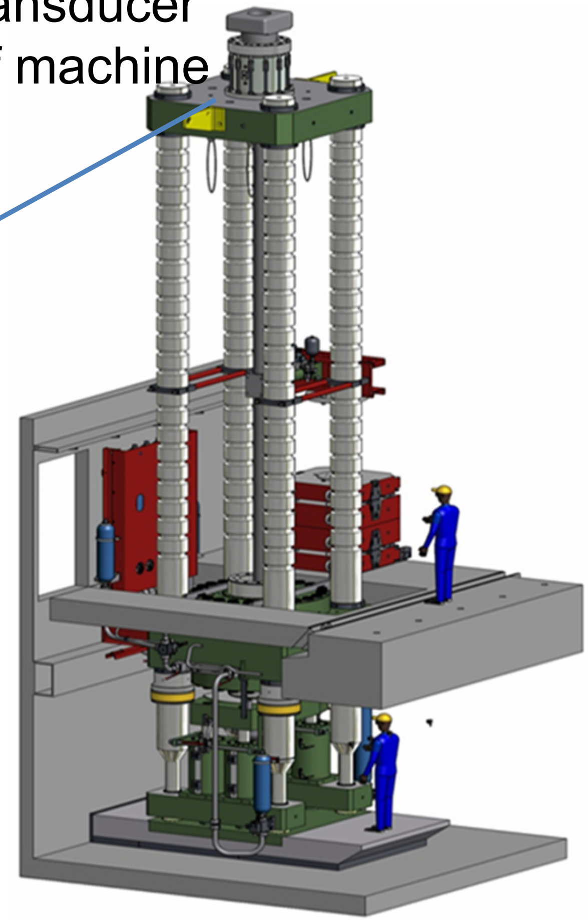
Concept of a Build-Up (BU) system used as a Transfer Standard

Force Standard Machine



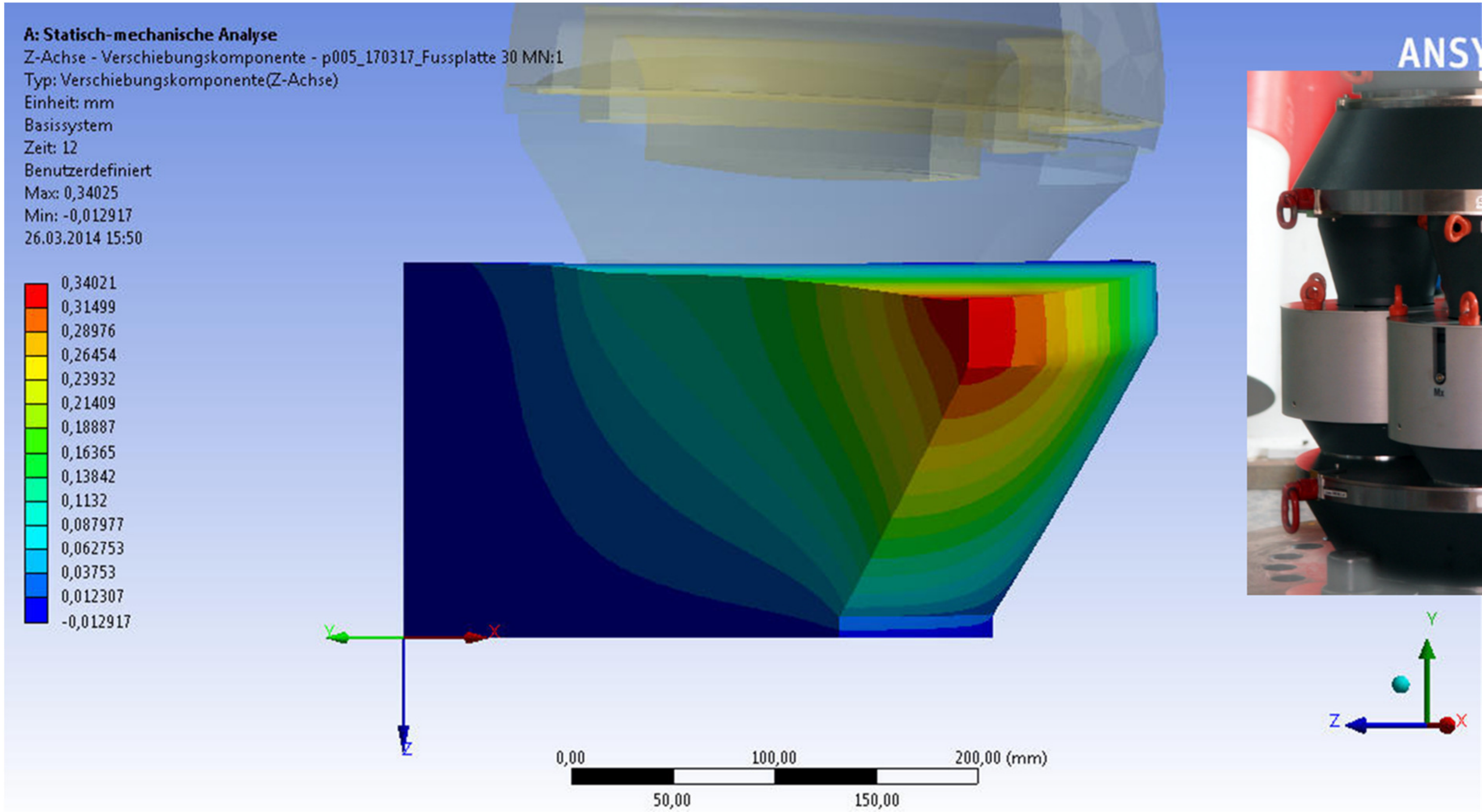
Build-Up System used
as a transfer standard

Reference transducer
of machine

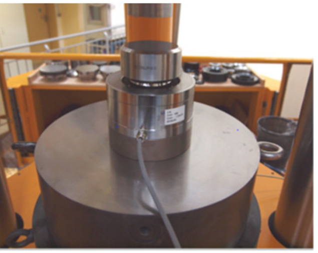


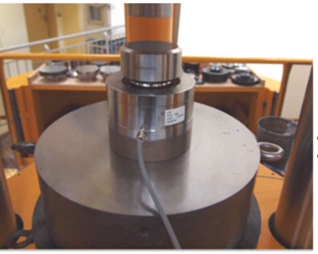
Force Calibration Facility

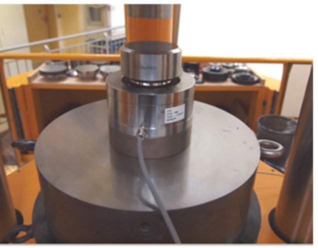
Elastic deformations causing cross forces



Deviation *d* of Build-Up Systems







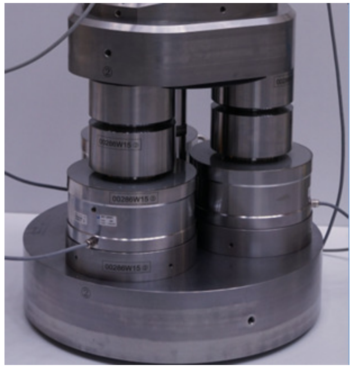
Sensitivity of single transducers

*

Applied force of the Force Standard Machine

=

(



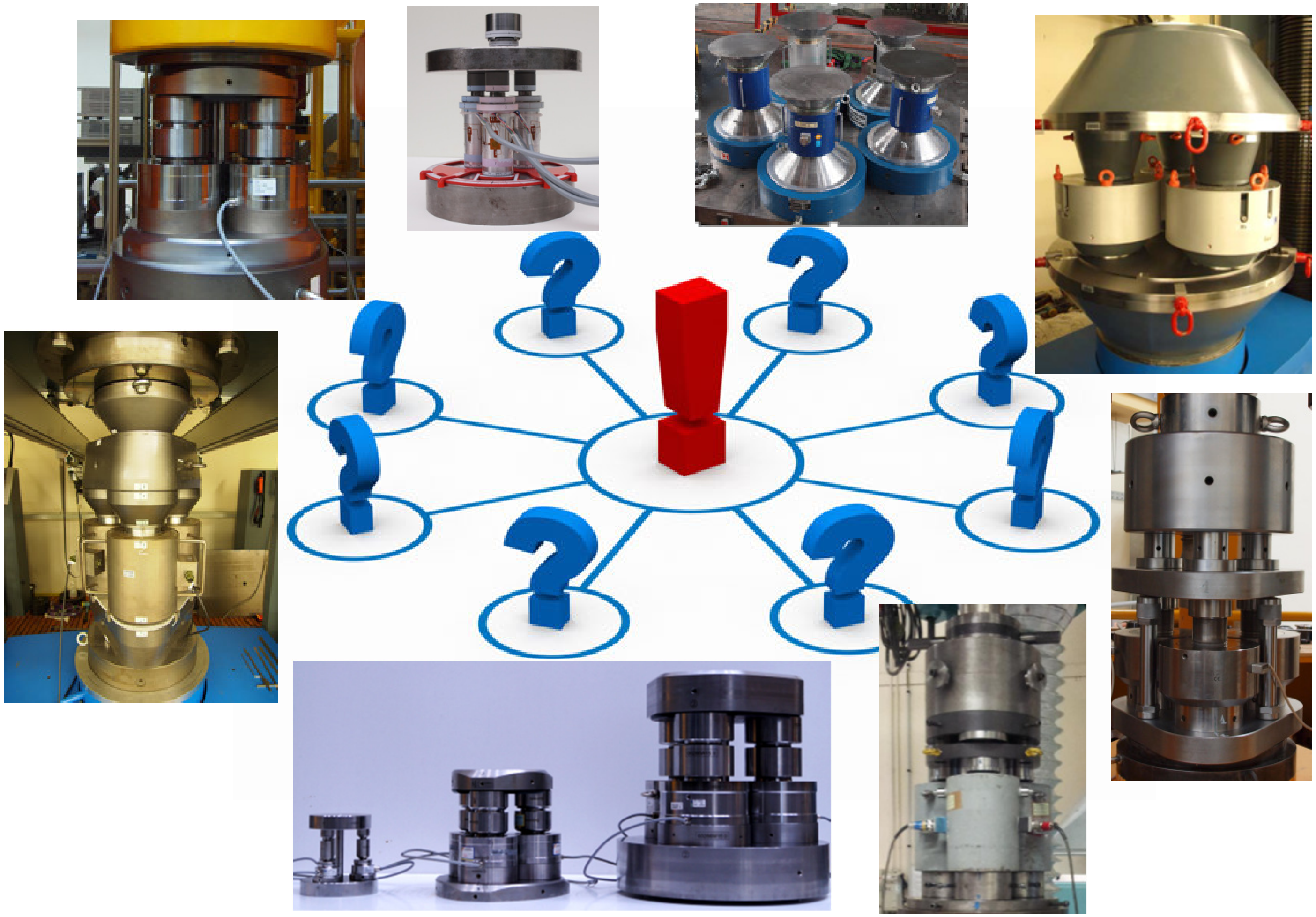
Sensitivity of single transducers with the interaction of the adaptation parts

