Report of the CCM Working Group on Force and Torque

Rolf Kumme

17th CCM meeting, 16 May 2019

Bureau International des Poids et Mesures

Proposed changes of membership

Changes of membership:

- Simon Dignan, Australia, NMIA
- Vavrecka Lukàs, Czech Republic, CMI
- Sipho Dlamini, South Africa, NMISA
- Bulent Aydemir, Turkey, UME

List of CCM WGFT members

FirstName	LastName	Country	Institute
		-	BIPM
Simon	Dignan	Australia	NMIA
Dietmar	Steindl	Austria	BEV
NN	NN	Belgium	Metrology Div
Rafael	Soares de Oliveira	Brazil	INMETRO
Zhimin	Zhang	China	NIM
Vavrecka	Lukàs	Czech Republic	CMI
Aykurt	Altintas	Denmark	Force Technology
Ali	Abuelezz	Egypt	NIS
Jani	Korhonen	Finland	VTT MIKES
Philippe	Averlant	France	LNE
Rolf	Kumme	Germany	PTB
Dirk	Röske	Germany	PTB (Torque Expert)
S. Seela Kumar	Titus	India	NPLI
Alessandro	Germak	Italy	INRiM
Koji	Ohgushi	Japan	NMIJ
Toshiyuki	Hayashi	Japan	NMIJ (Force Expert)
Yon-Kyu	Park	Korea	KRISS
Jorge	Torres-Guzman	Mexico	CENAM
NN	NN	Poland	GUM
Isabel	Spohr	Portugal	IPQ
Alexander	Ostrivnoy	Russia	VNIIM
Sipho	Dlamini	South Africa	NMISA
NN	NN	Singapore	A*STAR
Nieves	Medina	Spain	CEM
Per	Nyfeldt	Sweden	SP
Christian	Wüthrich	Switzerland	METAS
Bulent	Aydemir	Turkey	UME
Andy	Knott	UK	NPL
NN	NN	Uruguay	LATU
Rick	Seiferth	USA	NIST (Force Expert)
Zeina J.	Kubarych	USA	NIST

WG Meetings held since last CCM

- PTB in Braunschweig from 6th until 8th June 2017

- 2 hours meeting on 4th Sept. 2018 in Belfast during XXII. IMEKO World Congress

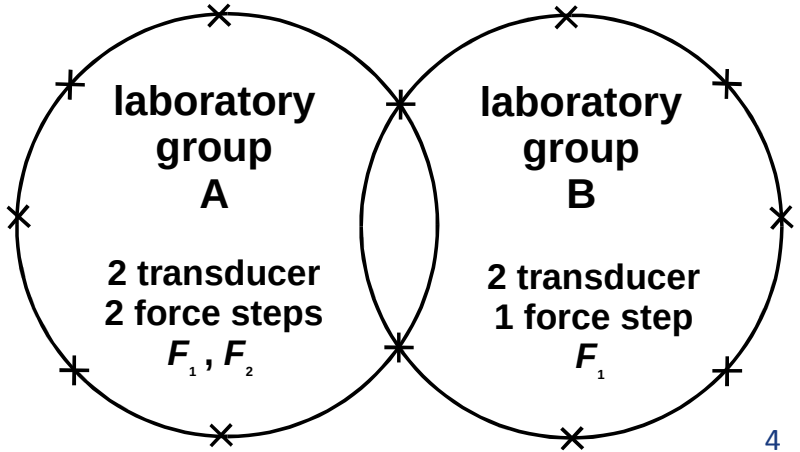
KCs in Force completed and underway

Summary of completed and approved KCs in Force

- CCM.F-K1.a (5 kN, 10 kN) & CCM.F-K1.b (5 kN), pilot: MIKES, 16 participants
- CCM.F-K2.a (50 kN, 100 kN) & CCM.F-K2.b (50 kN), pilot: NPL, 16 participants
- CCM.F-K3.a (0.5 MN, 1 MN) & CCM.F-K3.b (0.5 MN), pilot: PTB, 12 participants
- CCM.F-K4.a (2 MN, 4 MN) & CCM.F-K-4.b (2 MN), pilot: NIST, 8 participants

In all KCs each pilot selected 4 transducers which are circulated in star type formation.

= > excellent results obtained,
but a lot of work for pilot lab.

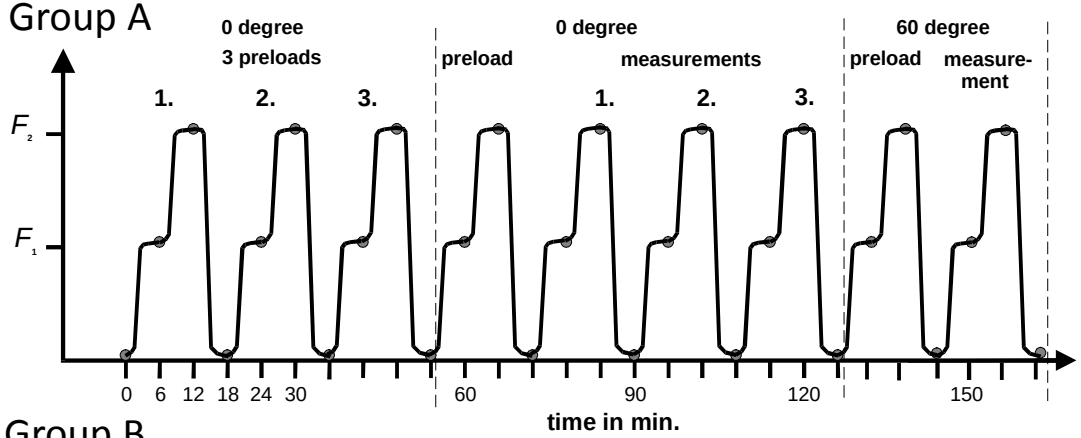


KCs underway (measurements completed)

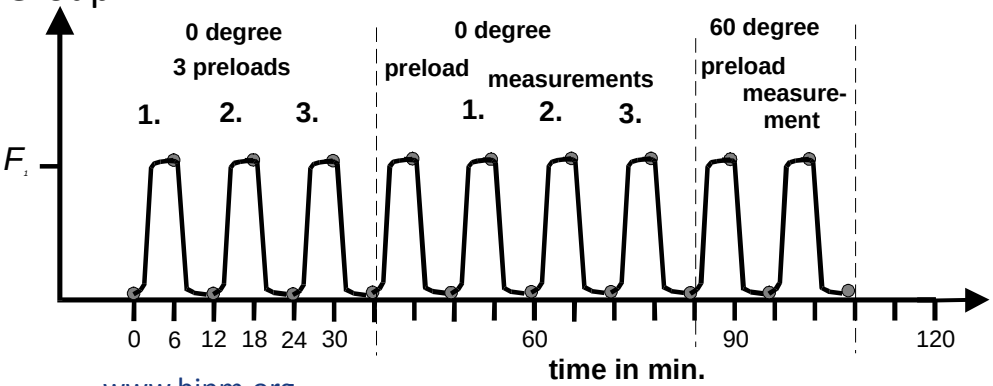
- CCM.F-K2.a.2
  (5 kN, 10 kN, 50 kN, 100 kN, 200 kN), NPL, PTB
- CCM.F-K3.1 (0.5 MN, 1 MN), PTB, KRISS

