ComTraForce – EMPIR project for continuous and dynamic force measurements

19th meeting of CCM – 25.-26. May 2023

Frank Hauschild

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Dr. Rolf Kumme (PTB)
E-Mail: comtraforce@ptb.de

Project Structure

ComTraForce

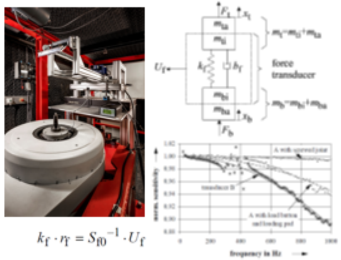
Sept. 2019

WP 1 Review of machines and standards (NPL)

- Overview of conditions and measurement systems at existing test stands

WP 2 Transfer standards – modelling & digital twin(PTB)

- Development of advanced practical models of force measuring devices
- Development of digital twins



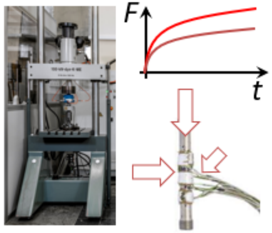
$k_f \cdot r_f = S_{f0}^{-1} \cdot U_f$

$m_t \cdot \ddot{r}_f + b_f \cdot \dot{r}_f + k_f \cdot r_f = F_t - m_t \cdot \ddot{x}_b$

$m_b \cdot \ddot{r}_f + b_f \cdot \dot{r}_f + k_f \cdot r_f = -F_b + m_b \cdot \ddot{x}_t$

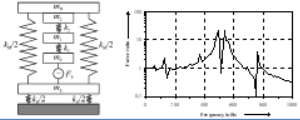
WP 3 Traceability chain for static and continuous force(NPL)

- Development of methods for continuous force measurement and multi-component transducers



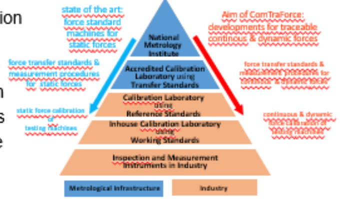
WP 4 Traceabilty chain for dynamic force (UStutt)

- Development of methods for dynamic force measurement



WP 5 Procedures & recommendations (PTB)

- Develop calibration procedure for continuous and dynamic loads in testing machines
- Validation of the procedures



WP 6 Creating impact (PTB)

- Interaction with stakeholders
- Publications, Workshops
- Input to standardisation

EURAMET guides
ISO standards

Conferences
Papers
Workshops

WP 7 Management & coordination (PTB)

Sept. 2022
Corona extension

Feb. 2023

Key Objectives

ComTraForce

- Review of existing testing machines and standards
- Developing advanced models and digital twins of force measuring devices
- Developing a force traceability chain for metrological services for static, continuous and dynamic forces
- Developing new recommendations and standards for static, continuous and dynamic forces
- Facilitation of the take up of the developed procedures for end users

The **overall aim** of the project was to provide calibration services, in the field of mechanical and material testing, with the methods and guidelines needed for comprehensive traceability of static, continuous and dynamic force measurements.

WP 1 Roadmap

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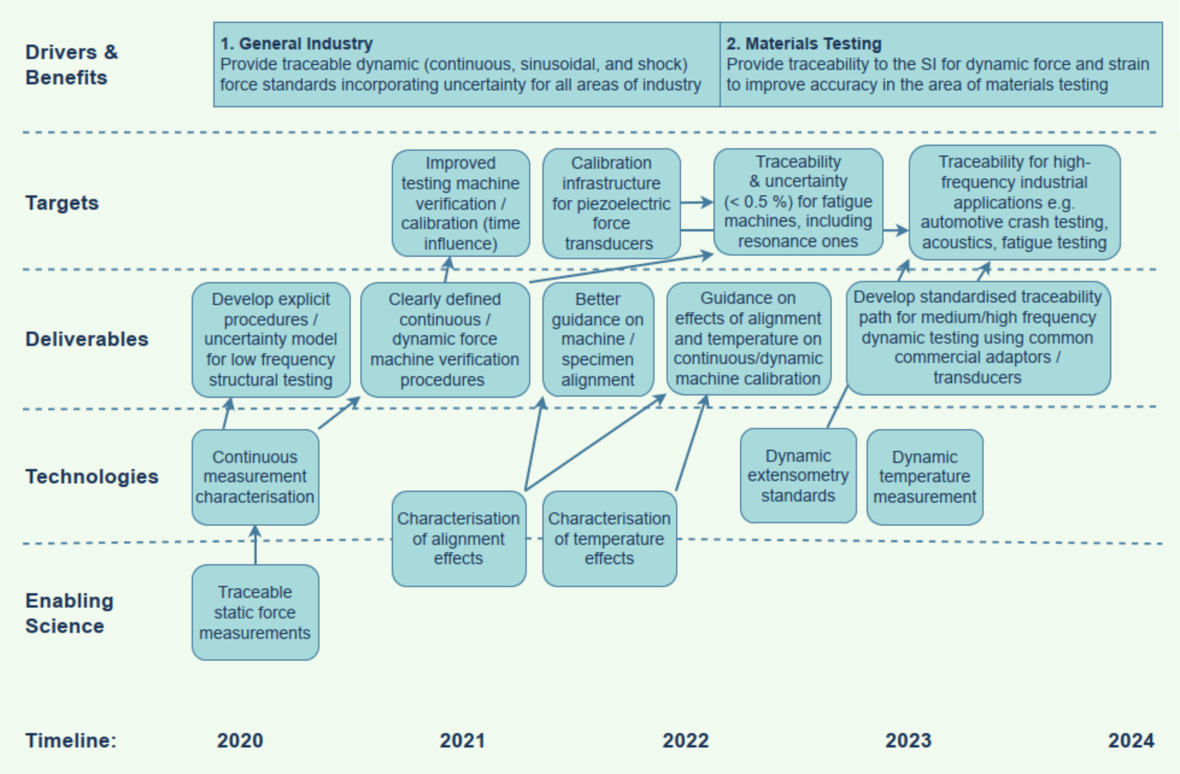


NPL National Physical Laboratory

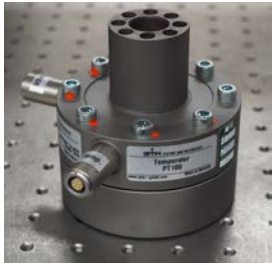
Deliverable 1

Source: https://www.ptb.de/empir2019/fileadmin/documents/empir-2019/ComTraForce/documents/04_Deliverables/ComTraforce_D1.pdf

WP 2 Selection of the Transfer Standards

ComTraForce

Piezoelectric force transducer – A_{PK} / ©Kistler



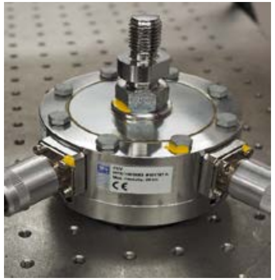
Strain gauge force transducer – B_{DMS} / ©GTM