*

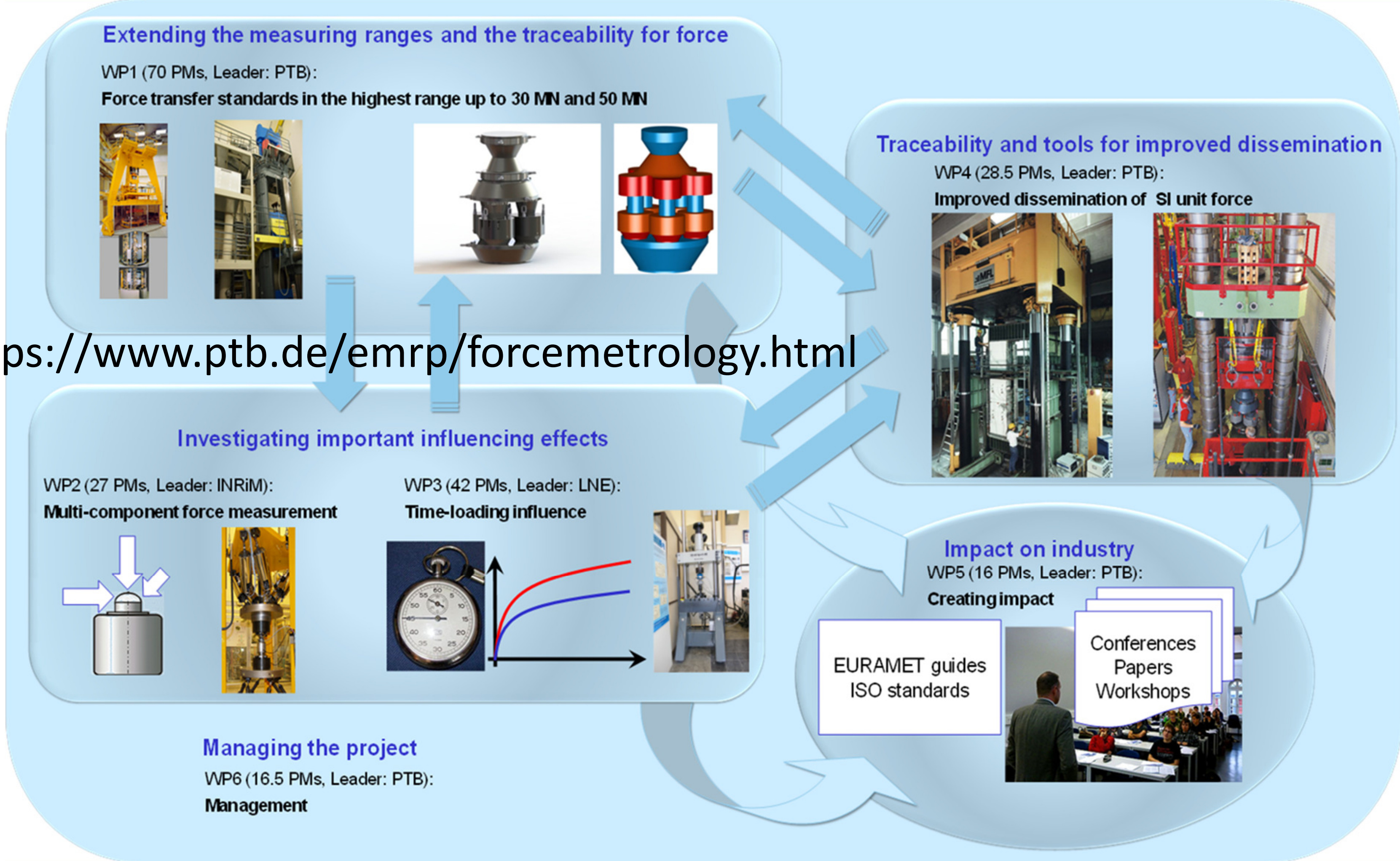
Applied force of the machine to be calibrated

)(1+*d*)

EMRP SIB 63 project: Creating of a knowledgebase for typical properties of BU Systems



EMRP Project SIB 63



https://www.ptb.de/emrp/forcemetrology.html

SIB63 Force

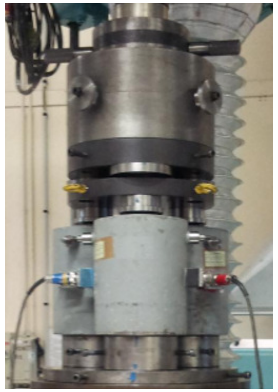
https://www.ptb.de/emrp/forcemetrology.html

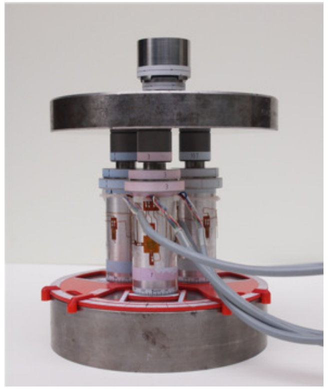
Final Publishable JRP Summary for SIB63 Force
Force traceability within the meganewton range

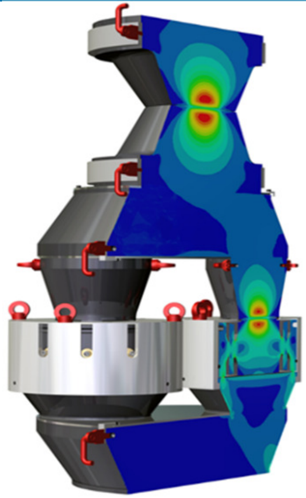
Analyzing the influence of different constructional outlines

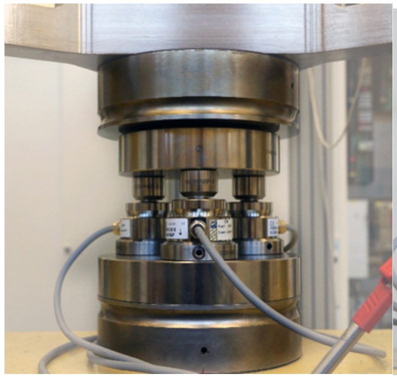
Investigations of different

- types of force transducers
  - bending ring transducers
  - column type transducers
- types of adaptation parts

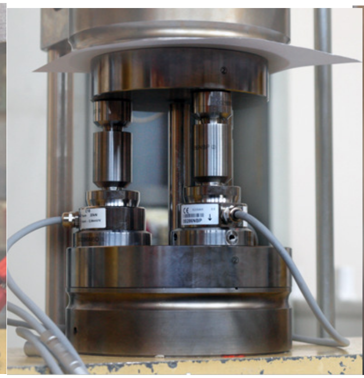




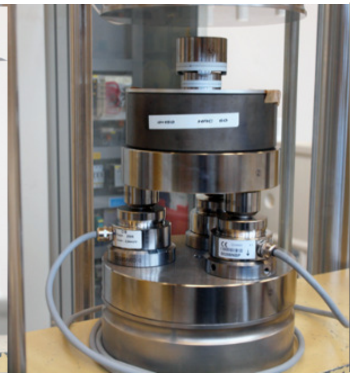




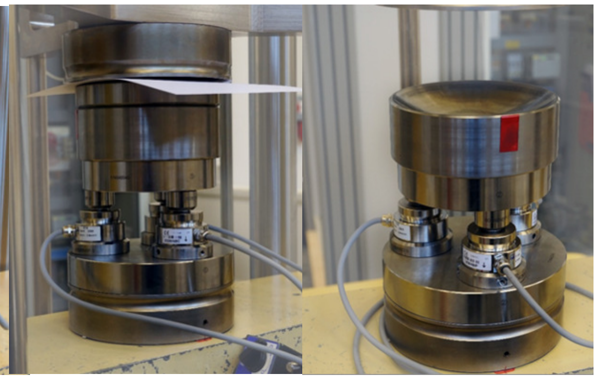
usual load cups



additional pendulums

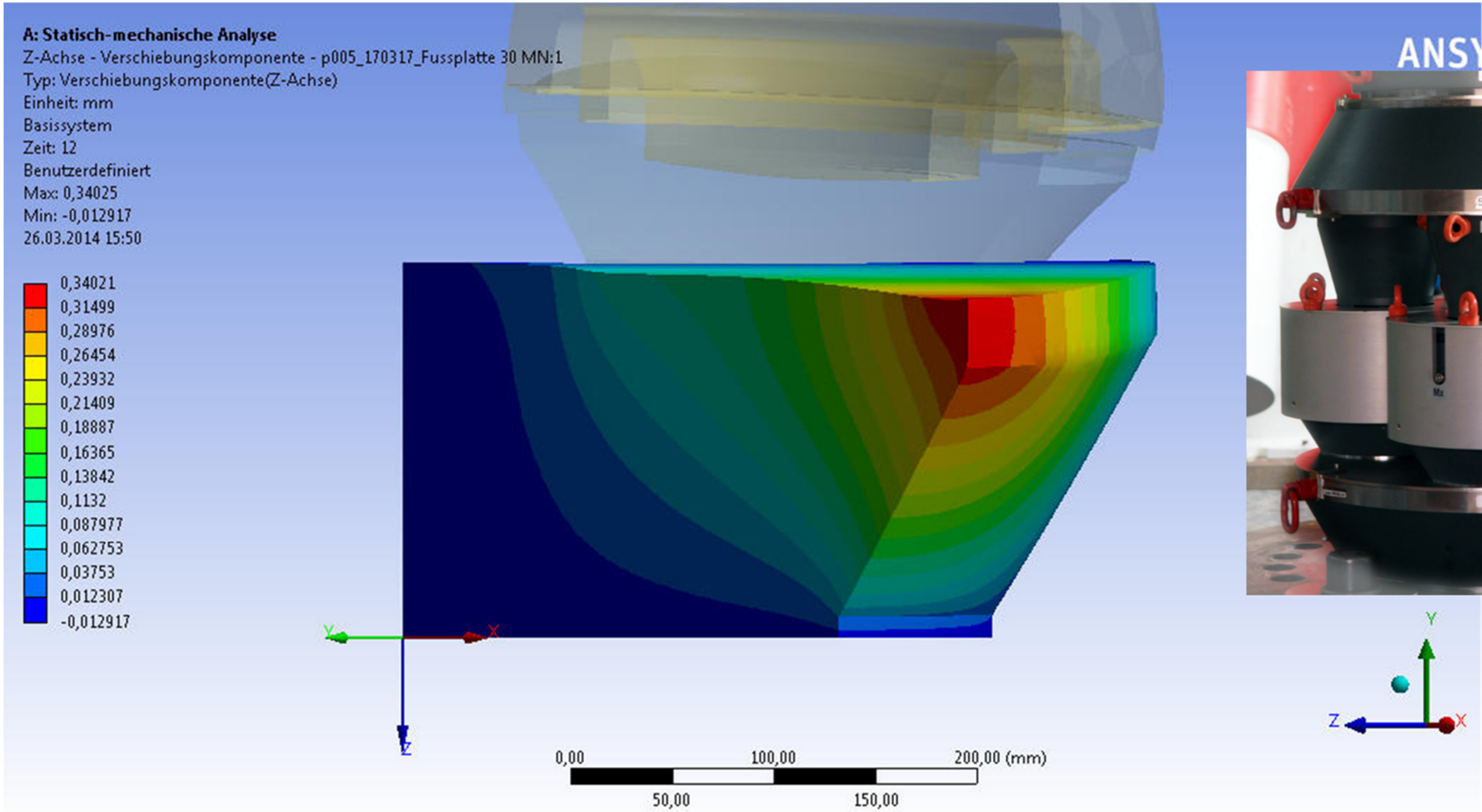


additional load cup on the top



conical sphere on the top

Elastic deformations causing cross forces



Elastic deformations causing cross forces

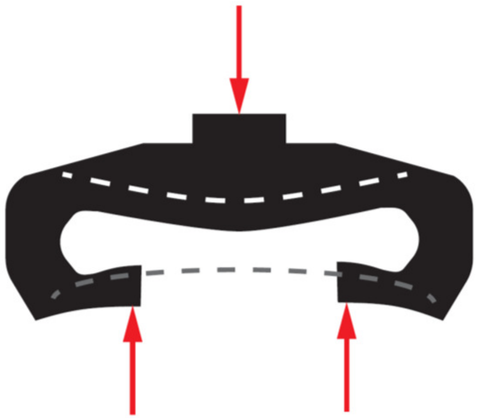
Force in kN	Deviation high stiffness $d_{L,135}$	Deviation low stiffness $d_{L,135}$
1500	-0,020%	0,131%
3000	-0,005%	0,145%
4500	0,004%	0,150%
6000	0,010%	0,151%
7500	0,011%	0,150%
9000	0,014%	0,149%
10500	0,012%	0,147%
12000	0,013%	0,145%
13500	0,013%	0,145%
15000	0,014%	0,144%
16500	0,011%	0,140%