KCs completed and underway, Measurement principle

Group A



Group B



1 preload +
1 measurement
cycle in position

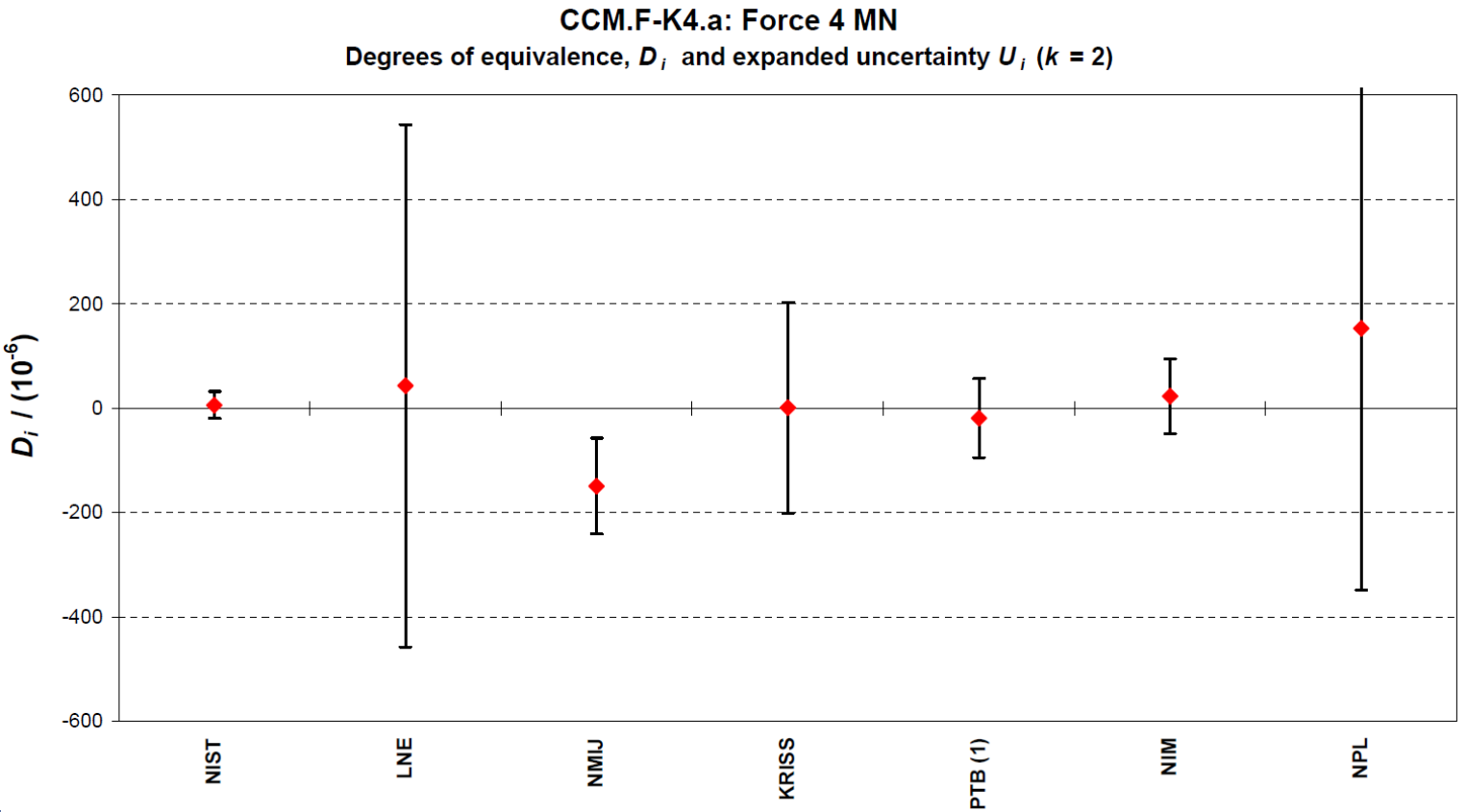
60°	60°
120°	120°
180°	180°
240°	240°
300°	300°
360°/0°	360°
1.rotation	2.rotation

Deflection = reading - zero signal

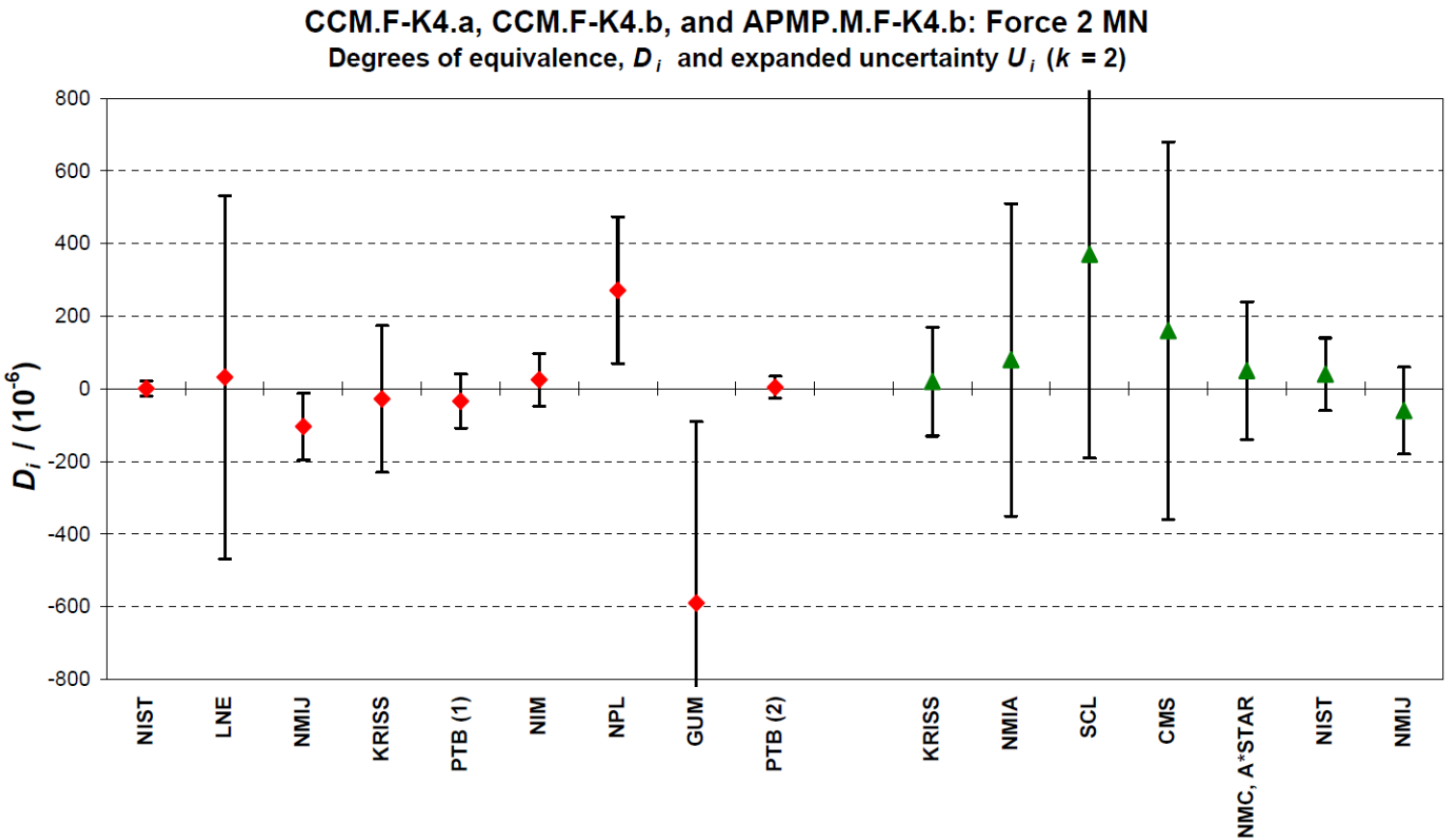
3 measurements in 0 degree positions
=> repeatability