Manufacturer information of the force transducer to be examined

		A_{PK}	B_{DMS}	C_{DMS}	D_{DMS}
Nominal force	F_{nom}	20 kN	20 kN	25 kN	25 kN
Measuring range		0.1 - 100 %	10 - 100 %	2 - 100 %	10 - 100 %
Interpolation error	f_c	0.5 % FSO	0.02 %	0.02 % FSO	0.04 %
Hysteresis	v		0.06 %	0.025 % FSO	0.09 %
Rotation	b	--	0.045 %	--	0.05 %
Repeatability	b'	--	0.023 %	0.005 %	0.02 %
Zero point deviation	f_0	--	0.01 %	--	0.01 %
Creep		--	0.01 %	0.01 % in 20 min	0.01 %
Temperature error on the characteristic value	TK_c	-0.02 %/K	0.001 %/K	0.0005 %/K	0.0015 %/K
Temperature error on the zero signal	TK_0	--	0.001 %/K	0.00025 %/K	0.00075 %/K
mass	m	0.33 kg	3.1 kg	4.1 kg	3.3 kg
Nominal temperature range	$B_{T, nom}$	--	17 to 27 °C	-10 to 45 °C	-10 to 45 °C
Operating temperature range	$B_{T, G}$	-40 to 120 °C	10 to 35 °C	-55 to 90 °C	-30 to 85 °C
Fundamental frequency	f_G	45 kHz	--	--	5.3 kHz
Rigidity	N/S	1.6 kN/µm	--	--	0.417 kN/µm

- Amplifier for strain gauge: DMP 40 and DMP 41 from HBM
  Dewetron DAQP- STG, Bridge-B
- Amplifier for PK: MGC Plus with ML01B (Voltage measurement)
- Charge amplifier for PK: Typ 5011B from Kistler

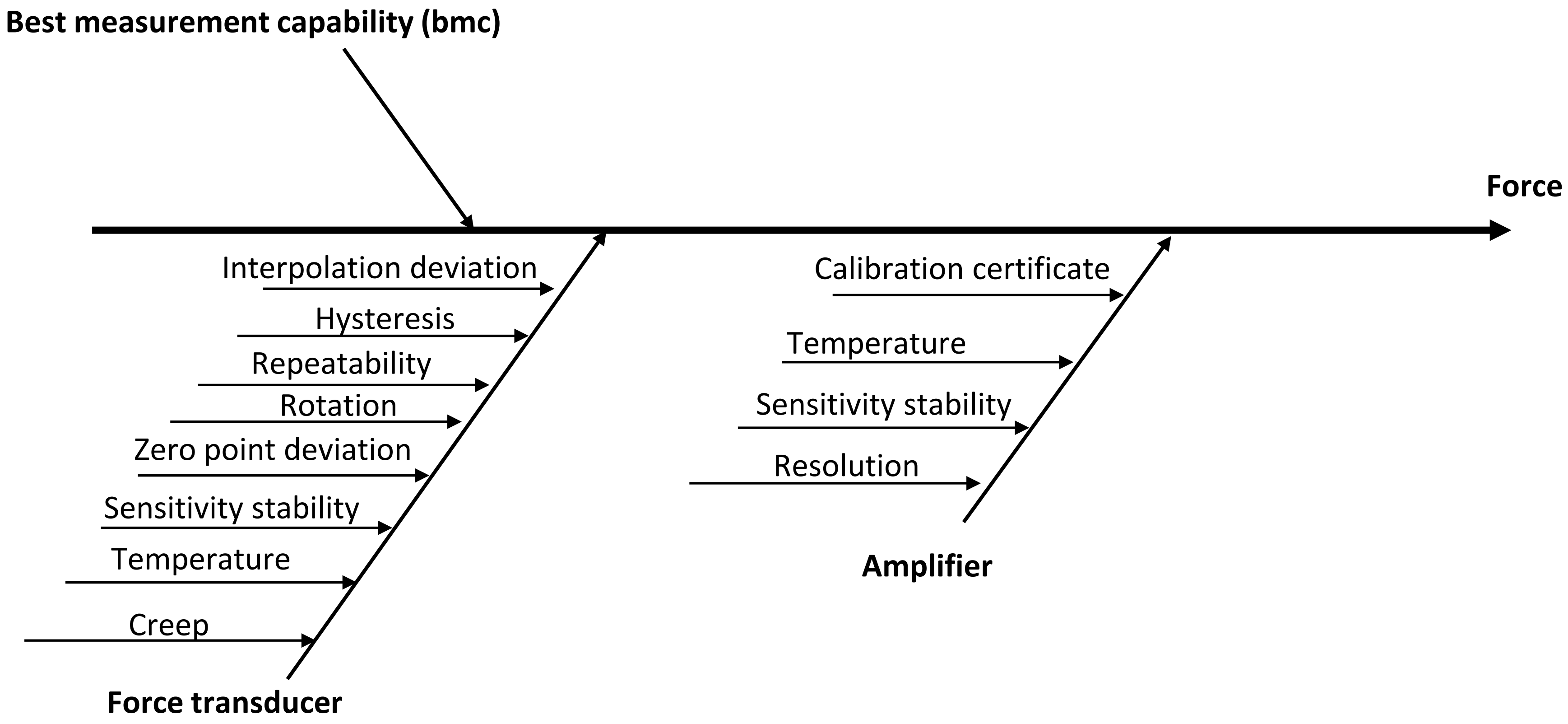
Strain gauge force transducer - C_{DMS}



Strain gauge force transducer – D_{DMS} / ©HBM

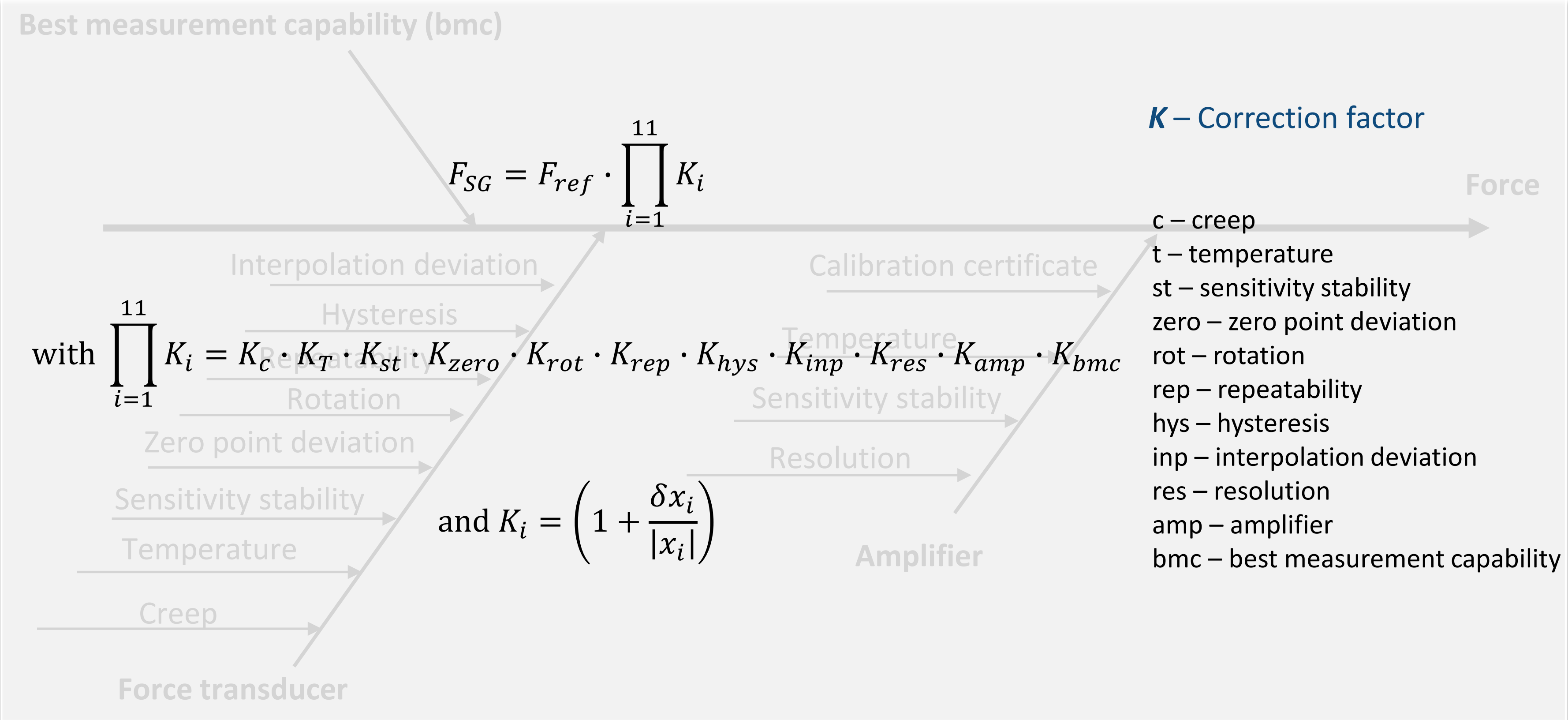
WP 2 Advanced Model Static - Strain Gauge