Elastic deformations causing cross forces

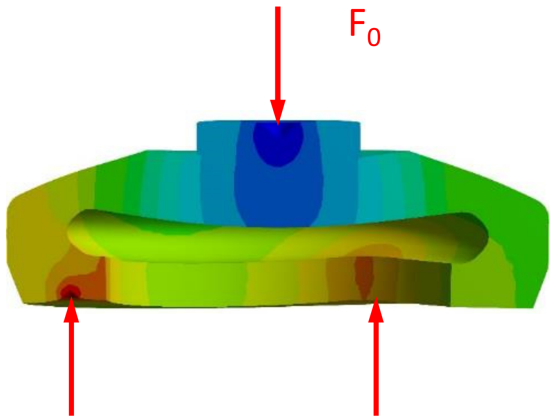
Force in kN	Deviation high stiffness $d_{L,135}$	Deviation low stiffness $d_{L,135}$
600.00	-0.015%	-0.017%
1200.00	-0.016%	-0.020%
1800.00	-0.017%	-0.022%
2400.00	-0.018%	-0.024%
3000.00	-0.018%	-0.025%
3600.00	-0.018%	-0.026%
4200.00	-0.017%	-0.026%
4800.00	-0.017%	-0.026%
5400.00	-0.015%	-0.025%
6000.00	-0.014%	-0.024%

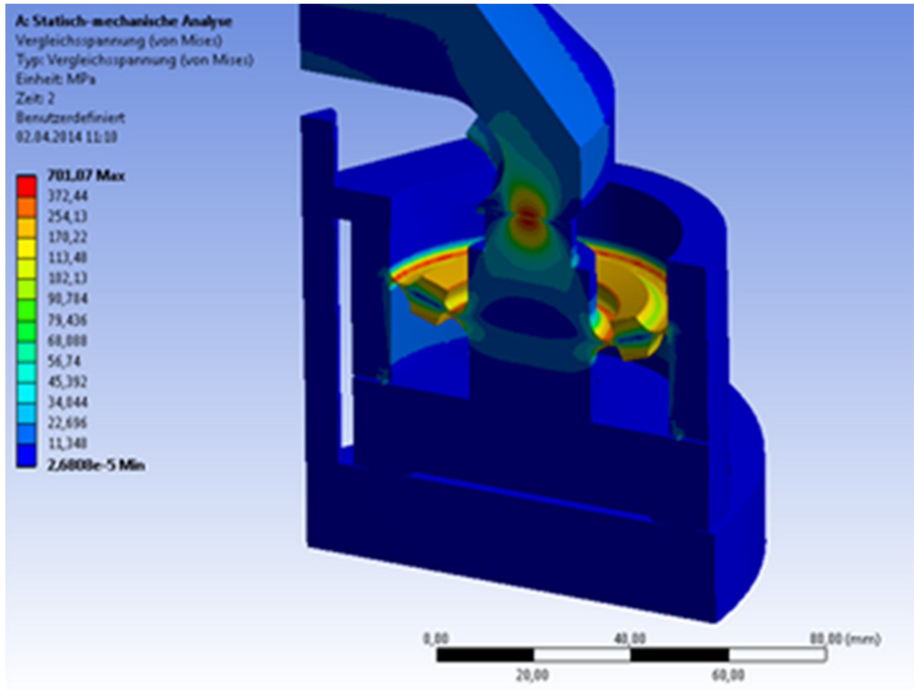
“Bending-neutral plate” to minimize cross forces

without load / loaded



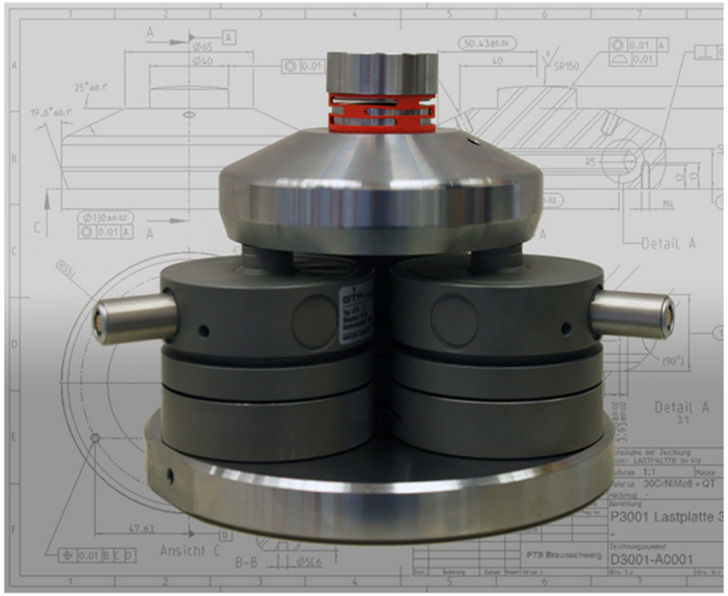
numerical simulation of deformation behavior

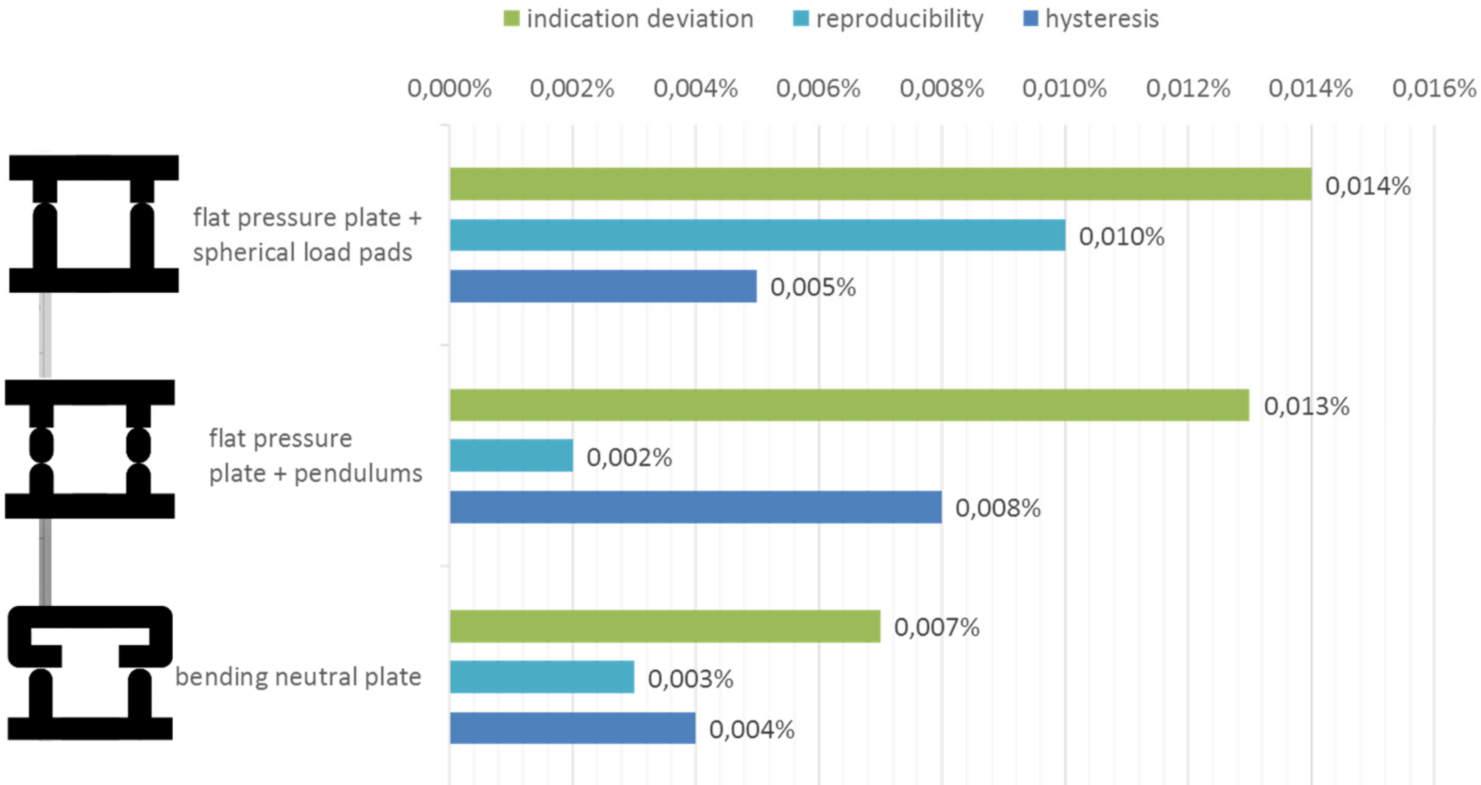




cross force generation: 0.01% · F_0

Constructional methods: Influence of adaptation parts





Deviation *d* between single transducer- and build-Up-System-calibration

d can not be totally reduced to zero !

A theory for the correction of *d* and the calculation of uncertainties is necessary

d of 30 MN version at 16,5 MN: 0,140 % 0,015 %

Procedure how to calibrate a Force Calibration Facility with a higher nominal load than the Force Standard machine using a BU-System

EMRP
European Metrology Research Programme
Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Force traceability within the meganewton range

- Home
- The Project
- The Consortium
- Work Packages
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  - WP1.6 Extrapolation
  - WP4 Questionnaire
  - WP4.1 Application conditions
  - WP4.2 Parameters and coefficients
  - WP4.3 Uncertainty contributions
  - WP4.4 Software tool
- Publications
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- Contact

WP1 Force transfer standards in the highest range up to 50 MN

WP1 has six tasks. Here we publish the results of these tasks.

Task 1.3 - Built-up Systems

An Excel file for offline use can be downloaded.

https://www.ptb.de/emrp/3294.html

Questions?

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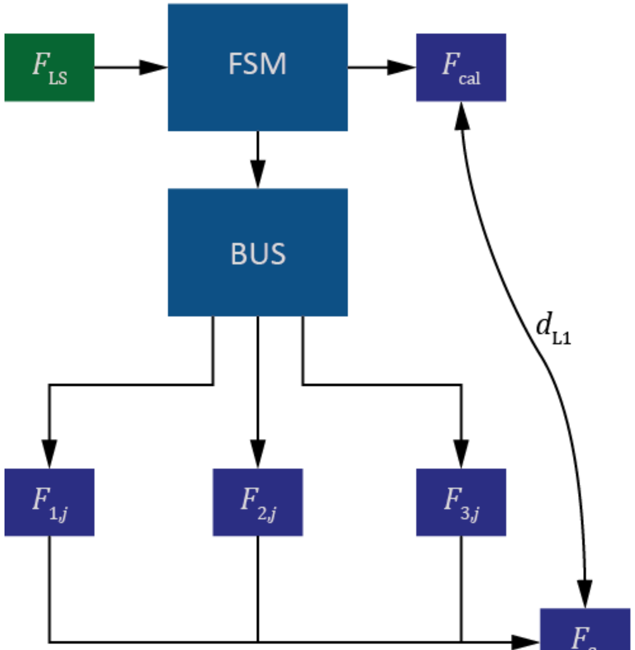
The research leading to these results has received funding from the European Union on the basis of Decision No 912/2009/EC.
Last updated: 2017-05-24