12 measurements from 60 to 360 degree positions
=> mean value + reproducibility

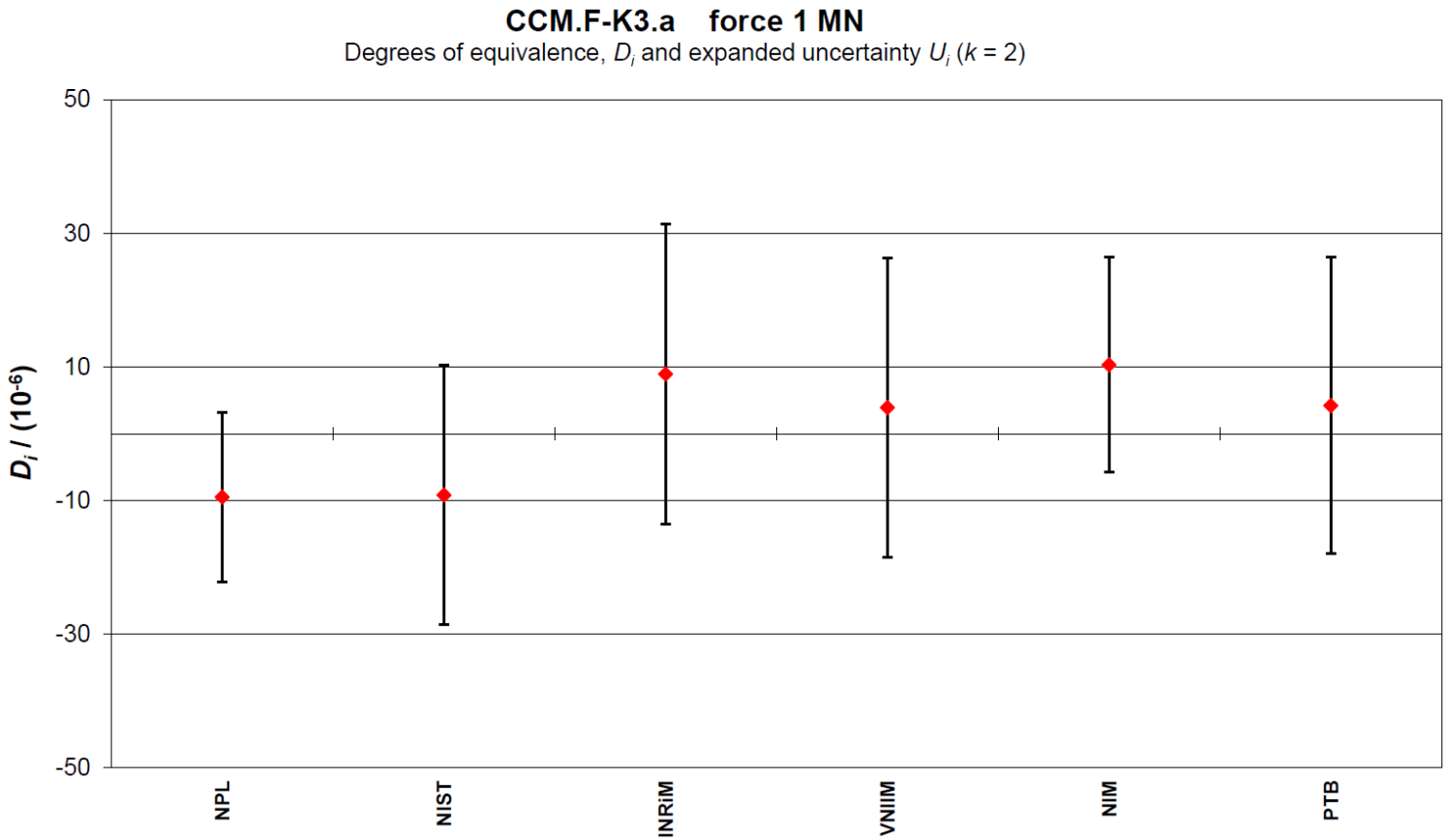
KCs completed, approved for equivalence, results available



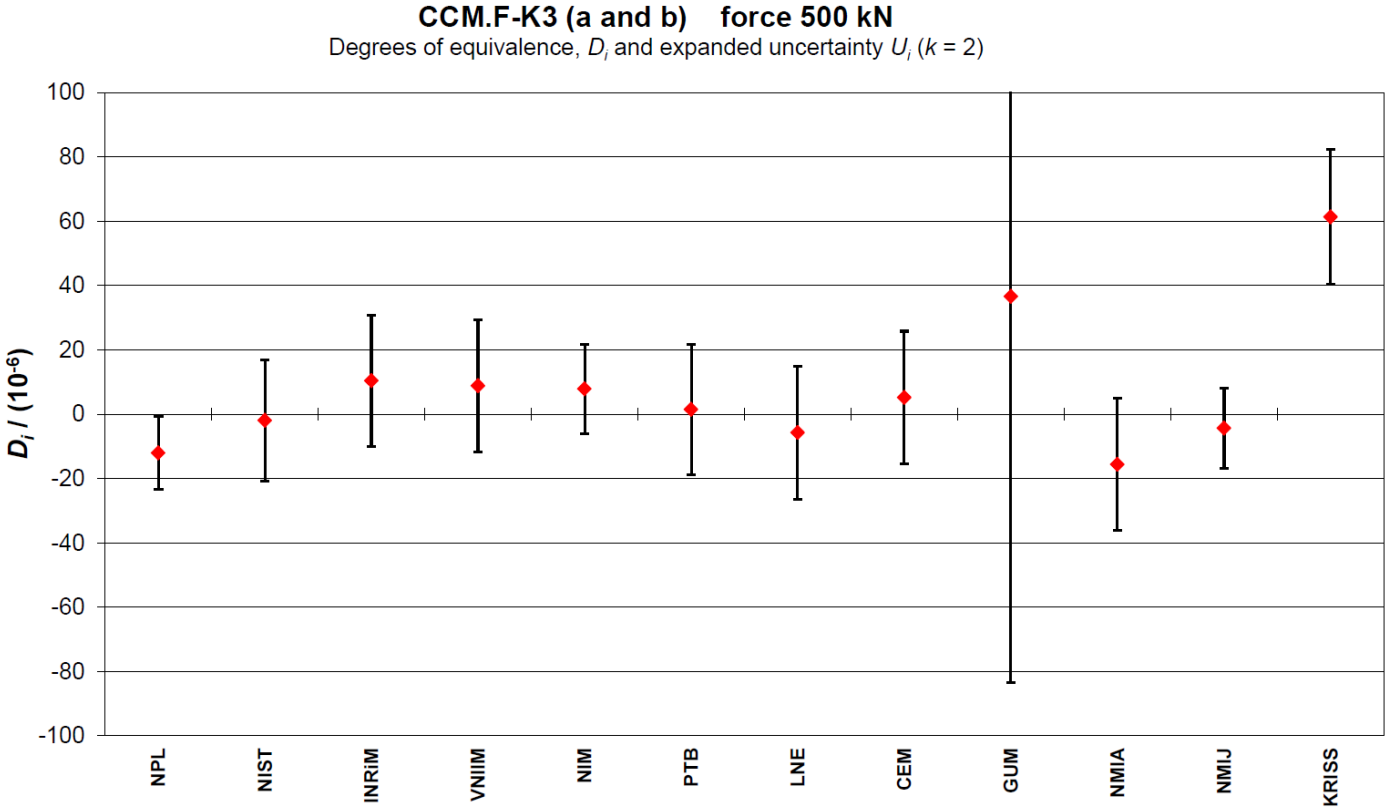
KCs completed, approved for equivalence, results available



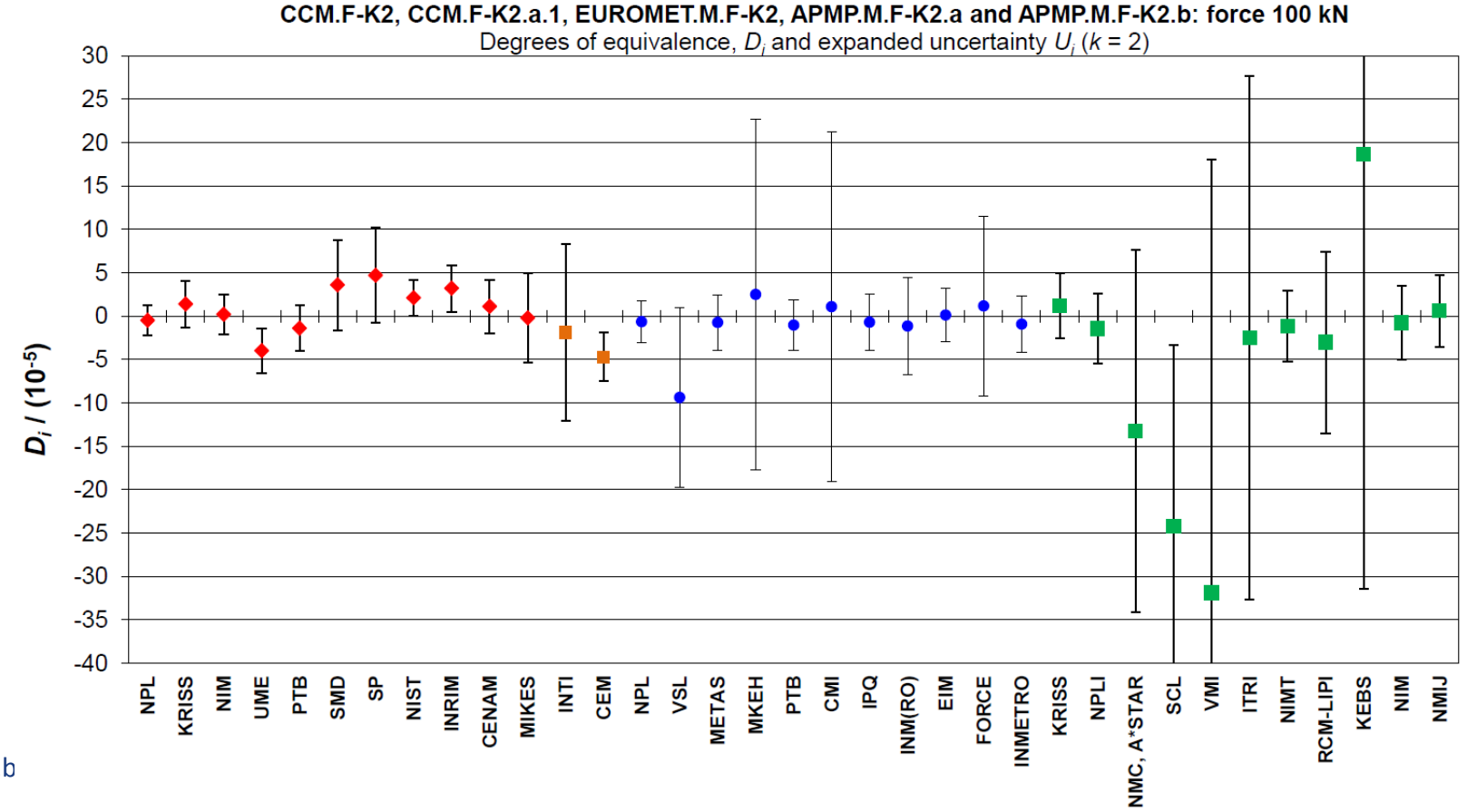
KCs completed, approved for equivalence, results available