ComTraForce



WP 2 Advanced Model Static - Strain Gauge

ComTraForce



$$F_{SG} = F_{ref} \cdot \prod_{i=1}^{11} K_i$$

with $$\prod_{i=1}^{11} K_i = K_c \cdot K_T \cdot K_{st} \cdot K_{zero} \cdot K_{rot} \cdot K_{rep} \cdot K_{hys} \cdot K_{inp} \cdot K_{res} \cdot K_{amp} \cdot K_{bmc}$$

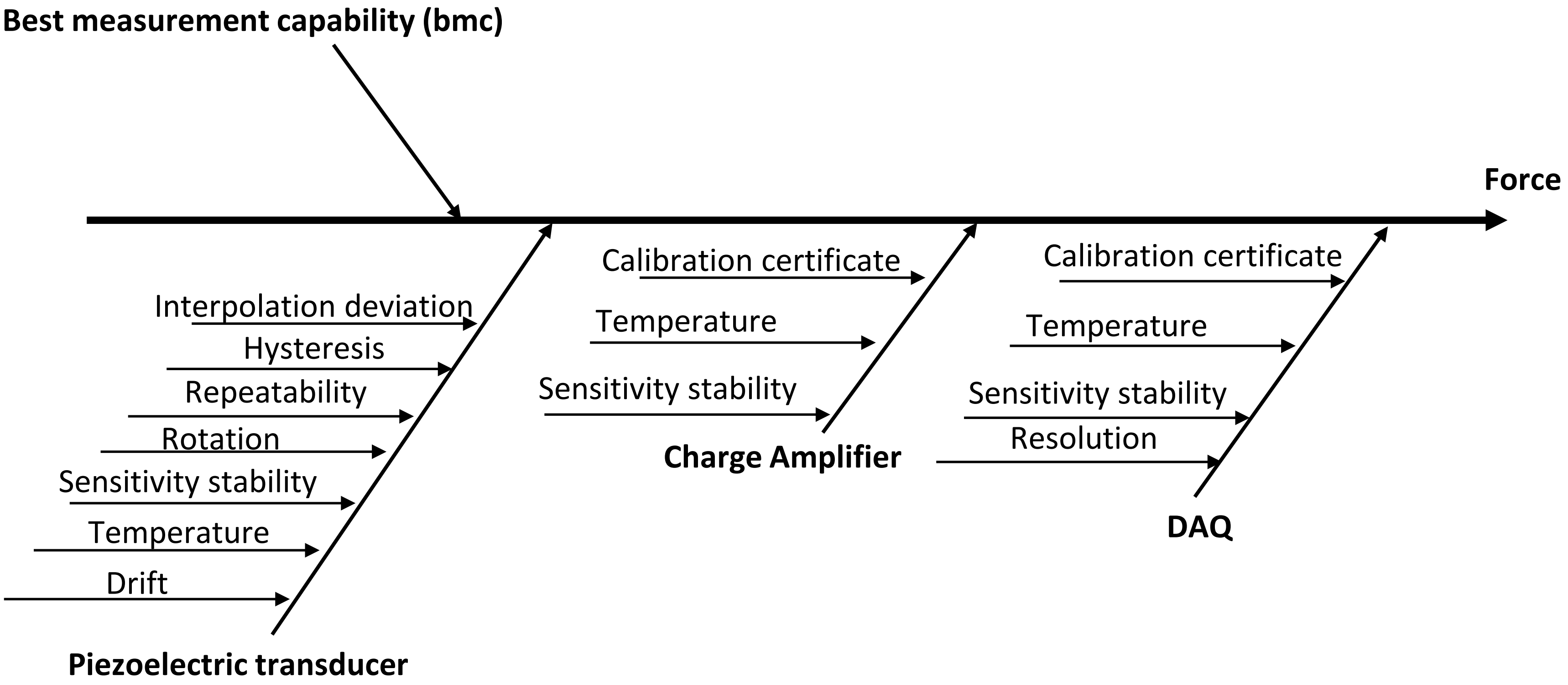
and $$K_i = \left(1 + \frac{\delta x_i}{|x_i|}\right)$$

K – Correction factor

c – creep
t – temperature
st – sensitivity stability
zero – zero point deviation
rot – rotation
rep – repeatability
hys – hysteresis
inp – interpolation deviation
res – resolution
amp – amplifier
bmc – best measurement capability

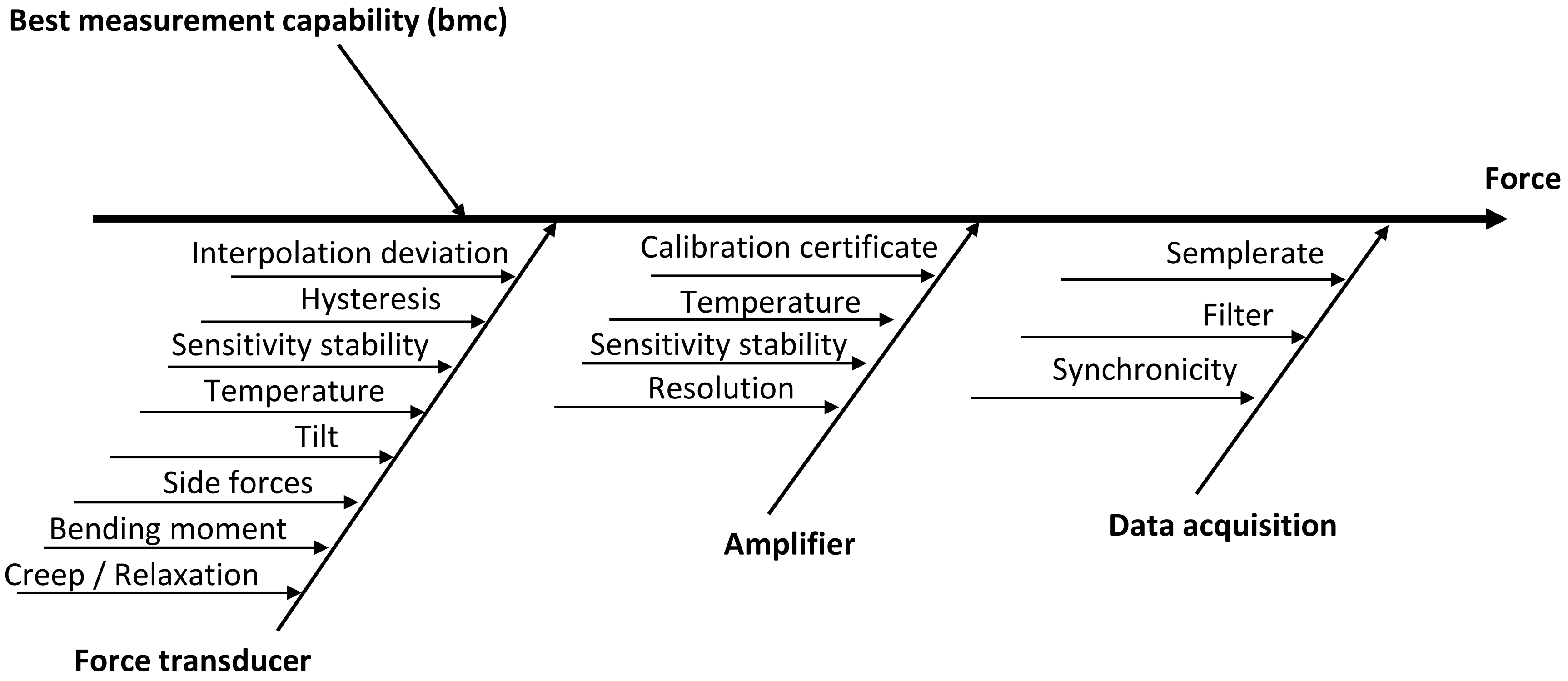
WP 2 Advanced Model Static - Piezoelectric