Uncertainty model based on ISO 376 uncertainties

calibration of a BU system



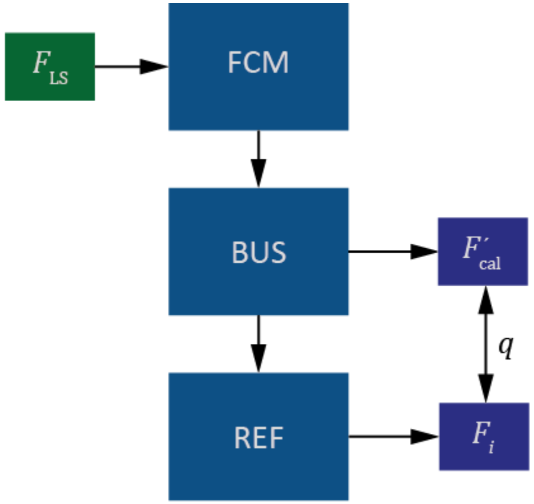
$$d_L = \frac{1}{m}\sum_{j=1}^{m} d_{L.j} = \frac{1}{m}\sum_{j=1}^{m}\frac{F_{S.j}-F_{LS}}{F_{LS}}$$

$$F_S = 1/m \sum_{j=1}^{m}\sum_{i=1}^{n} F_{i.j}$$

with: m: the number of measurement series and
n: the number of transducers

$$u^2(d_L) = \left(\frac{1}{m \cdot F_{LS}^2} \cdot \sum_{j=1}^{m}\sum_{i=1}^{n} F_{i.j}\right)^2 \cdot u^2(F_{LS}) + \left(\frac{1}{m \cdot F_{LS}}\right)^2 \cdot \sum_{j=1}^{m}\sum_{i=1}^{n} u^2(F_{i.j}) + u_{stability}$$

application of a BU system



$$F'_{cal} = \frac{1}{m(1+d'_L)}\sum_{j=1}^{m} F'_{S.j} = \frac{F'_S}{(1+d'_L)}$$

$$u_c^2(F'_{cal}) = \left(\frac{u(F'_S)}{1+d'_L}\right)^2 + \left(\frac{F'_S \cdot u(d'_L)}{(1+d'_L)^2}\right)^2$$

Procedure how to calibrate a Force Calibration Facility using a BU-System

A

Calibration of BUS in FSM

B

Plausibility Measurement in FCM

C

Calibration of FCM in full range

Procedure how to calibrate a Force Calibration Facility using a BU-System within **6 steps**

A

Calibration of BUS in FSM

- Calibration (ISO 376) of all single transducers up to nominal load
- *Calibration of all single transducers in partial range <u>if necessary</u>*
- Calibration of whole BUS in nominal range in FSM to determine *d*

B

Plausibility Measurement in FCM

- Calibration of all single transducers *(can also be used for the calibration in lower range without BUS)*
- Calibration of whole BU-System in partial range of FCM
  -> Argument for verification: E_N value of the comparison of *d*

C

Calibration of FCM in full range with extrapolated d´

- Calibration of whole BU-System in full range if FCM

Plausibility of the deviation ***d*** up to nominal load in the FSM

Indication deviation ***q*** of the FCM with uncertainty

Result

PTB

Procedure how to calibrate a Force Calibration Facility using a BU-System

A

Calibration of BUS in FSM

- Calibration of all single tranducers
- *(Calibration of all single transdcuers in partial range if necessary)*
- Calibration of whole BUS in nominal range if FCM to detrermine *d*

Why?

If nominal load of the single transducer calibration differs too much (50%) from the highest load within the BUS calibration at the FSM, than it is important to calibrate the single transducers two times:

Up to nominal load for the estimation of the sensitivity and the uncertainties for the calibration of the FCM.

A second calibration up to maximum load of the single transducer during the BUS calibration at FSM should be preferred for the determination of *d*.

Example: 50 MN BUS of PTB calibrated in 16,5 MN FSM:

2700,00		2700,00	0,544317	0,542921	2700,00	0,542066
3000,00		3000,00	0,604517	0,603121	3000,00	0,601923
3300,00		3300,00	0,664716	0,663320	3300,00	0,661773
0,00		0,00	0,001457	0,000061	0,00	0,002299
0,00		0,00	0,001424	0,000000	0,00	0,002276

A1-General information | A1-Measurement data | A1-Uncertainties | A1-Load distribution

d_L and uncertainties

1,395556	7000,00	1,400059	1,397702	7000,00
1,593945	8000,00	1,598749	1,596392	8000,00
1,792056	9000,00	1,797174	1,794817	9000,00
1,989970	10000,00	1,995334	1,992977	10000,00
0,000223	0,00	0,002568	0,000211	0,00

A2-Measurement data | A2-Uncertainties | B1-General information | B1-Me

sensitivity and uncertainties

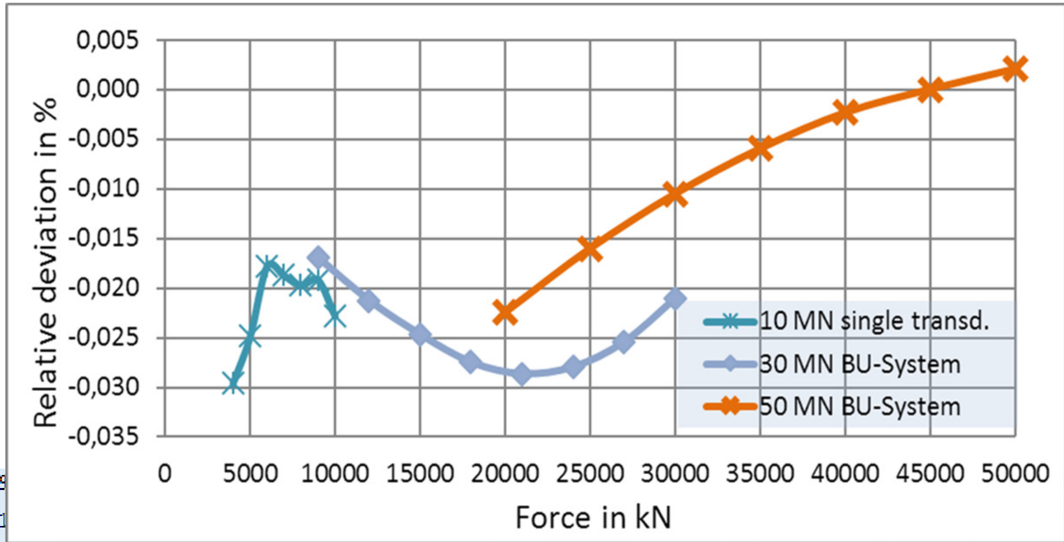
Procedure how to calibrate a Force Calibration Facility using a BU-System

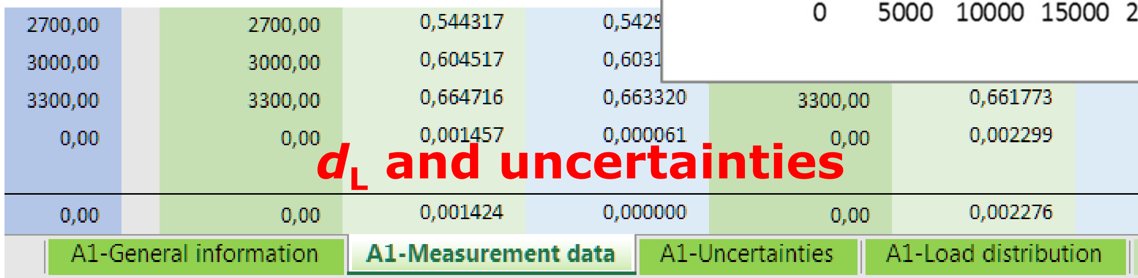
A

Calibration of BUS in FSM

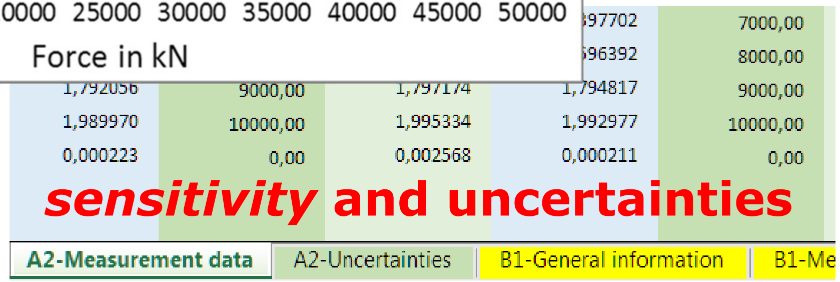
- Calibration of all single transducers
- *(Calibration of all single transducers in partial range if necessary)*
- Calibration of whole BUS in nominal range in FSM to determine *d*

Are the results safe?
Doublecheck overlap!