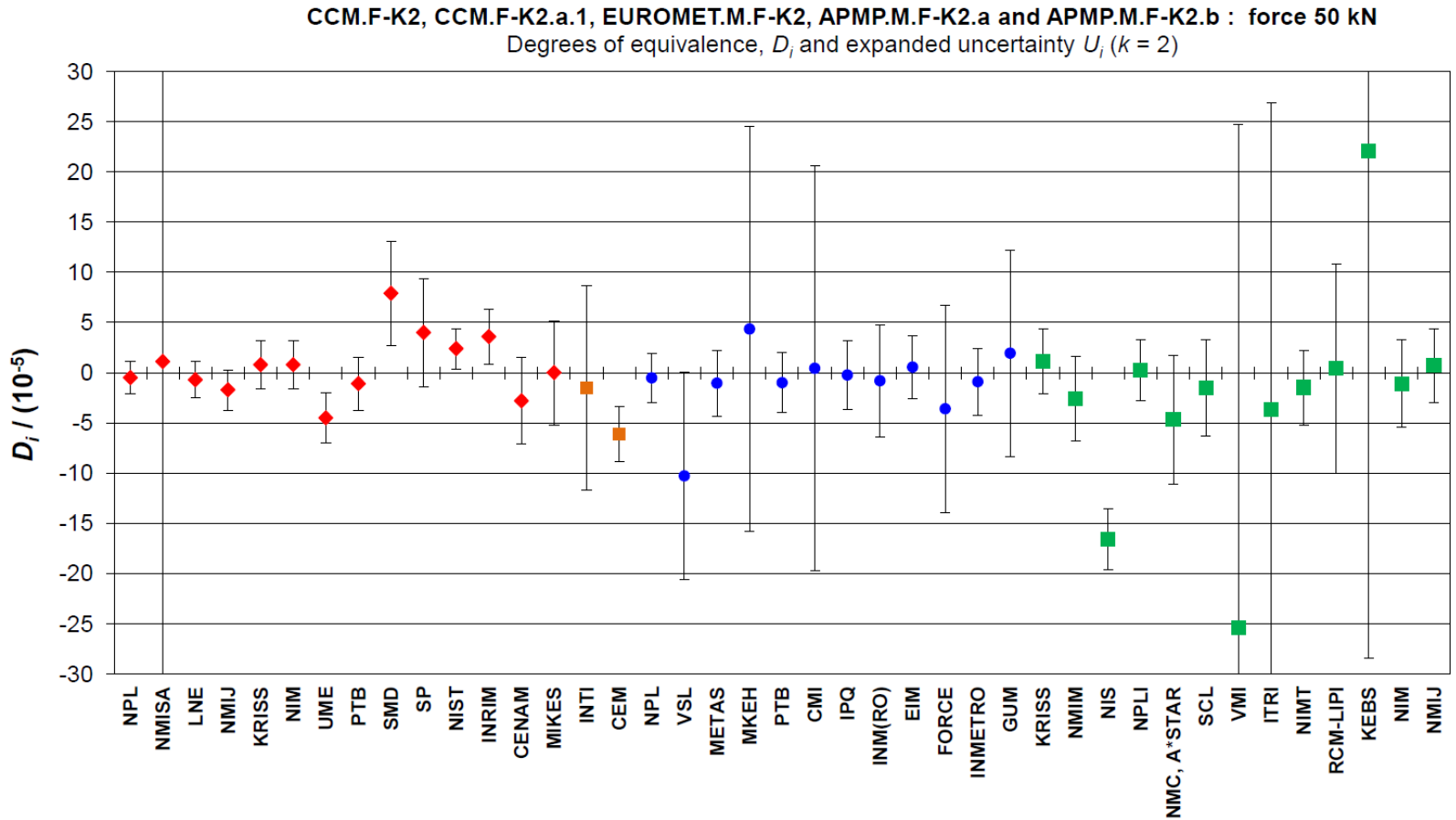
KCs completed, approved for equivalence, results available



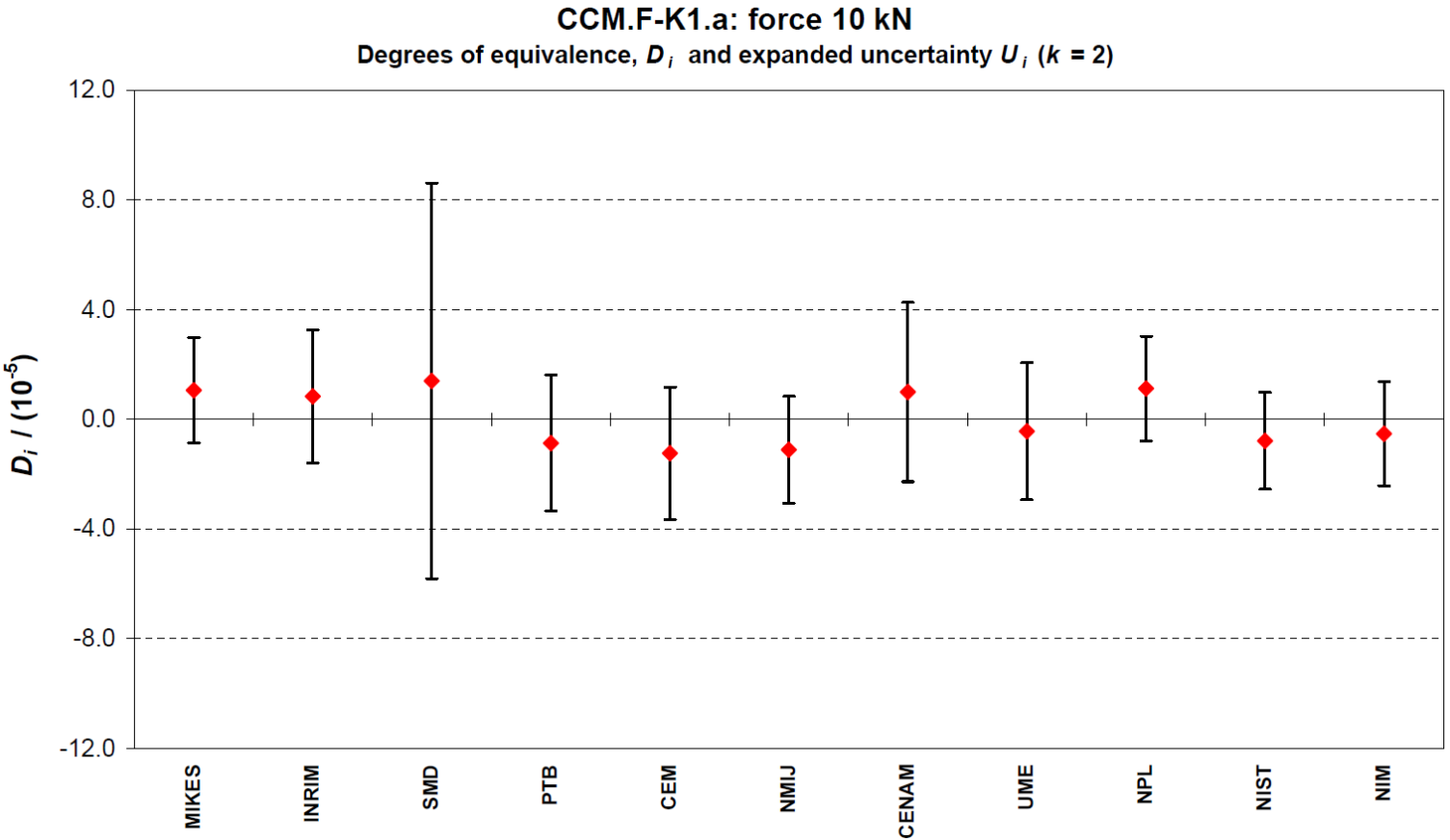
KCs completed, approved for equivalence, results available