ComTraForce



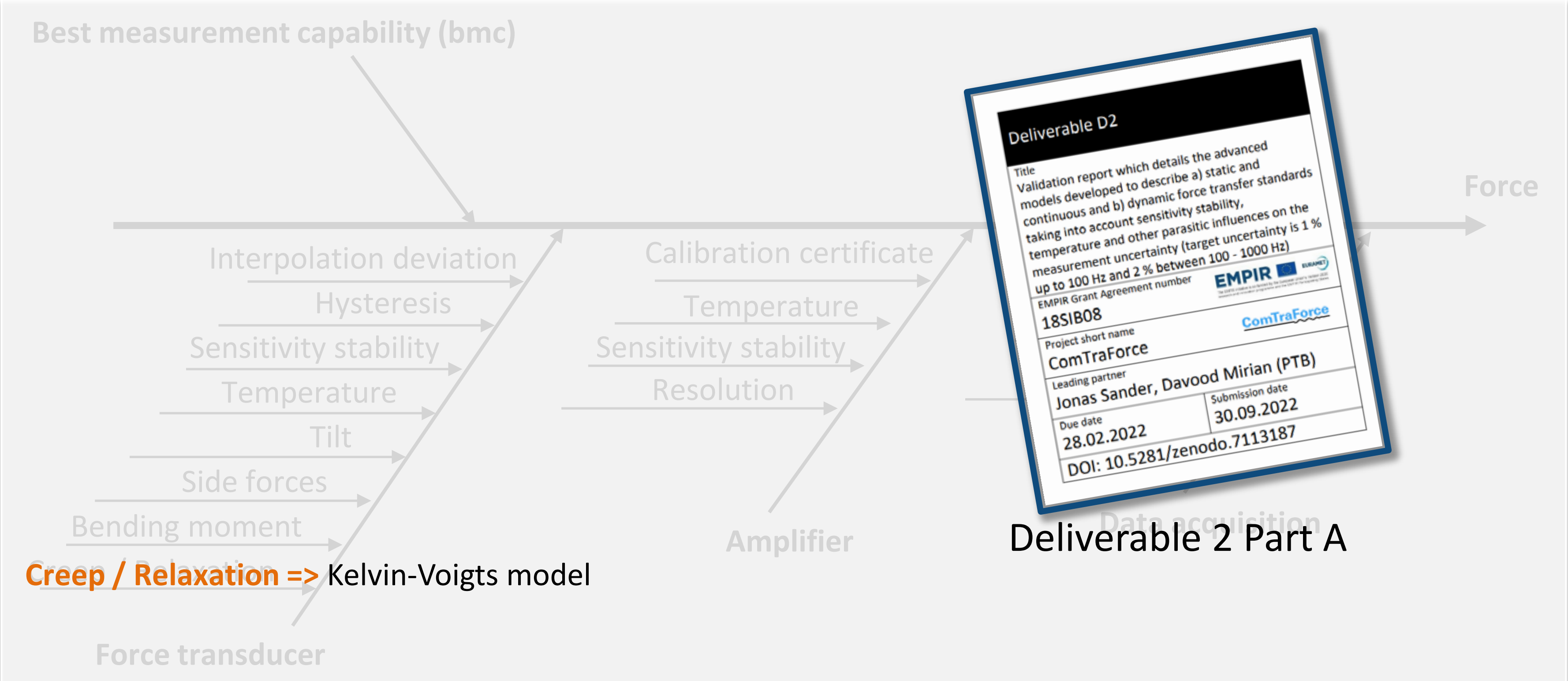
WP 2 Advanced Model Continuous

ComTraForce



WP 2 Advanced Model Continuous

ComTraForce



Deliverable D2

Title
Validation report which details the advanced models developed to describe a) static and continuous and b) dynamic force transfer standards taking into account sensitivity stability, temperature and other parasitic influences on the measurement uncertainty (target uncertainty is 1 % up to 100 Hz and 2 % between 100 - 1000 Hz)

EMPIR Grant Agreement number
18SIB08

Project short name
ComTraForce

Leading partner
Jonas Sander, Davood Mirian (PTB)

Due date
28.02.2022

Submission date
30.09.2022

DOI: 10.5281/zenodo.7113187

Creep / Relaxation => Kelvin-Voigts model

Deliverable 2 Part A

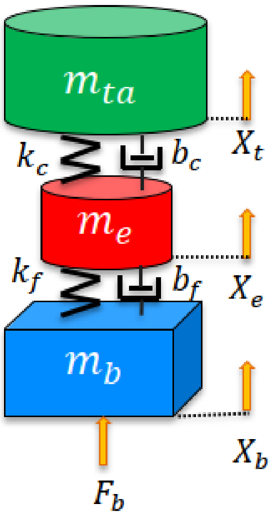
Source: https://www.ptb.de/empir2019/fileadmin/documents/empir-2019/ComTraForce/documents/04_Deliverables/ComTraForce_D2.pdf