d_L **and uncertainties**

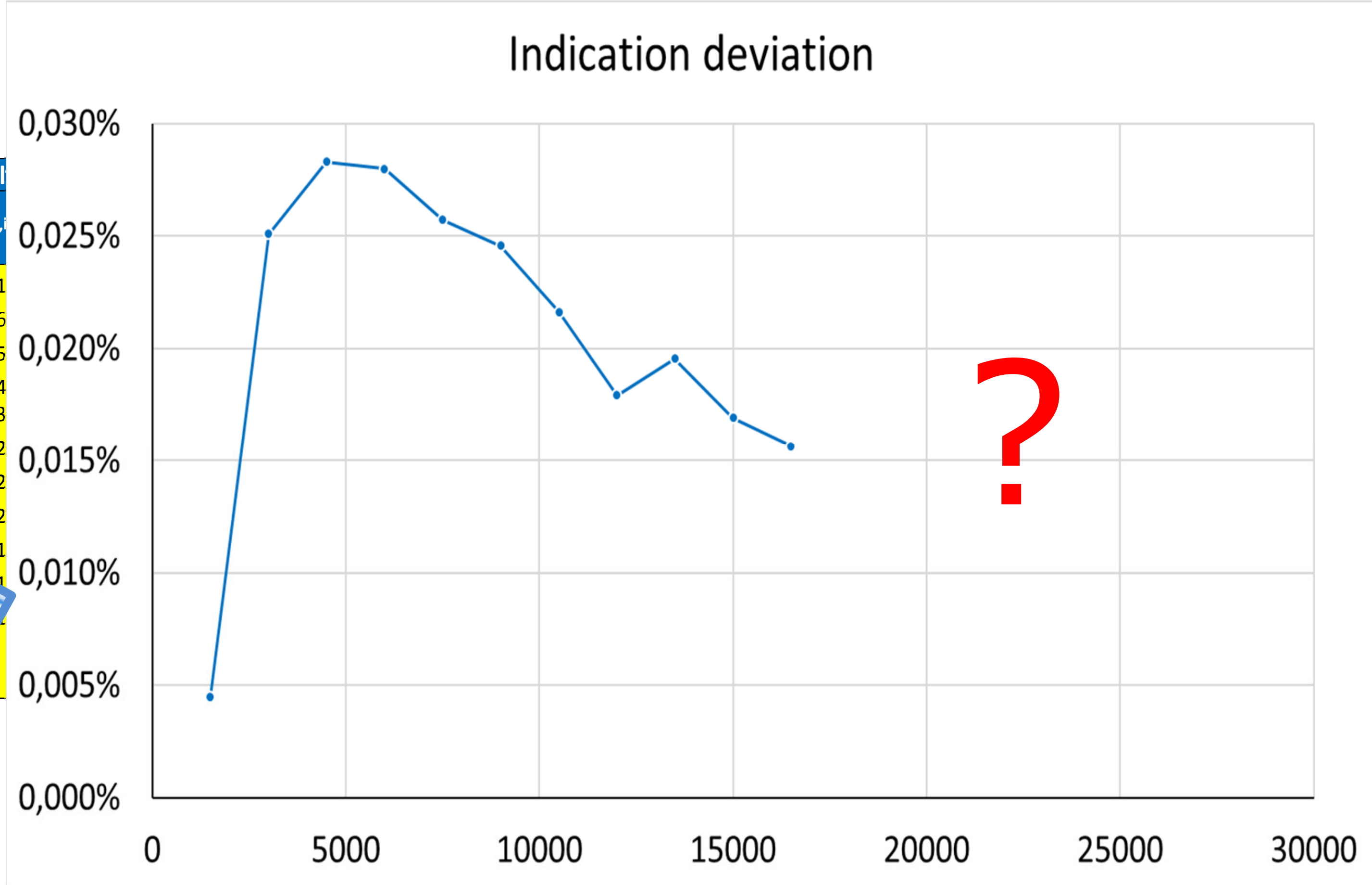


***sensitivity* and uncertainties**

Extraction of d_L´

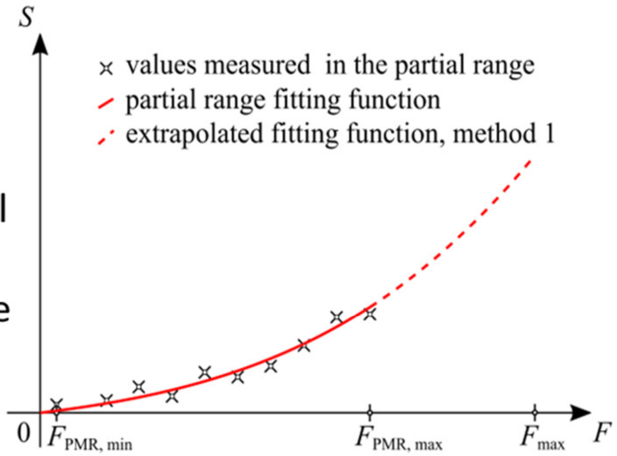
Load Step		Indication deviation		Calibration result	
F_{LS} kN	$W(F_{LS})$ %	d_L %	$U(d_L)$ %	$F_{S,int}$ kN	$W(F_{S,i}$ %
[illegible]	[illegible]	0,005%	0,022%	1500,43	0,031
[illegible]	[illegible]	0,025%	0,022%	3000,84	0,026
4500	[illegible]	[illegible]	0,022%	4501,21	0,025
6000	[illegible]	[illegible]	0,021%	6001,55	0,024
7500	[illegible]	[illegible]	[illegible]	7501,84	0,023
9000	0,010%	[illegible]	[illegible]	9002,09	0,022
10500	0,010%	[illegible]	[illegible]	10502,29	0,022
12000	0,010%	0,018%	[illegible]	[illegible]	0,022
13500	0,010%	0,020%	[illegible]	[illegible]	0,021
15000	0,010%	0,017%	0,021%	[illegible]	[illegible]
16500	0,010%	0,016%	0,021%	[illegible]	[illegible]

https://www.ptb.de/emrp/3294.html

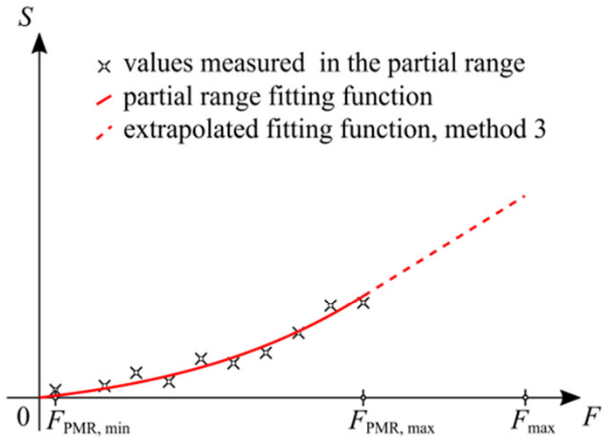


Extrapolation of d_L'

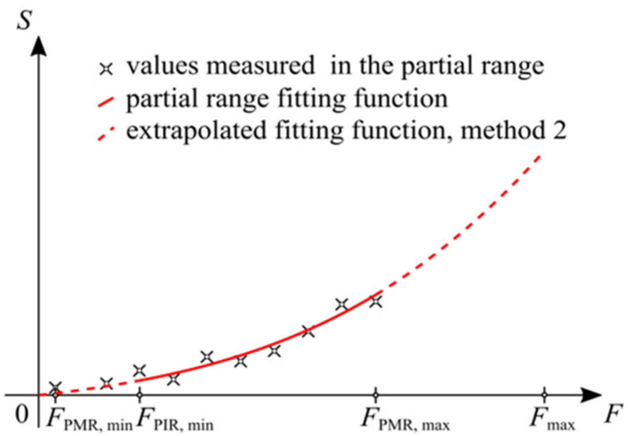
Method 1:
The fitting function found for the partial range is used in the full measuring range



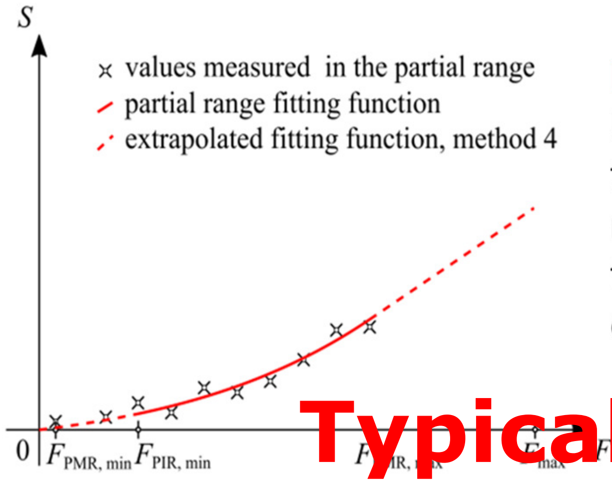
Method 3:
Uses the fitting function found in method 1 with the difference that its extension to larger forces follows the tangent to the function in the end point of the partial range



Method 2:
Many transducers show a nonlinear behaviour at lowest forces. This range is not used for the calculation of the partial range fitting function.



Method 4:
Uses the fitting function found in method 2 with a nonlinear behaviour at lowest forces and the tangent at the endpoint as method 3



Typical for BUS

Extrapolation of d_{L}´

„Engine for type of extrapolation"

- Developed for the extrapolation of force transducer signals in case of a partial calibration (EMRP, Task 1.6). This works also for d_{L}.
- Compares two partial calibrations to find the best strategy to extrapolate from smaller to bigger partial calibration.
- Deviation is shown in colors according to ISO 376 classes. (green 00, yellow 05, orange 1, red 2, blue none)

Detailed information in the final report of the EMRP project on its homepage

Summary:

EXTRAPOLATION1

MR1		linear: Extrapolated characteristic curve of				quadratic: Extrapolated characteristic curve of				cubic: Extrapolated characteristic curve of			
Force in k	Mean	75%	50%	30%	0%	75%	50%	30%	0%	75%	50%	30%	0%
100	-0.041493	-0.508%	-0.347%	-0.251%	#NV	-0.028%	-0.043%	-0.127%	#NV	-0.047%	-0.101%	-0.197%	#NV
250	-0.103662	-0.440%	-0.279%	-0.184%	#NV	0.015%	0.000%	-0.076%	#NV	-0.002%	-0.046%	-0.123%	#NV
500	-0.207283	-0.420%	-0.260%	-0.164%	#NV	-0.008%	-0.021%	-0.085%	#NV	-0.021%	-0.051%	-0.102%	#NV
1000	-0.414359	-0.371%	-0.210%	-0.114%	#NV	-0.042%	-0.053%	-0.093%	#NV	-0.049%	-0.058%	-0.083%	#NV
1500	-0.621045	-0.291%	-0.130%	-0.034%	#NV	-0.047%	-0.055%	-0.072%	#NV	-0.049%	-0.048%	-0.081%	#NV
2000	-0.827309	-0.201%	-0.040%	0.056%	#NV	-0.041%	-0.046%	-0.039%	#NV	-0.040%	-0.040%	-0.113%	#NV
2500	-1.033224	-0.113%	0.048%	0.145%	#NV	-0.037%	-0.040%	-0.009%	#NV	-0.035%	-0.046%	-0.194%	#NV
3000	-1.238790	-0.026%	0.136%	0.232%	#NV	-0.035%	-0.034%	0.020%	#NV	-0.033%	-0.067%	-0.321%	#NV
3500	-1.444059	0.057%	0.218%	0.315%	#NV	-0.037%	-0.034%	0.044%	#NV	-0.038%	-0.104%	-0.499%	#NV
4000	-1.648976	0.141%	0.302%	0.399%	#NV	-0.039%	-0.032%	0.070%	#NV	-0.043%	-0.153%	-0.722%	#NV
4500	-1.853609	0.221%	0.383%	0.479%	#NV	-0.043%	-0.034%	0.092%	#NV	-0.053%	-0.217%	-0.994%	#NV
5000	-2.057923	0.301%	0.463%	0.559%	#NV	-0.048%	-0.037%	0.113%	#NV	-0.066%	-0.295%	-1.314%	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV

EXTRAPOLATION2

MR1		linear: Extrapolated characteristic curve of				quadratic: Extrapolated characteristic curve of				cubic: Extrapolated characteristic curve of			
Force in k	Mean	75%	50%	30%	0%	75%	50%	30%	0%	75%	50%	30%	0%
100	-0.041493	-0.509%	-0.348%	-0.251%	#NV	-0.024%	-0.038%	-0.122%	#NV	-0.028%	-0.087%	-0.188%	#NV
250	-0.103662	-0.441%	-0.280%	-0.184%	#NV	0.019%	0.005%	-0.072%	#NV	0.015%	-0.034%	-0.117%	#NV
500	-0.207283	-0.421%	-0.260%	-0.164%	#NV	-0.004%	-0.017%	-0.082%	#NV	-0.007%	-0.042%	-0.099%	#NV
1000	-0.414359	-0.372%	-0.210%	-0.114%	#NV	-0.039%	-0.050%	-0.092%	#NV	-0.041%	-0.055%	-0.084%	#NV
1500	-0.621045	-0.292%	-0.131%	-0.035%	#NV	-0.045%	-0.053%	-0.073%	#NV	-0.045%	-0.049%	-0.080%	#NV
2000	-0.827309	-0.202%	-0.040%	0.056%	#NV	-0.039%	-0.046%	-0.042%	#NV	-0.039%	-0.041%	-0.107%	#NV
2500	-1.033224	-0.114%	0.048%	0.144%	#NV	-0.037%	-0.041%	-0.014%	#NV	-0.036%	-0.046%	-0.178%	#NV
3000	-1.238790	-0.027%	0.135%	0.232%	#NV	-0.035%	-0.037%	0.013%	#NV	-0.035%	-0.062%	-0.291%	#NV
3500	-1.444059	0.056%	0.218%	0.315%	#NV	-0.038%	-0.037%	0.036%	#NV	-0.038%	-0.092%	-0.450%	#NV
4000	-1.648976	0.139%	0.302%	0.398%	#NV	-0.040%	-0.037%	0.059%	#NV	-0.040%	-0.131%	-0.650%	#NV
4500	-1.853609	0.220%	0.382%	0.479%	#NV	-0.045%	-0.040%	0.079%	#NV	-0.047%	-0.184%	-0.894%	#NV
5000	-2.057923	0.300%	0.462%	0.559%	#NV	-0.051%	-0.044%	0.099%	#NV	-0.054%	-0.247%	-1.182%	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV

EXTRAPOLATION3

MR1		linear: Extrapolated characteristic curve of				quadratic: Extrapolated characteristic curve of				cubic: Extrapolated characteristic curve of			
Force in k	Mean	75%	50%	30%	0%	75%	50%	30%	0%	75%	50%	30%	0%
100	-0.041493	-0.508%	-0.347%	-0.251%	#NV	-0.028%	-0.043%	-0.127%	#NV	-0.047%	-0.101%	-0.197%	#NV
250	-0.103662	-0.440%	-0.279%	-0.184%	#NV	0.015%	0.000%	-0.076%	#NV	-0.002%	-0.046%	-0.123%	#NV
500	-0.207283	-0.420%	-0.260%	-0.164%	#NV	-0.008%	-0.021%	-0.085%	#NV	-0.021%	-0.051%	-0.102%	#NV
1000	-0.414359	-0.371%	-0.210%	-0.114%	#NV	-0.042%	-0.053%	-0.093%	#NV	-0.049%	-0.058%	-0.083%	#NV
1500	-0.621045	-0.291%	-0.130%	-0.034%	#NV	-0.047%	-0.055%	-0.080%	#NV	-0.049%	-0.048%	-0.080%	#NV
2000	-0.827309	-0.201%	-0.040%	0.056%	#NV	-0.041%	-0.046%	-0.031%	#NV	-0.040%	-0.040%	-0.064%	#NV
2500	-1.033224	-0.113%	0.048%	0.145%	#NV	-0.037%	-0.044%	0.033%	#NV	-0.035%	-0.044%	-0.021%	#NV
3000	-1.238790	-0.026%	0.136%	0.232%	#NV	-0.035%	-0.024%	0.103%	#NV	-0.033%	-0.041%	0.035%	#NV
3500	-1.444059	0.057%	0.218%	0.315%	#NV	-0.037%	0.010%	0.174%	#NV	-0.038%	-0.019%	0.097%	#NV
4000	-1.648976	0.141%	0.302%	0.399%	#NV	-0.036%	0.057%	0.249%	#NV	-0.038%	0.019%	0.164%	#NV
4500	-1.853609	0.221%	0.383%	0.479%	#NV	-0.022%	0.110%	0.322%	#NV	-0.028%	0.064%	0.232%	#NV
5000	-2.057923	0.301%	0.463%	0.559%	#NV	0.005%	0.167%	0.397%	#NV	-0.004%	0.116%	0.302%	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV

EXTRAPOLATION4

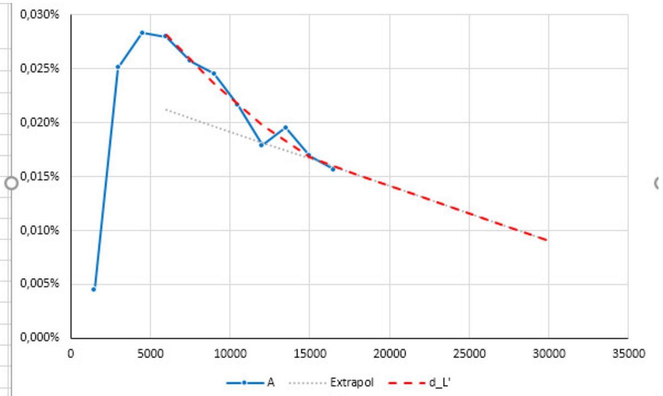
MR1		linear: Extrapolated characteristic curve of				quadratic: Extrapolated characteristic curve of				cubic: Extrapolated characteristic curve of			
Force in k	Mean	75%	50%	30%	0%	75%	50%	30%	0%	75%	50%	30%	0%
100	-0.041493	-0.509%	-0.348%	-0.251%	#NV	-0.024%	-0.038%	-0.122%	#NV	-0.028%	-0.087%	-0.188%	#NV
250	-0.103662	-0.441%	-0.280%	-0.184%	#NV	0.019%	0.005%	-0.072%	#NV	0.015%	-0.034%	-0.117%	#NV
500	-0.207283	-0.421%	-0.260%	-0.164%	#NV	-0.004%	-0.017%	-0.082%	#NV	-0.007%	-0.042%	-0.099%	#NV
1000	-0.414359	-0.372%	-0.210%	-0.114%	#NV	-0.039%	-0.050%	-0.092%	#NV	-0.041%	-0.055%	-0.084%	#NV
1500	-0.621045	-0.292%	-0.131%	-0.035%	#NV	-0.045%	-0.053%	-0.080%	#NV	-0.045%	-0.049%	-0.080%	#NV
2000	-0.827309	-0.202%	-0.040%	0.056%	#NV	-0.039%	-0.046%	-0.032%	#NV	-0.039%	-0.041%	-0.062%	#NV
2500	-1.033224	-0.114%	0.048%	0.144%	#NV	-0.037%	-0.044%	0.030%	#NV	-0.036%	-0.044%	-0.017%	#NV
3000	-1.238790	-0.027%	0.135%	0.232%	#NV	-0.035%	-0.025%	0.100%	#NV	-0.035%	-0.039%	0.041%	#NV
3500	-1.444059	0.056%	0.218%	0.315%	#NV	-0.038%	0.008%	0.170%	#NV	-0.038%	-0.014%	0.103%	#NV
4000	-1.648976	0.139%	0.302%	0.398%	#NV	-0.036%	0.055%	0.245%	#NV	-0.037%	0.025%	0.171%	#NV
4500	-1.853609	0.220%	0.382%	0.479%	#NV	-0.023%	0.106%	0.318%	#NV	-0.024%	0.071%	0.239%	#NV
5000	-2.057923	0.300%	0.462%	0.559%	#NV	0.003%	0.163%	0.392%	#NV	0.001%	0.124%	0.309%	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV
#NV		#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV

EXTRAPOLATION1 linear quadratic cubic

Extrapolation of d_L´

Load Step FLS kN	Indication deviation dL %	U(dL) %	dL (FitA) %
1500,00	0,005%	0,022%	0,035%
3000,00	0,025%	0,022%	0,033%
4500,00	0,028%	0,022%	0,030%
6000,00	0,028%	0,021%	0,028%
7500,00	0,026%	0,021%	0,026%
9000,00	0,025%	0,021%	0,024%
[illegible]	0,022%	0,021%	0,022%
[illegible]	0,018%	0,021%	0,020%
[illegible]	0,020%	0,021%	0,018%
[illegible]	[illegible]	0,021%	0,017%
[illegible]	[illegible]	0,021%	0,016%

Load Step FLS kN	Indication deviation dL %	U(dL) %	dL (FitB) %
3000	0,103%	0,103%	0,106%
4500	0,116%	0,103%	0,112%
6000	0,112%	0,102%	0,109%
7500	0,097%	0,102%	0,100%
9000	0,084%	0,102%	0,086%
10500	0,068%	0,102%	0,070%
12000	0,054%	0,102%	0,053%
13500	0,040%	0,102%	0,038%
15000	0,028%	0,102%	0,025%
16500	0,016%	0,102%	0,018%

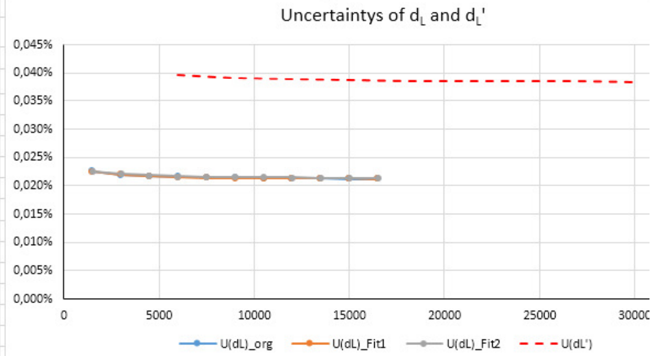


Extrapolati[illegible]

Load Step FLS kN	U_{org} / %	U_{Fit1} / [illegible]	[illegible]	[illegible]
1500,00	0,022%	0,022%	[illegible]	[illegible]
3000,00	0,022%	0,022%	1,20E-[illegible]	[illegible]
4500,00	0,022%	0,022%	4,36E-07	[illegible]
6000,00	0,021%	0,021%	-2,63E-07	0,02[illegible]
7500,00	0,021%	0,021%	-5,45E-07	0,021%
9000,00	0,021%	0,021%	-4,53E-07	0,021%
10500,00	0,021%	0,021%	-1,28E-07	0,021%
12000,00	0,021%	0,021%	2,46E-07	0,021%
13500,00	0,021%	0,021%	4,54E-07	0,021%
15000,00	0,021%	0,021%	3,07E-07	0,021%
16500,00	0,021%	0,021%	-4,19E-07	0,021%

Results of the extrapolation:

Load Step FLS kN	Indication deviation dL' %	U(dL') %
6000	0,028%	0,040%
[illegible]	0,024%	0,039%
[illegible]	0,020%	0,039%
[illegible]	0,017%	0,039%
[illegible]	0,015%	0,039%
[illegible]	0,014%	0,039%
[illegible]	0,012%	0,038%
[illegible]	0,011%	0,038%
30000	0,009%	0,038%



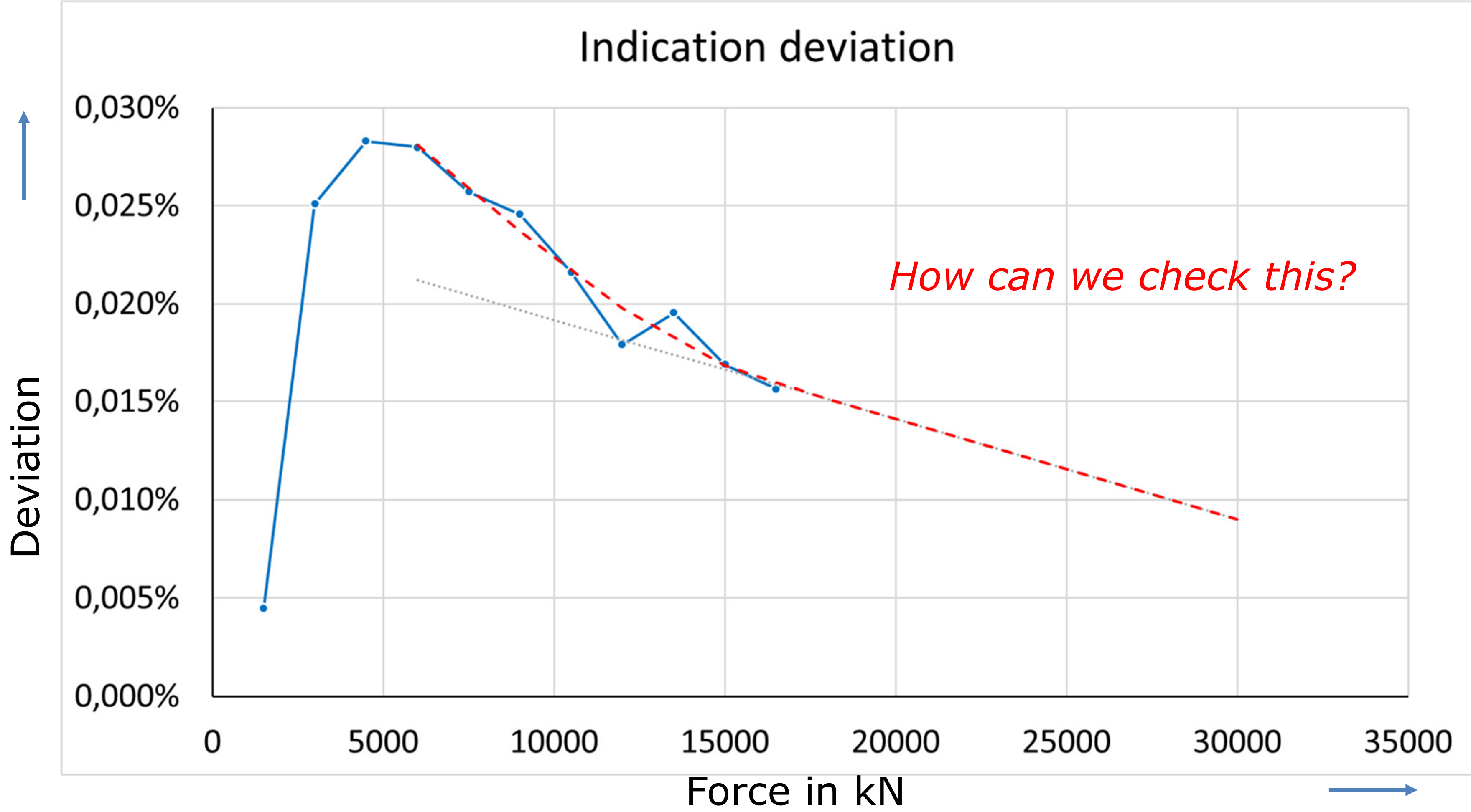
Fits:

	a_1	a_2	a_3	a_4
	$d_L(F) = a_1 \cdot F + a_2 \cdot F^2 + a_3 \cdot F^3 + a4$			
A:	-1,255E-08	-4,658E-13	2,797E-17	3,671E-04
B:	2,319E-07	-3,138E-11	9,517E-16	6,248E-04
1:	-4,369E-09	3,786E-13	-1,100E-17	2,297E-04
2:	-4,369E-09	3,786E-13	-1,100E-17	2,309E-04