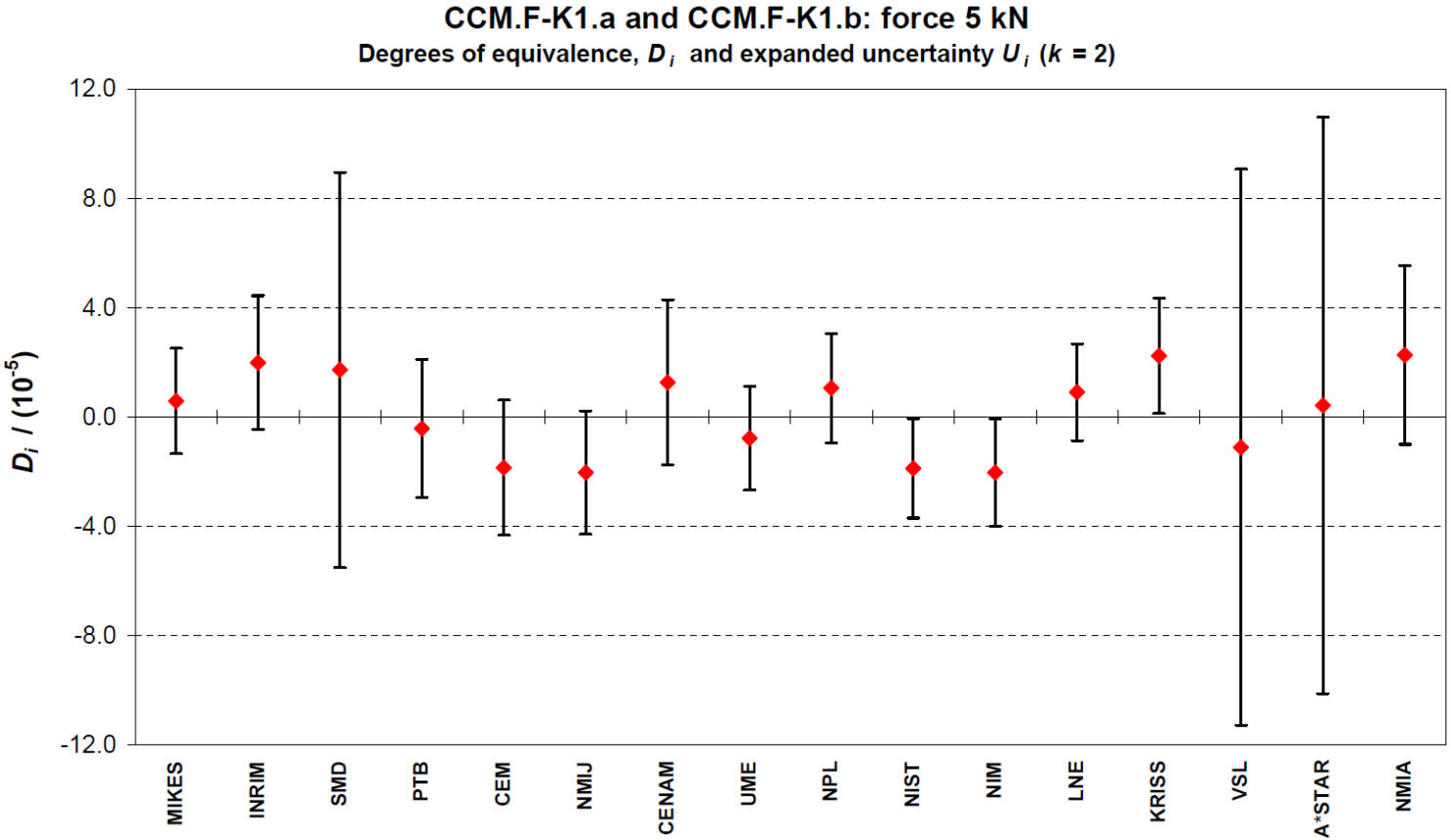
KCs completed, approved for equivalence, results available



KCs completed, approved for equivalence, results available



KCs completed, approved for equivalence, results available



RMO Force key and supplementary comparisons

- APMP.M.F-K2.a and b (force transducer 50 kN, 100 kN), Pilot: KRISS, 13 participants
  Approved for equivalence, Results available
- APMP.M.F-K3.a (force transducer 500 kN, 1000 kN), Pilot: NIM
  In progress, Measurements completed
- APMP.M.F-K3.b (force transducer 500 kN), Pilot: NIM
  In progress, Measurements completed
- APMP.M.F-S2.1 (force transducer 100 kN), Pilot: KRISS, VMI (Vietnam)
  Planned
- APMP.M.F-K4.b (force transducer 2000 kN), Pilot: NMIJ
  Approved for equivalence, Results available
- AFRIMET.M.F-S1 (force transducer 2 kN to 100 kN
  In progress, Measurements completed, Participants: PTB, KEBS (Kenya)
- AFRIMET.M.F-S2 (force tranducer 250 kN and 500 kN)
  In progress: Measurements started, Participants: KEBS (Kenya), PTB, NMISA (South Africa)

RMO Force key and supplementary comparisons

- COOMET.M.F-S1 (Force: 20 kN, 50 kN, 100 kN, 250 kN, 500 kN, 1000 kN and 2000 kN)
  Report in progress, Draft B
- COOMET.M.F-S2 (Force: 10 kN, 14 kN, 16 kN, 20 kN, 50 kN, 60 kN, 80 kN and 100 kN)
  Approved and published
- EUROMET.M.F-K1 (force transducer 5 kN, 10 kN), Report in progress, Draft B, Pilot: MIKES
- EUROMET.M.F-K2 (force transducer 50 kN, 100 kN)
  Approved for equivalence, Results available, Pilot: NPL
- EUROMET.M.F-K3 (force transducer 500 kN, 1000 kN, 2 MN, 4 MN)
  In progress, Measurements 500 kN, 1000 kN to be finished in 2019, Pilot: PTB, 16 participants
- EURAMET.M.F-S5 (10kN to 500 kN) Pilot: NPL, FSB-LIMS (Croatia), Protocol completed
- GULFMET.M.F.-S1 (force comparison 40 kN to 1 MN), Report in progress, Draft A,
  Participants: UME (Turkey), SASO-NMCC (Saudi Arabia), QCC-EMI (United Arab Emirates)
- GULFMET.M.F-S2 (force comparison 0.4 kN to 100 kN)
  Report in progress, Draft B, Participants: UME (Turkey), SASO-NMCC (Saudi Arabia)

RMO Force key and supplementary comparisons

- SIM.M.F-S1 (Calibration of a force testing machine in compression, Force: 10 kN to 100 kN)
  Approved and published
- SIM.M.F-S2 (Calibration of a force testing machine in compression, Force: 10 kN to 100 kN)
  Draft A, Participants: IDIC (Chile), CENAMEP AIP (Panama)
- SIM.M.F-S3 (Charpy V-notch reference specimen: 20 J and 100 J)
  Report in progress, Draft B
- SIM.M.F-S4 (force transducer 50 kN, 100 kN)
  In progress
- SIM.M.F-S5 Comparison of force testing machines
  Approved and published
- SIM.M.F-S6 Comparison of force testing machines 10 kN to 100 kN
  Draft A, Participants: IDIC (Chile), INTN (Paraguay)
- SIM.M.F-S7 (force comparison 500 kN to 1000 kN)
  Measurements completed, Participants: INMETRO (Brazil), IDIC (Chile)
- SIM.M.F-S8 (comparison of force testing machines 20 kN to 100 kN)
  Measurements completed, Participants: IDIC (Chile), IBMETRO (Bolivia)