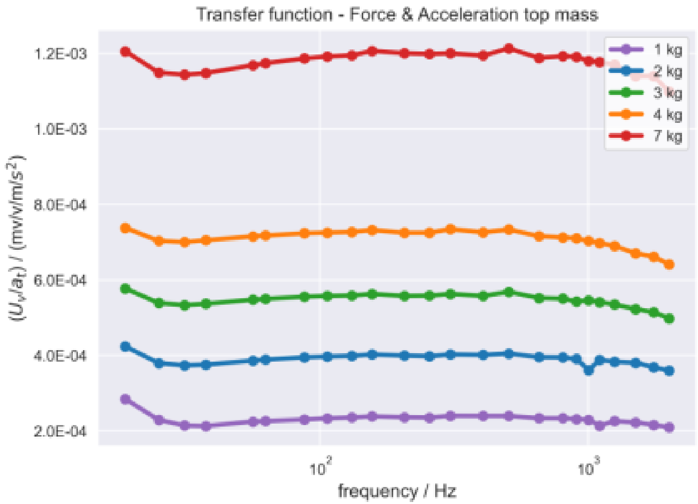
WP 2 Dynamic Force Measurement

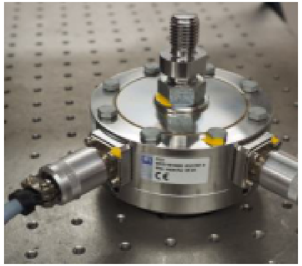
ComTraForce

Frequency dependency of the sensitivity

$$S_f = S_{f0}.\left(1 - \frac{\mu_{te}}{k_c}.\omega^2\right)$$







WP 2 Dynamic Force Measurement

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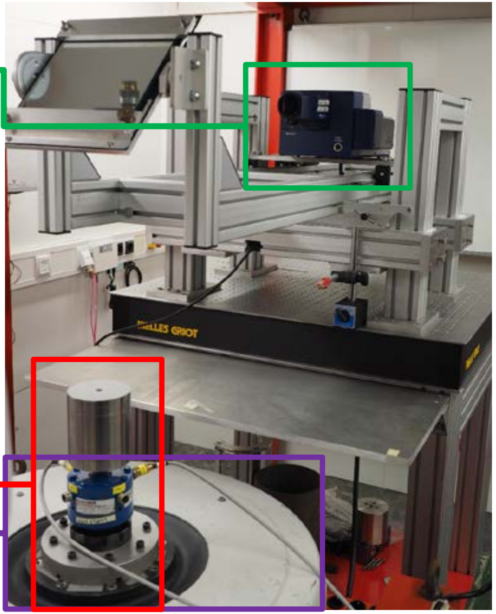
- Setup

Top Mass

Transducer

Mechanical adapter

Laser interferometry
Manufacture: Polytec
Laser: He-Ne
Wavelength: 633 nm
Laser class: 2



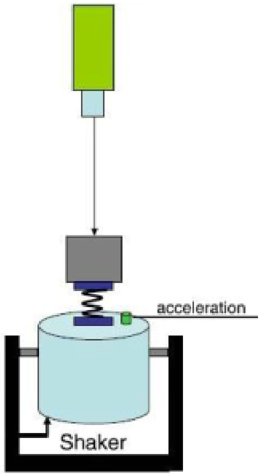
Electrodynamic shaker
Manufacture: LDS
Model: V850T-SPA-K
Sine force peak: 17792 N
Effective mass of moving element: 14.34 kg
Velocity sine peak: 2.0 m/s
Acceleration sine peak: 1225.8 m/s^2

WP 2 Dynamic Force Measurement

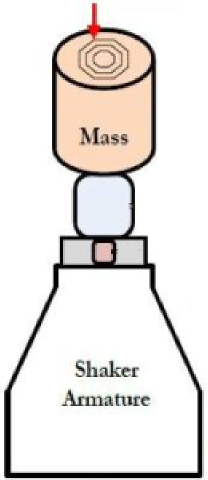
ComTraForce

Different methods of the acceleration measurement

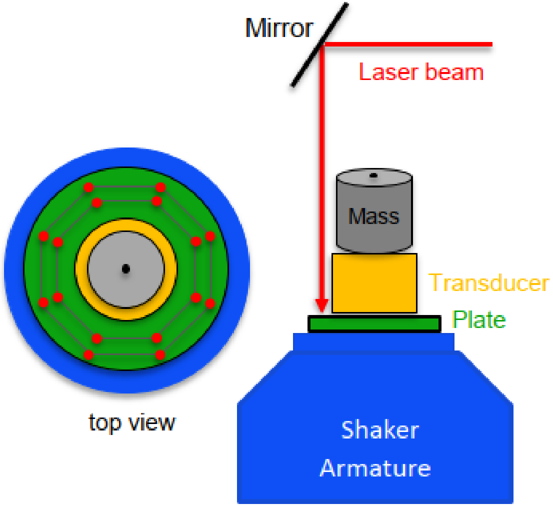
Definition of the stiffness and damping coefficient



Measurement : sided
Position: on the shaker
Sensor : Piezoelectric
No. of signal : 1 Top / 1 Bottom



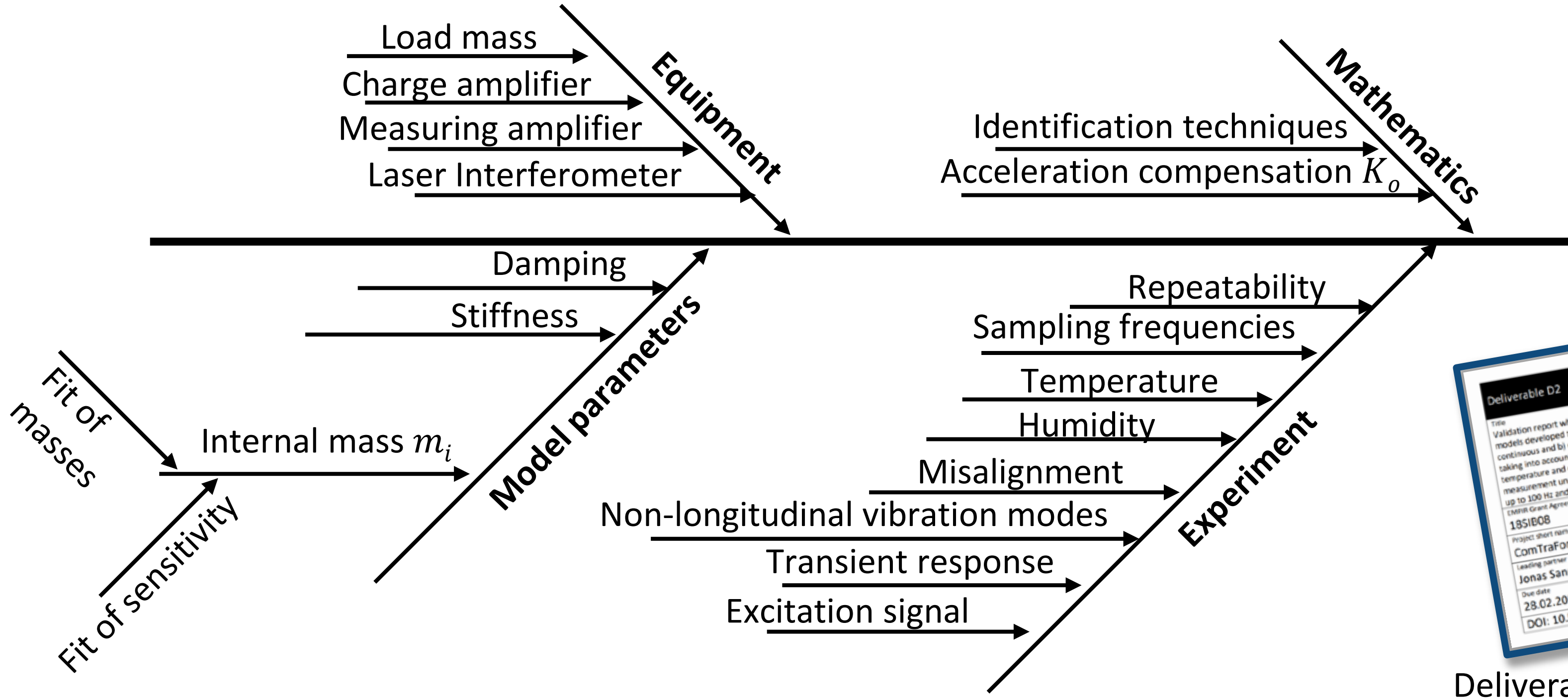
Measurement : axial
Position: on the shaker
Sensor : Piezoelectric
No. of signal : 24 Top / 1 Bottom