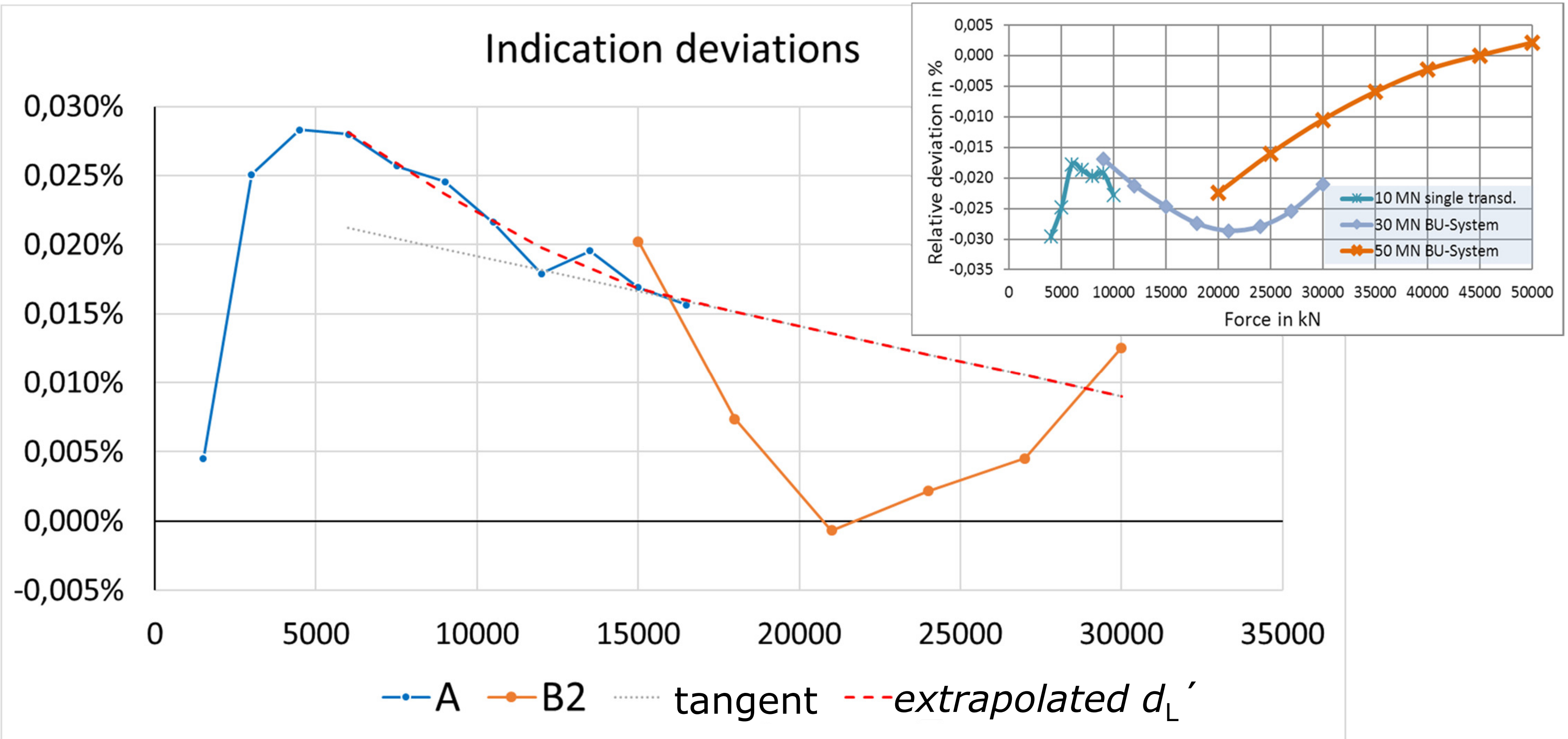
Tangente	Korrektur:
-5,08E-09	0,00E+00
2,43E-04	0,00E+00
m:	1,8

https://www.ptb.de/emrp/3294.html

Extrapolation of $d_L{}'$



Extrapolation of d_L´



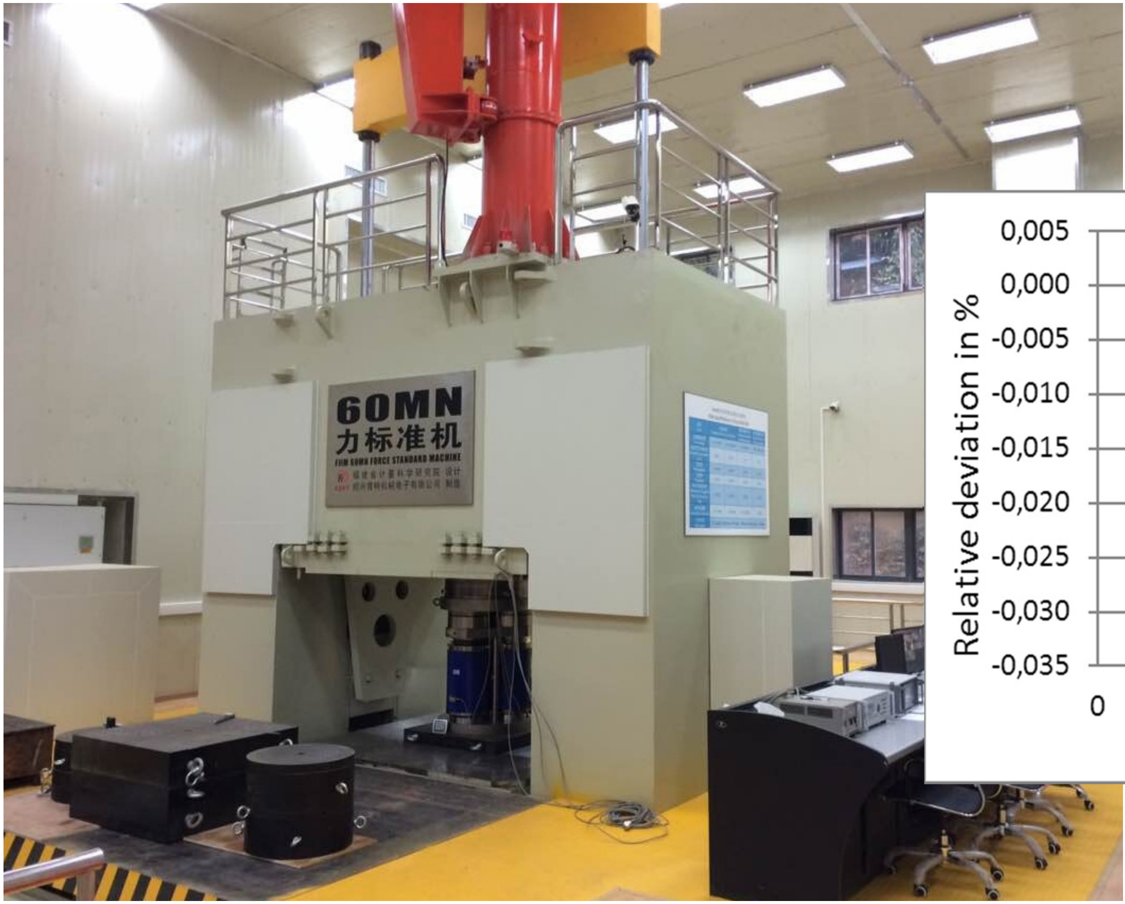
Advanced 50 MN BU-System using VN class LF transducers

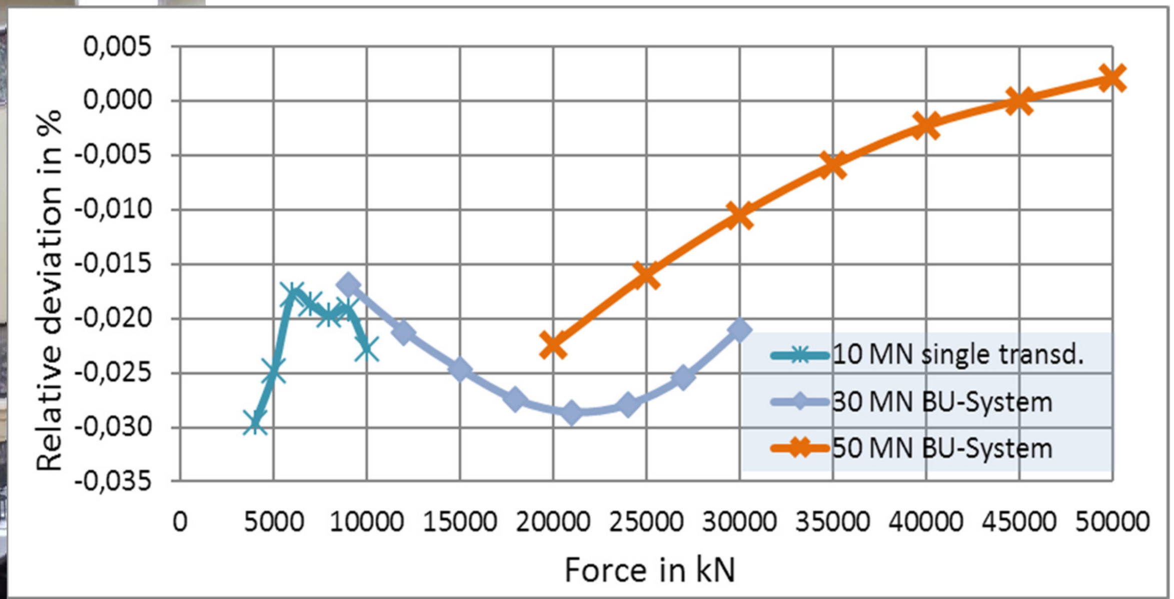
uncertainty contributions			
rotation w_2	repeatability w_3	creep w_5	drift of the zero signal w_6
0,002%	0,002%	0,004%	0,006%
0,002%	0,001%	0,004%	0,006%
0,002%	0,000%	0,004%	0,006%
0,002%	0,000%	0,004%	0,006%
0,001%	0,000%	0,004%	0,006%
0,001%	0,001%	0,004%	0,006%
0,001%	0,001%	0,004%	0,006%
0,001%	0,000%	0,004%	0,006%
0,000%	0,000%	0,004%	0,006%
0,000%	0,001%	0,004%	0,006%

Load Step		Indication deviation		Calibration result	
F_{LS} kN	$W(F_{LS})$ %	d %	$U(d_L)$ %	$F_{S.int}$ kN	$W(F_{S.int})$ %
1500	0.010%	0.005%	0.022%	1500.43	0.031%
3000	0.010%	0.025%	0.022%	3000.84	0.026%
4500	0.010%	0.028%	0.022%	4501.21	0.025%
6000	0.010%	0.028%	0.021%	6001.55	0.024%
7500	0.010%	0.026%	0.021%	7501.84	0.023%
9000	0.010%	0.025%	0.021%	9002.09	0.022%
10500	0.010%	0.022%	0.021%	10502.29	0.022%
12000	0.010%	0.018%	0.021%	12002.44	0.022%
13500	0.010%	0.020%	0.021%	13502.53	0.021%
15000	0.010%	0.017%	0.021%	15002.57	0.021%
16500	0.010%	0.016%	0.021%	16502.53	0.021%