KCs completed: Summary of approved KCs in Torque

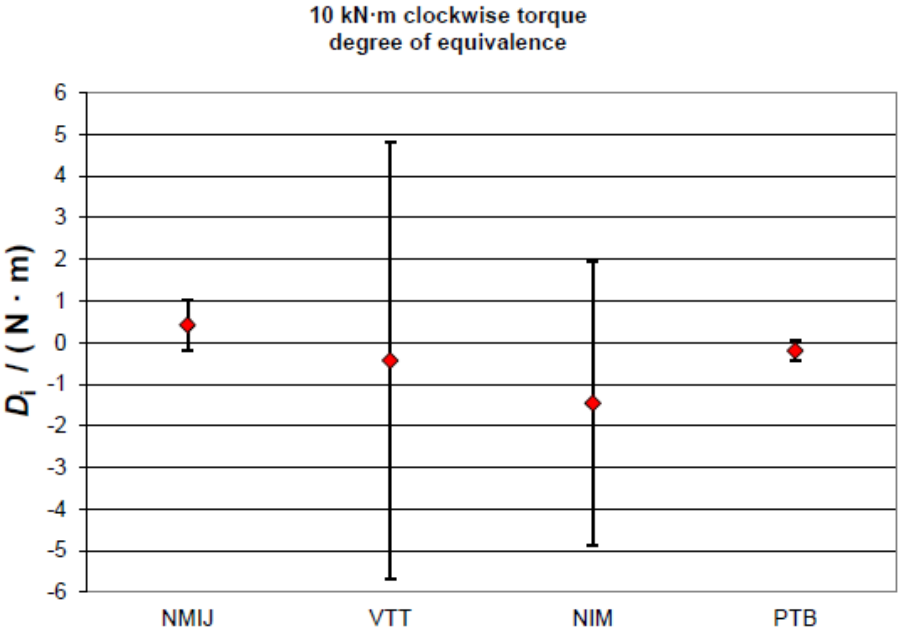
- CCM.T-K1 (500 N m, 1000 N m), pilot: PTB, 8 participants
- CCM.T-K1.1 (500 N m, 1000 N m), PTB, NPLI
- CCM.T-K1.2 (500 N m, 1000 N m), PTB, NIMT
- CCM.T-K1.3 (500 N m, 1000 N m), PTB, NIS
- CCM.T-K2 (10 kN m, 20 kN m), pilot: PTB, 4 participants

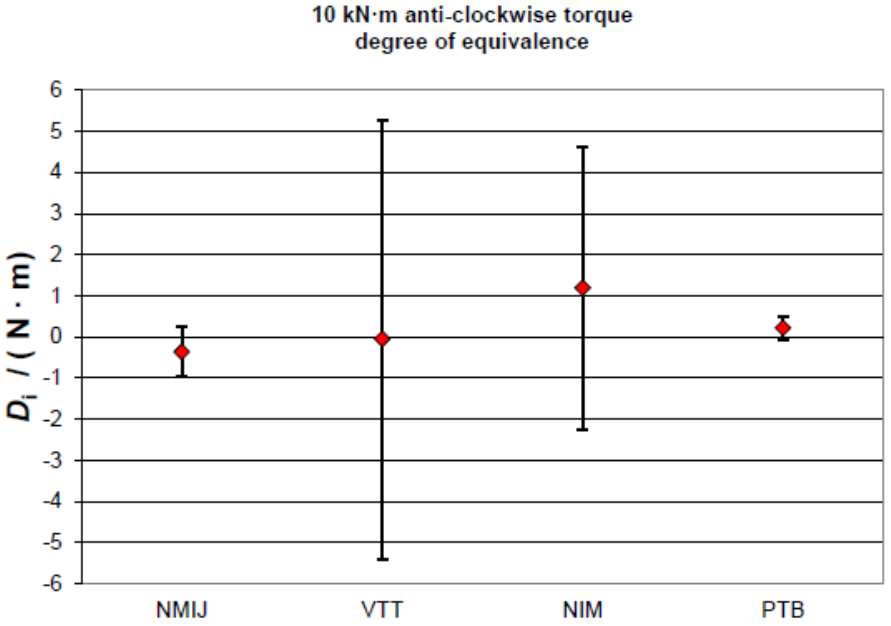
Same measurement principle like force comparison in group A.
For each KC the pilot selected 2 transducers which are measured in 2 torque steps clockwise and anticlockwise

$\Rightarrow$ excellent results obtained, but a lot of work for the pilot.

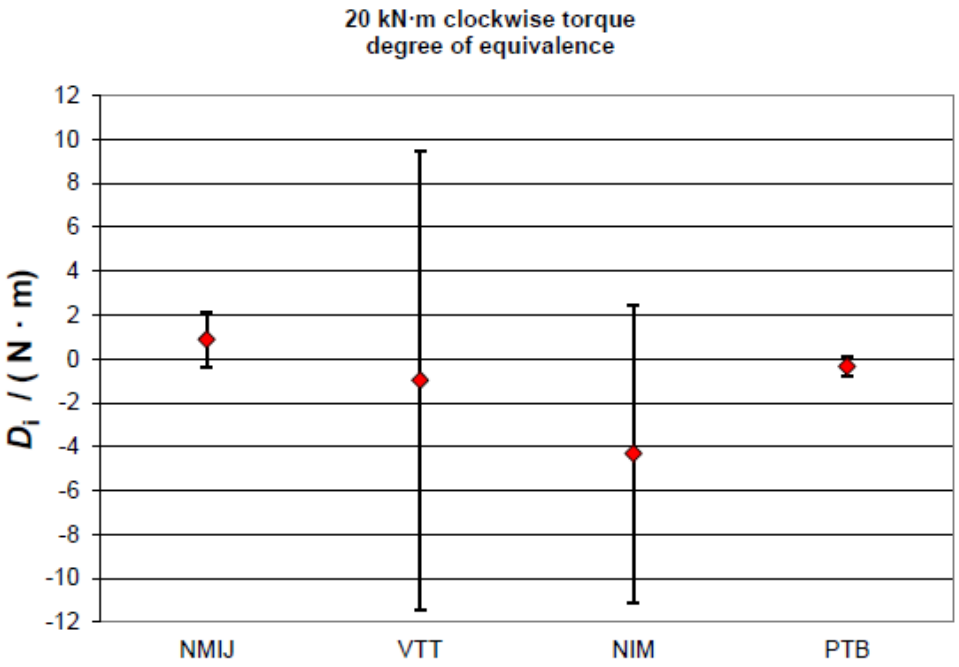
$\Rightarrow$ Future plan for torque comparisons ?

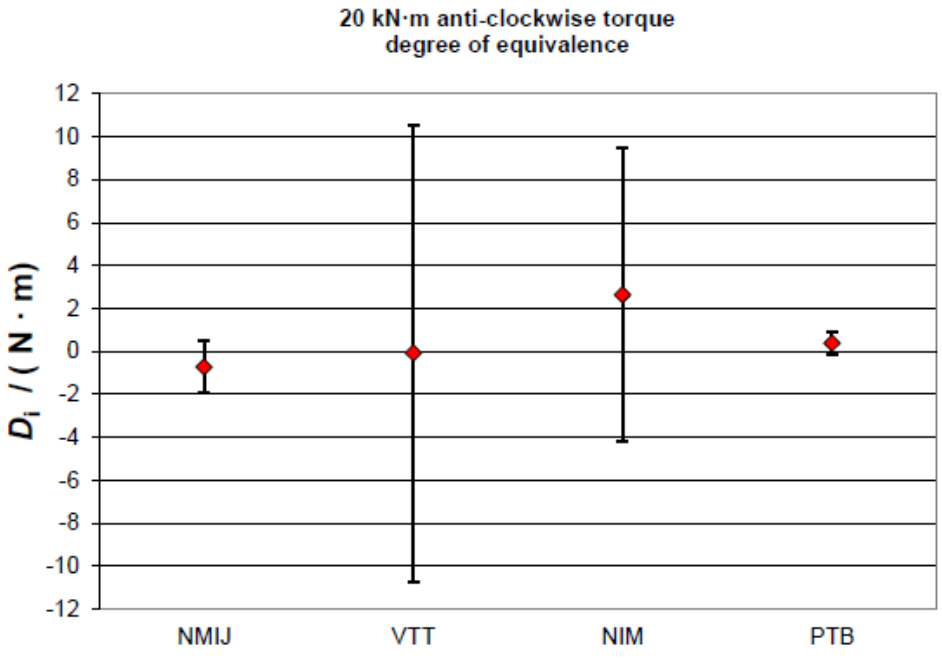
KCs completed, approved for equivalence, results available