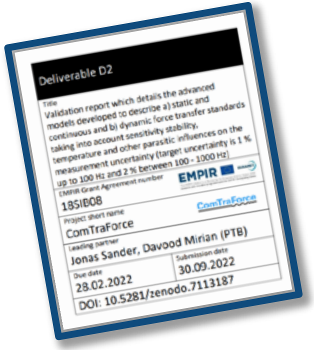


Measurement : sided
Position: on the plate
Sensor : Laser
No. of signals : 24 Top / 16 Bottom

WP 2 Advanced Model Dynamic

ComTraForce





Deliverable D2

Title
Validation report which details the advanced models developed to describe a) static and continuous and b) dynamic force transfer standards taking into account sensitivity stability, temperature and other parasitic influences on the measurement uncertainty (target uncertainty is 1 % up to 100 Hz and 2 % between 100 - 1000 Hz)

EMPIR Grant Agreement number
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ComTraForce

Leading partner
Jonas Sander, Davood Mirian (PTB)

Due date	Submission date
28.02.2022	30.09.2022

DOI: 10.5281/zenodo.7113187

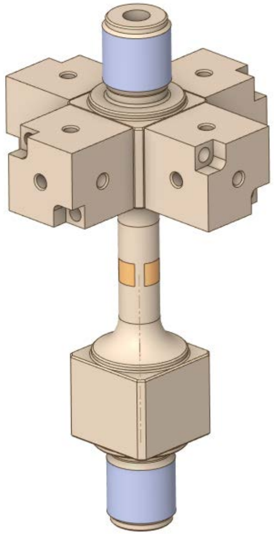
Deliverable 2 Part B

Source: https://www.ptb.de/empir2019/fileadmin/documents/empir-2019/ComTraForce/documents/04_Deliverables/ComTraForce_D2.pdf

ComTraForce

WP 2 Digital Twin

Real Space



DCC

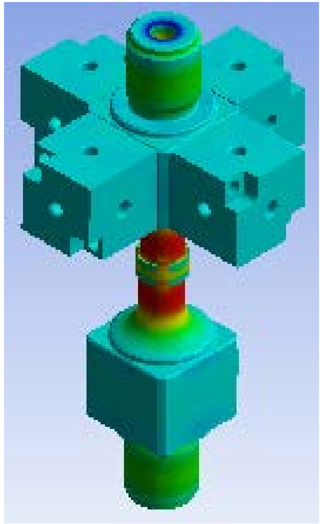
- force profile
- temperature

PYTHON

- measurement uncertainty
- prognosis
- stability

Virtual Space

Uncertainty Calculation



FEM (ANSYS)

Database

Deliverable D3

Title

Validation report for the digital twin software, considering requirements of digitisation and industry 4.0, for static, continuous and dynamic force transfer standards including measurement uncertainty determination

EMPIR Grant Agreement number

18SIB08

Project short name

ComTraForce

Leading partner

Dr. Claudiu Giusca (CU)

Due date

28.02.2022

Submission date

08.12.2022

DOI: 10.5281/zenodo.7404128

Deliverable 3

Source: https://www.ptb.de/empir2019/fileadmin/documents/empir-2019/ComTraForce/documents/04_Deliverables/ComTraForce_D3.pdf

WP 3 Traceability Chain Static / Continuous

ComTraForce

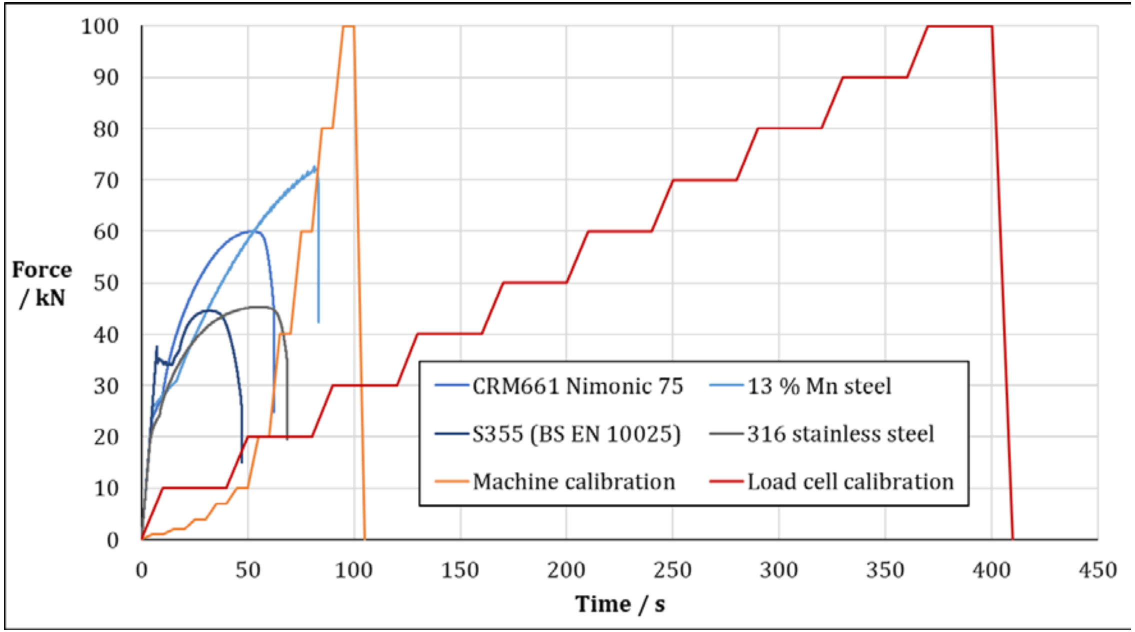


Diagram demonstrating force against time profiles for four different steel testpieces

WP 3 Proposed force traceability method

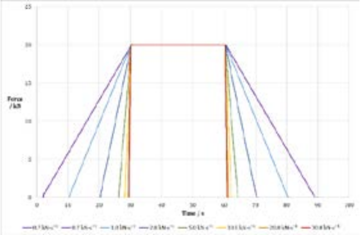
ComTraForce

NPL National Physical Laboratory

Step 1

Develop continuous force calibration reference standard

- Top class force transfer standard, based on static calibration results
- Additional short-term creep test and associated performance criteria



Step 2

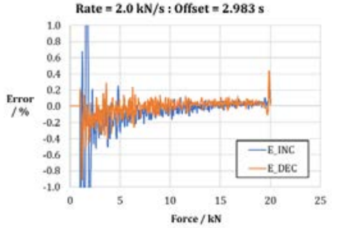
Calibrate proving instrument against reference standard

- Range of force application rates, determine sensitivity differences
- Proving instrument also to be calibrated statically

Step 3

Use proving instrument to calibrate testing machine force display

- Range of force application rates, determine machine errors
- Care needed in data synchronisation