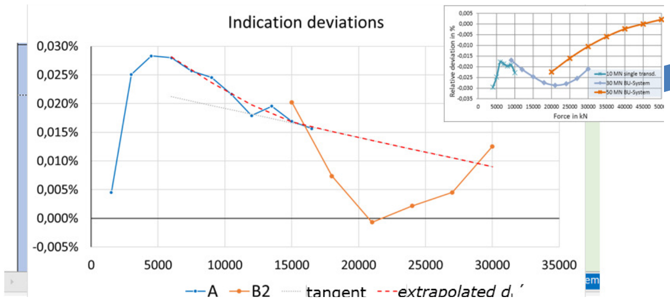
- 5 single transducer class 00 according to ISO 376 (even VN class as a better class in GTM´s notification)
- Highly effective compensation of bending moments and cross forces. reproducibility is much lower than 0.01%
- Ultracompact. stiff structure
- The low sensitivity against cross forces and the effective reduction of the generation of such components by the stiffness result in a very low indication deviation d of the system

Comparison with the 60 MN FSM at FJIM – overall results





Generating an ISO 7500-1 Certificate using BUS

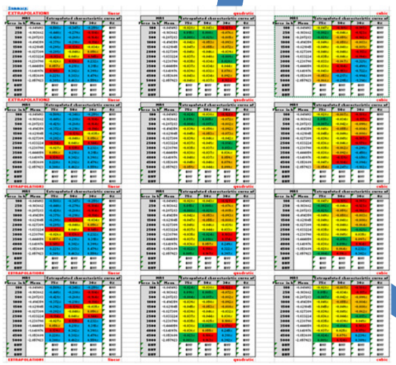


Verification B2 measurement

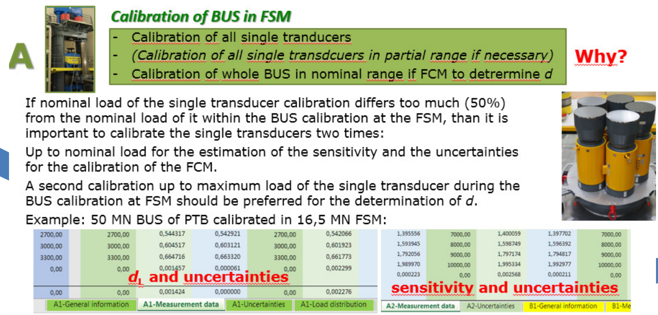
https://www.ptb.de/emrp/3294.html

$$F'_{\mathrm{cal}} = \frac{1}{m(1+d'_{\mathrm{L}})}\sum_{j=1}^{m} F'_{\mathrm{S}.j} = \frac{F'_{\mathrm{S}}}{(1+d'_{\mathrm{L}})}$$

BUS evaluation template of EMRP SIB 63



„Extrapolation Engine" for *d*



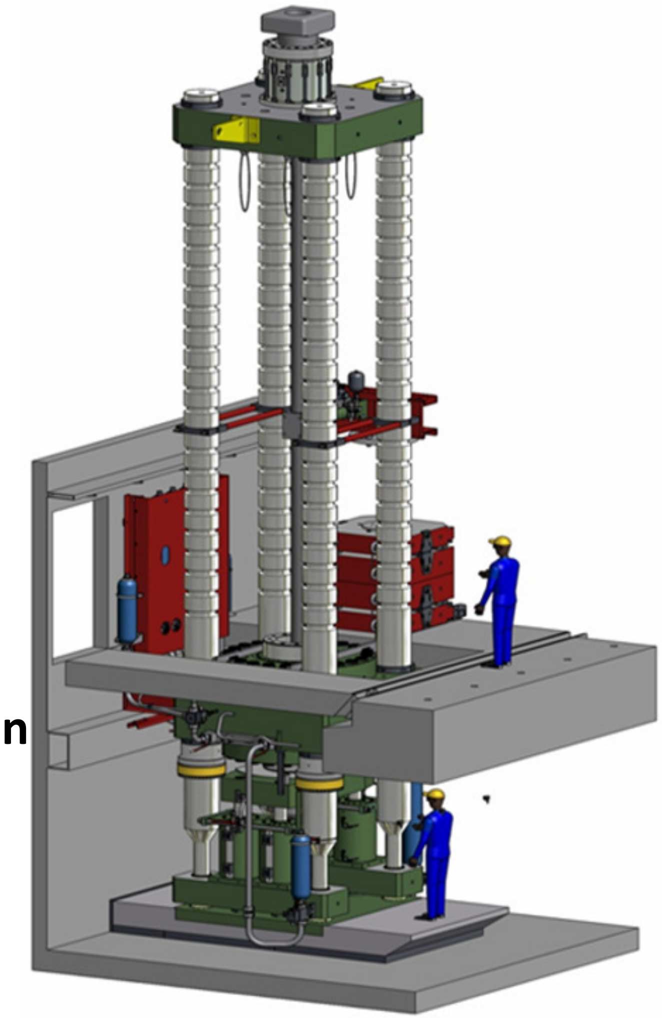
Partial A2 calibration if necessary

ISO 7500-1

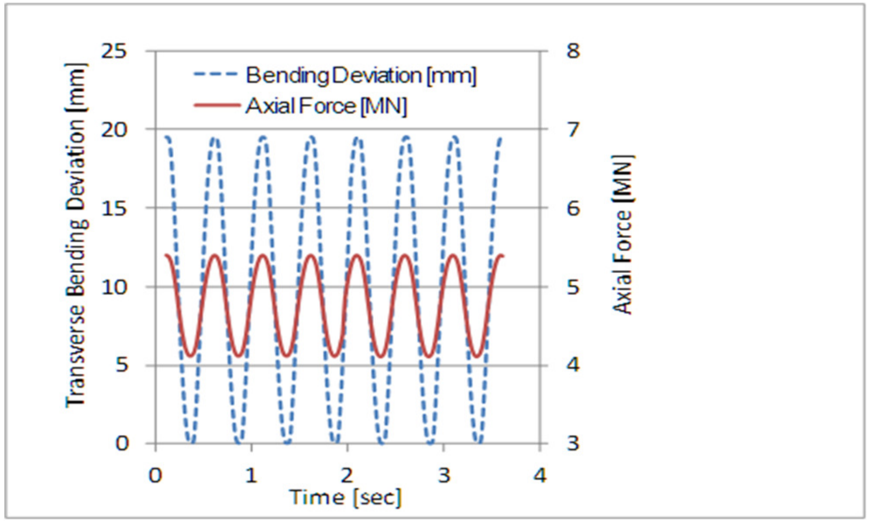
"Qualified" BUS

30 MN material testing machine of the iBMB/MPA Braunschweig

- **Static / dynamic force in tension and compression**
  - max. stat. / dyn. Force: 33 MN / 24 MN
  - max. piston stroke : 0.4 m
  - max. frequency: 5 Hz (at 5 mm stroke)
- **Dimension of test specimen in tension**
  - max. length: 10.3 m
  - max. diameter at the anchor coupler : 0.5 m
- **Dimension of test specimen in compression**
  - max. height: 5.0 m
  - max. diameter: 1.1 m / 1.1 m



30 MN material testing machine of the iBMB/MPA Braunschweig



Dynamic test of a bridge stay cable

Forth Replacement Crossing Queensferry Bridge, Edinburgh/Scotland

- Axial dynamic load
- Synchronized bending moment loaded to the stay cable to investigate influence of wind/rain induced sideway swinging

3. Prüfmittel/*Test equipment*

3.1 Kraftaufnehmer/*Force transducer*

30 MN Build-Up System mit elektrischer Verformungsmessung (PTB)
30 MN Build-Up system with electrical deformation measurement (PTB)

Hersteller: / *Manufacturer:* GTM Testing and Metrology GmbH, 64404 Bickenbach

Typ: / *Type:* 3 x 10 MN LF

Seriennummern: / *Serial numbers:* 64042; 64053; 64111

3.2 Anzeigegerät/*Display device*

Digitales Anzeigegerät: / *Digital indicator:* Typ: DMP 41, Nr.: 819192502 PTB

Hersteller: / *Manufacturer:* Hottinger Baldwin Messtechnik GmbH, 64293 Darmstadt

Messkanäle / *Measuring channels:* 1-3

Kalibrierwert: / *Calibration signal:* 2,500001

Auflösung in mV/V: / *Resolution in mV/V:* 0,000001

Speisespannung: / *Excitation voltage:* 5 V

Tiefpassfilter: / *Low-pass filter:* 0,10 Hz Be

Messbereich: / *Measuring range:*

3.3 Gültigkeit der Kalibrierung/*Validity of the calibration*

Kalibrierzeichen: / *Calibration mark:* 12209 PTB 16; 12212 PTB 16; 12213 PTB 16

Gültigkeit bis: / *Valid until:* 24.11.2018

$$q = \Delta F(F'_S) = F_i(F'_S) - F'_{cal}(F'_S)$$

Tabelle 7: Mean values of the force indication of the standard, absolute and relative resolution of the test machine, mean value of the indication deviation, repeatability

Kraft in kN *Force in kN* F	Mittelwert in kN *mean value in kN* $\bar{F}$	Auflösung der Anzeige der Prüfmaschine in kN *Indicated resolution of the testing machine in kN* r	Relative Auflösung in % *Relative indication resolution in %* a	Mittlere Anzeige-abweichung in % *Indication deviation in %* q	Wiederhol-präzision in % *Repeatability in %* b
3000	2987,61	0,1	0,003	0,415	0,164
6000	5973,53	0,1	0,002	0,443	0,065
9000	8994,81	0,1	0,001	0,058	0,038
12000	12007,85	0,1	0,001	-0,065	0,032
15000	14999,84	0,1	0,001	0,001	0,024
18000	17981,42	0,1	0,001	0,103	0,031
21000	20972,01	0,1	0,000	0,133	0,015
24000	23983,24	0,1	0,000	0,070	0,023
27000	27002,49	0,1	0,000	-0,009	0,020
30000	29979,42	0,1	0,000	0,069	0,028

ISO 7500-1 Certificate


Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Kalibrierschein
Calibration Certificate

Gegenstand: *Object:* Zug-Druckprüfmaschine 30 MN *Tension/compression testing machine*

Hersteller: *Manufacturer:*

Typ: *Type:*

Kennnummer: *Serial No.:*

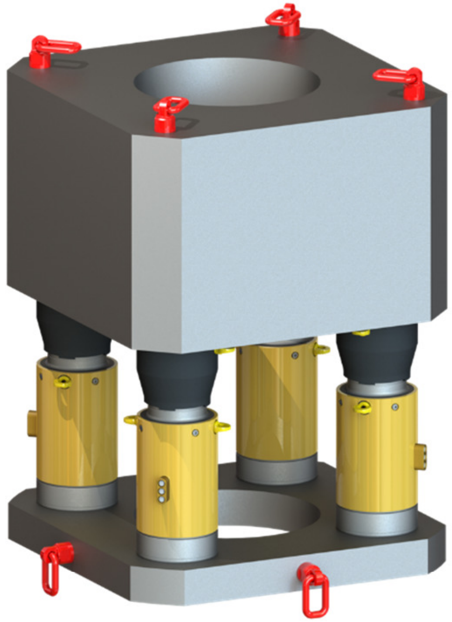
Auftraggeber: *Applicant:*

PTB

“Competence Center Large Force”

iBMB MPA TU BRAUNSCHWEIG

Calibration of the Transfer-Standard in PTB´s 16,5 MN FSM



Dissemination of the quantity Force to the new 30 MN Reference System

Thank you very much for your attention !

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Bundesallee 100
38116 Braunschweig / GERMANY

Dr. Falk Tegtmeier
Working group 1.23 „Force Measuring Technique“

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