KCs completed, approved for equivalence, results available

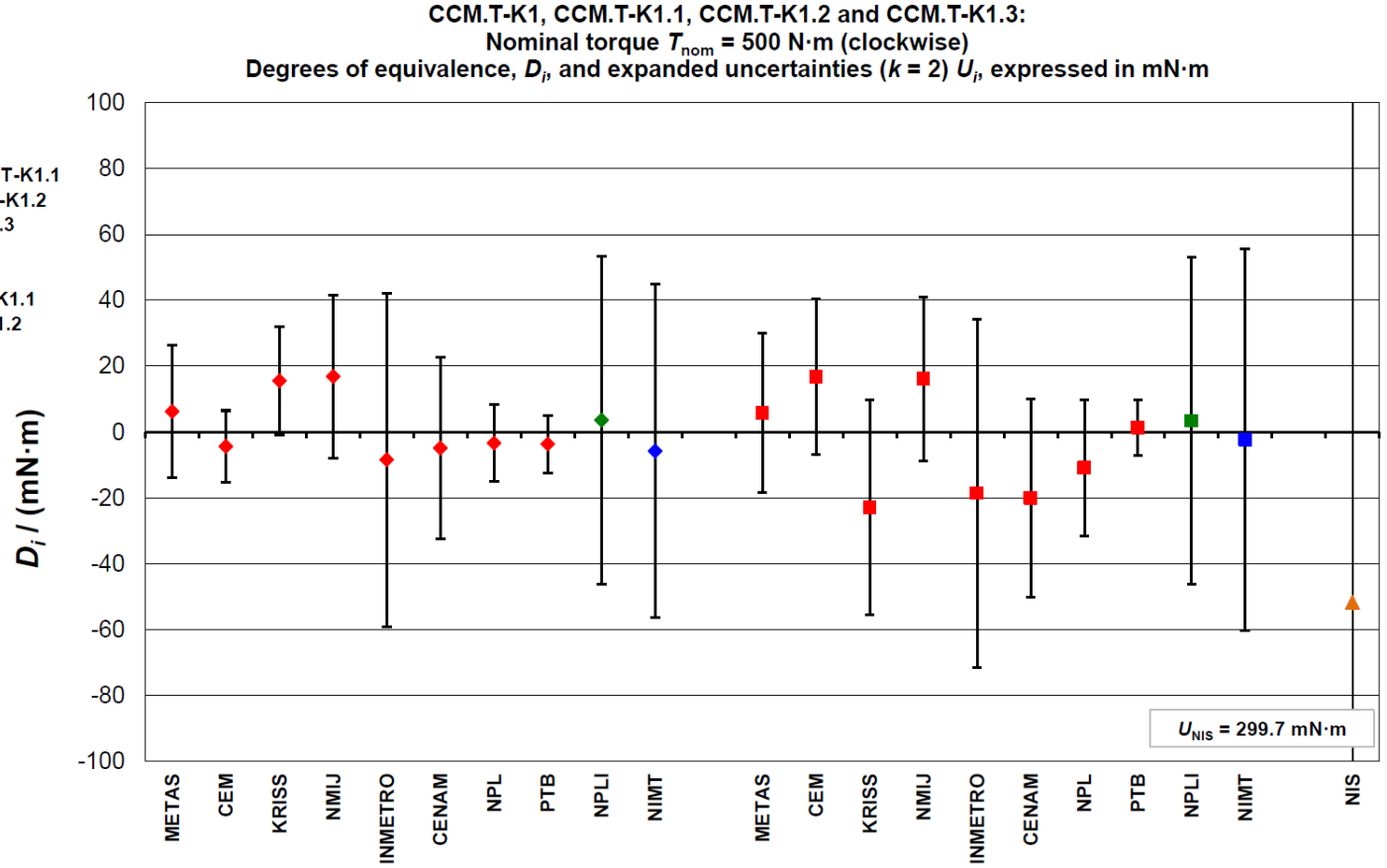




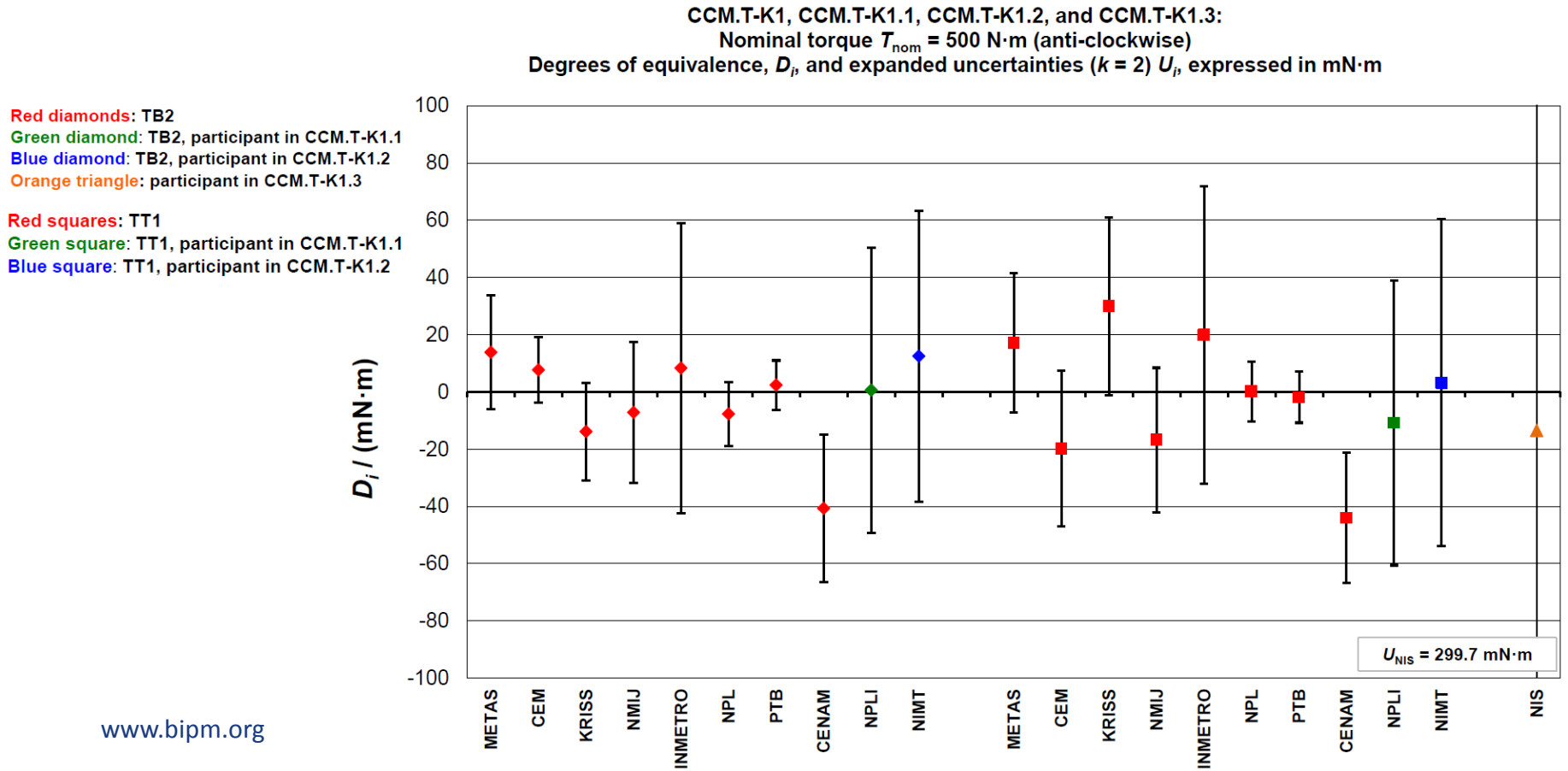
KCs completed, approved for equivalence, results available

Red diamonds: TB2
Green diamond: TB2, participant in CCM.T-K1.1
Blue diamond: TB2, participant in CCM.T-K1.2
Orange triangle: participant in CCM.T-K1.3