WP 3 Proposed force traceability method

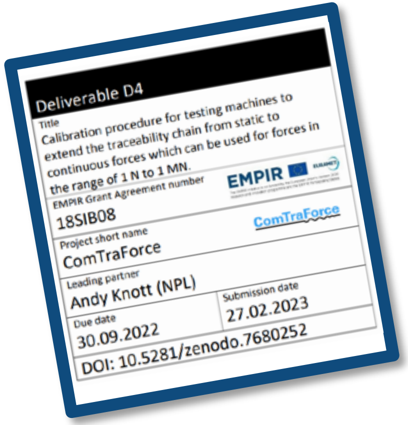
ComTraForce

Methodology for continuous calibration of testing machine force indicator has been developed

- Reference standard criteria proposed
- Proving instrument calibration procedure
- Testing machine calibration procedure

Issues identified to have major effect on results

- Data synchronisation – procedure should be as automated as possible
- Instrumentation settings


Deliverable D4
Title
Calibration procedure for testing machines to extend the traceability chain from static to continuous forces which can be used for forces in the range of 1 N to 1 MN.
EMPIR Grant Agreement number
18SIB08
Project short name
ComTraForce
Leading partner
Andy Knott (NPL)
Due date
30.09.2022
Submission date
27.02.2023
DOI: 10.5281/zenodo.7680252

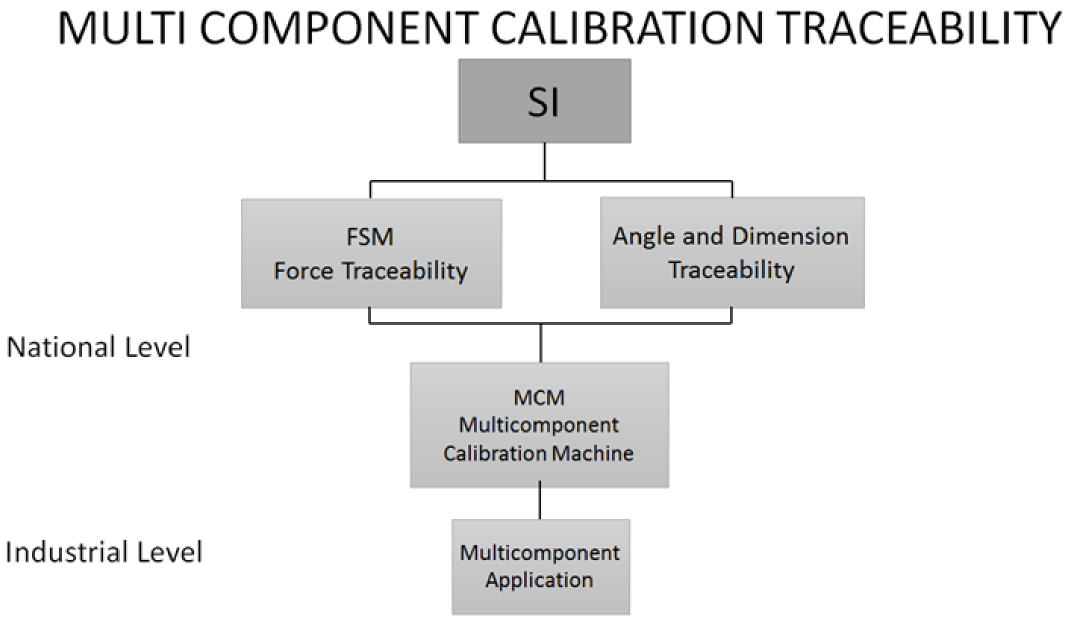
Deliverable 4

Source: https://www.ptb.de/empir2019/fileadmin/documents/empir-2019/ComTraForce/documents/04_Deliverables/ComTraForce_D4.pdf

Traceability Chain for Multicomponent Forces and Moments

ComTraForce

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

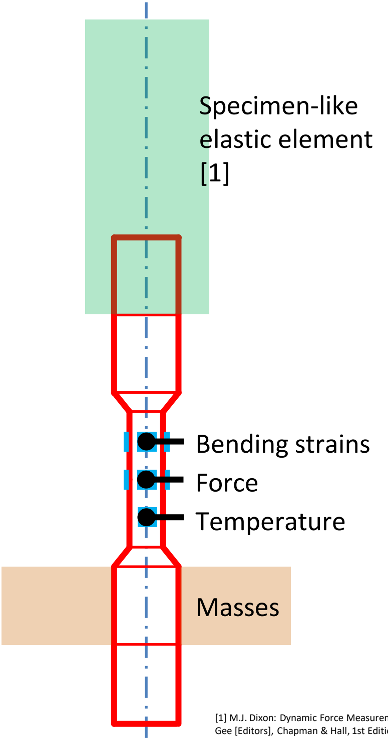


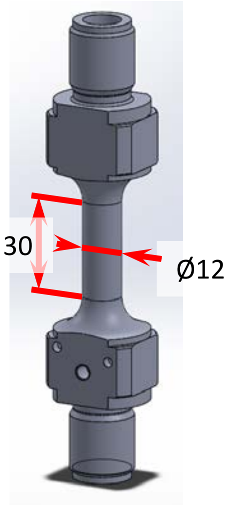
A multicomponent force and moment transducer (MCFMT) during calibration

Source: https://doi.org/10.5281/zenodo.7844513

WP 4 Traceability Chain Dynamic

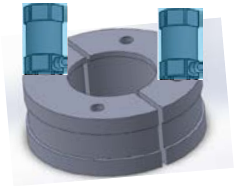
ComTraForce

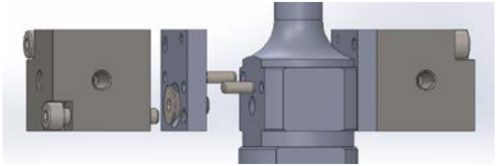




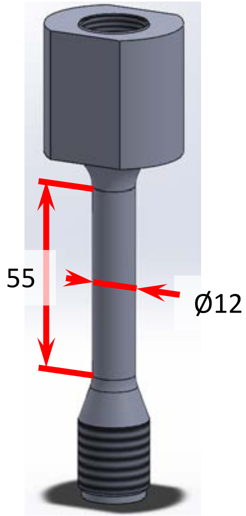
Dynamometer:
Fatigue resistant,
1.6580QT

Accelerometer on additional masses





Stiffness Adapter: Fatigue resistant, EN AW 7075-T6



$$c = \frac{E \cdot A}{l}$$

140 kN/mm

Universität Stuttgart

[1] M.J. Dixon: Dynamic Force Measurement, in Materials Metrology and Standards for Structural Performance, B.F. Dyson, M.S. Loveday, M.G. Gee [Editors], Chapman & Hall, 1st Edition, London, 1995

WP 4 Traceability Chain Dynamic

ComTraForce

Universität Stuttgart

Physikalisch-Technische Bundesanstalt

DKD

Deliverable 5

Guideline DKD-R 9-4 — **Dynamic Calibration of Material Testing Machines**

Edition 2022A

https://doi.org/...

DKD — Dynamic Calibration of Material Testing Machines — https://doi.org/ — DKD-R 9-4 — Ausgabe: 2022A — Revision: 0 — Seite: 5 / 26

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DKD — Dynamic Calibration of Material Testing Machines — https://doi.org/ — DKD-R 9-4 — Ausgabe: 2022A — Revision: 0 — Seite: 6 / 26

Introduction

Preliminary Work

Calibration Work

Uncertainty

Appendices

Source: https://www.ptb.de/empir2019/fileadmin/documents/empir-2019/ComTraForce/documents/04_Deliverables/ComTraForce_D5.pdf

WP 5 Procedures & Recommendations

ComTraForce

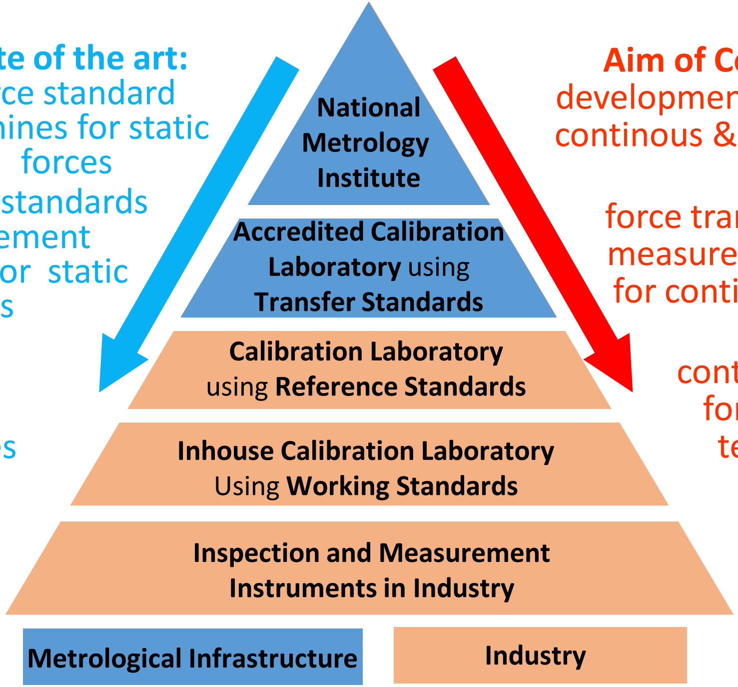
PTB

- Develop calibration procedure for continuous and dynamic loads in testing machines
- Validation of the procedures

State of the art:
force standard machines for static forces

force transfer standards & measurement procedures for static forces

static force calibration of testing machines



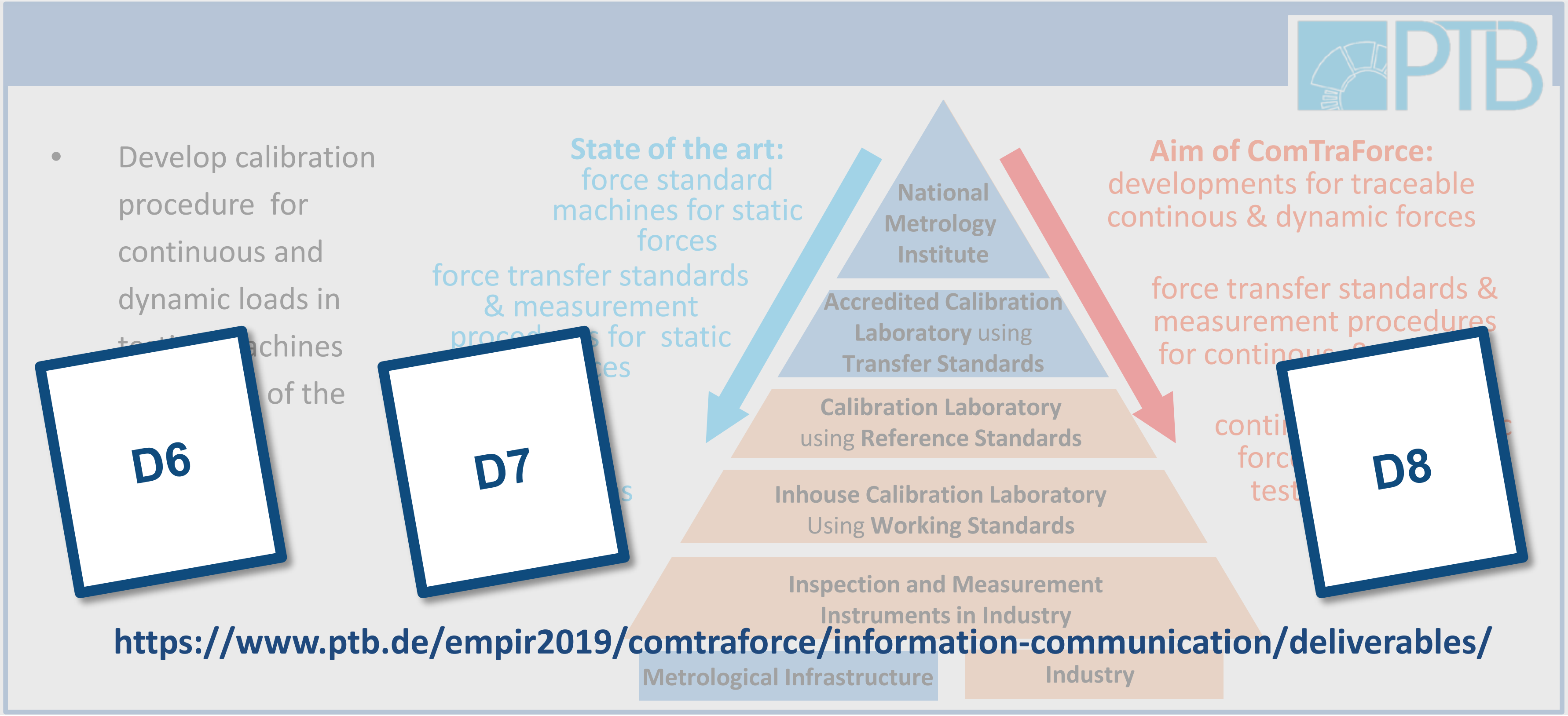
Aim of ComTraForce:
developments for traceable continous & dynamic forces

force transfer standards & measurement procedures for continous & dynamic forces

continuous & dynamic force calibration of testing machines

WP 5 Procedures & Recommendations

ComTraForce



https://www.ptb.de/empir2019/comtraforce/information-communication/deliverables/

Impact by Networking

ComTraForce

Bureau International des Poids et Mesures – the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards.

ABOUT US | WORLDWIDE METROLOGY | INTERNATIONAL EQUIVALENCE

> You are here: worldwide metrology: committee structure > Consultative Committees > CCM > CCM-WGFT

CCM Working Group on Force and Torque (CCM-WGFT)

TC-M
Mass and Related Quantities
EURAMET Technical Committee

ISO
TECHNICAL COMMITTEES
ISO/TC 164
Mechanical testing of metals

DKD

IMEKO
International Measurement Confederation

COOMET

DAkkS
Deutsche Akkreditierungsstelle

bsi. Standards Development

UCAS

GULFMET

EA EUROPEAN ACCREDITATION

IAF MEMBER OF MULTILATERAL RECOGNITION ARRANGEMENT

ilac-MRA

VMPA

DIN

SIM SISTEMA INTERAMERICANO DE METROLOGIA

Summary

ComTraForce

- Traceable validated methods for continuous time-dependent forces
- Traceable validated methods for measuring dynamic forces
- Development of advanced force measurement devices with input to industrial market
- Developed methods and techniques enable compensation of dynamic and temperature influences
- Calibration laboratories can extend their accreditation to continuous and dynamic forces
- The project is successful because force traceability is extended from static to continuous and dynamic force through comprehensive traceable force measurement methods

EMPIR
EURAMET
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

ComTraForce

Coordinator

PTB, Germany

Partner

CEM, Spain

CMI, Czech Republic

INRIM, Italy

NPL, UK

RISE, Sweden

VTT, Finland

TUBITAK, Turkey

CU, UK

USTUTT, Germany

ZAG, Slovenia

INMETRO, Brazil

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