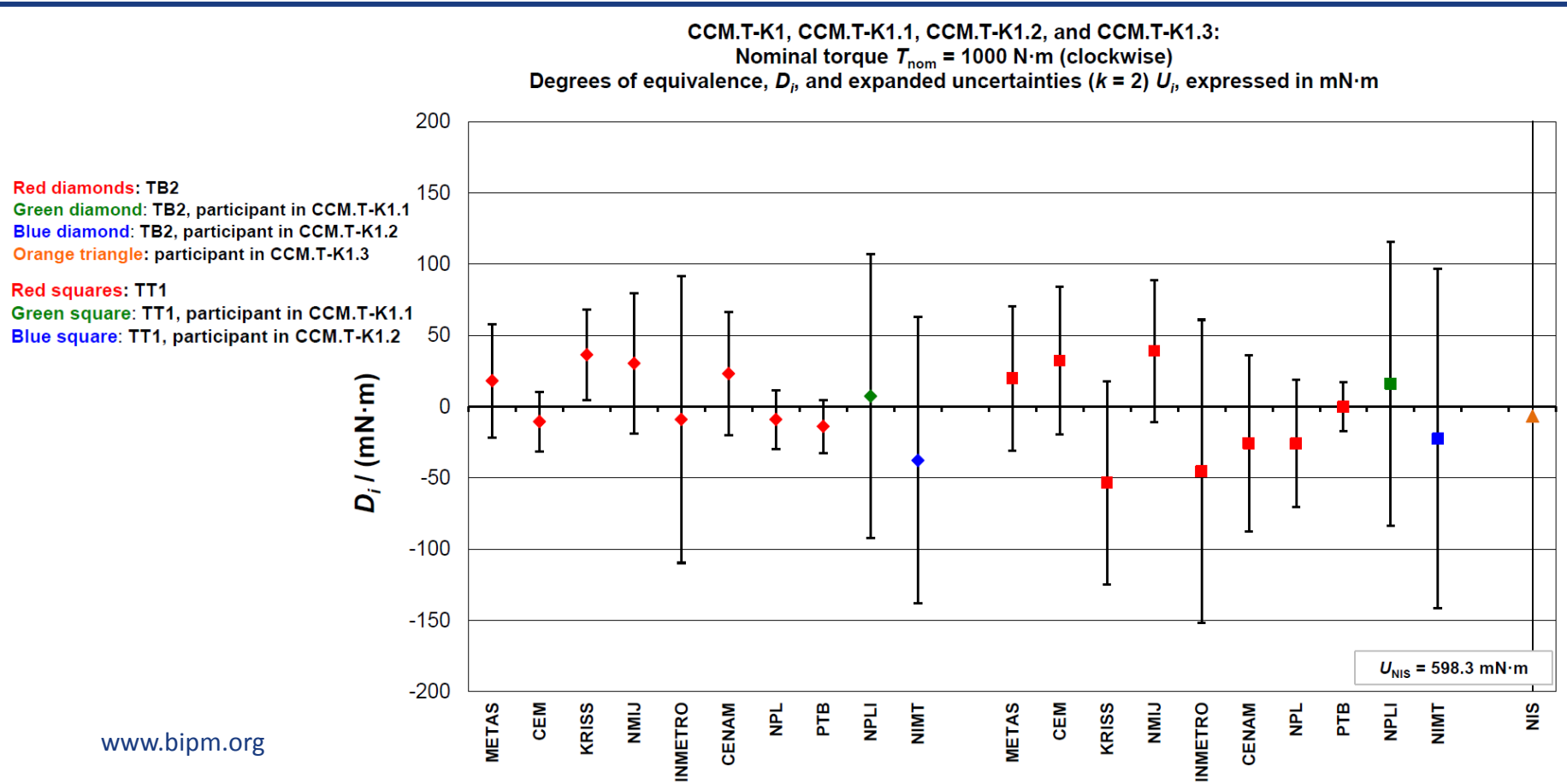
Red squares: TT1
Green square: TT1, participant in CCM.T-K1.1
Blue square: TT1, participant in CCM.T-K1.2



KCs completed, approved for equivalence, results available



KCs completed, approved for equivalence, results available

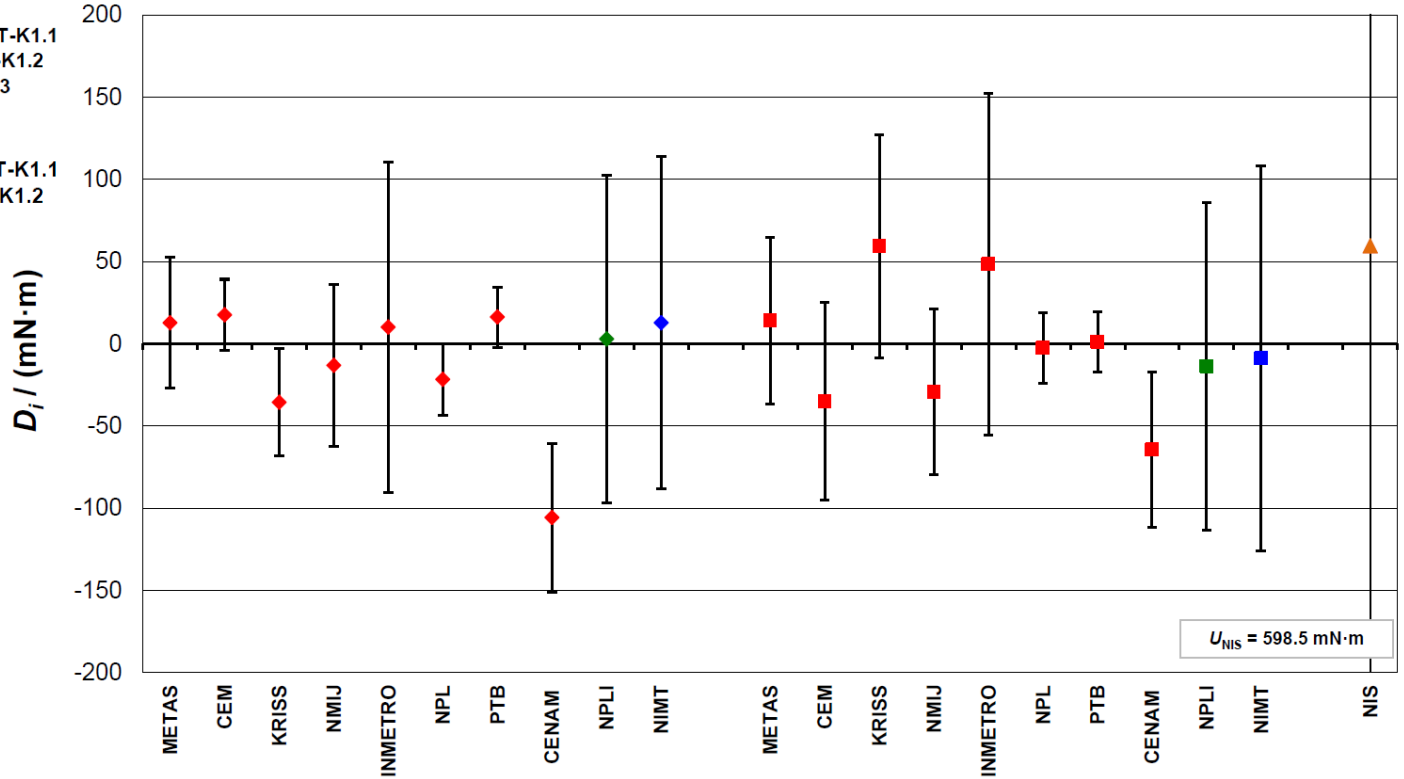


KCs completed, approved for equivalence, results available

CCM.T-K1, CCM.T-K1.1, CCM.T-K1.2, and CCM.T-K1.3:
Nominal torque T_{nom} = 1000 N·m (anti-clockwise)
Degrees of equivalence, D_i, and expanded uncertainties (k = 2) U_i, expressed in mN·m

Red diamonds: TB2
Green diamond: TB2, participant in CCM.T-K1.1
Blue diamond: TB2, participant in CCM.T-K1.2
Orange triangle: participant in CCM.T-K1.3

Red squares: TT1
Green square: TT1, participant in CCM.T-K1.1
Blue square: TT1, participant in CCM.T-K1.2



RMO Torque key and supplementary comparisons

- APMP.M.T- K1 Pilot: KRISS, 6 participants
  2015 – 2016, 500 N·m, 1000 N·m, Planned
- APMP.M.T-S1
  2016, 1 kN·m to 2 kN·m, Approved and published
- COOMET.M.T- S1
  2012 – 2014, 100 N·m to 2500 N·m, Approved and published
- EURAMET.M.T- S1
  2008, 1 N·m, 5 N·m, 10 N·m, 50 N·m, 200 N·m, 500 N·m, and 1000 N·m, Approved and published
- EURAMET.M.T- S2
  2008, 10 N·m, 20 N·m, 40 N·m, 60 N·m, 80 N·m, and 100 N·m,), Approved and published
- EURAMET.M.T- S3
  2010, 10 N·m, 20 N·m, ... 1 kN·m (torque wrenches), Approved and published

RMO Torque key and supplementary comparisons

- EURAMET.M.T- S4, participants: PTB, LNE
  2015, 5 N·m, ... 50 N·m, measurement completed
- EURAMET.M.T- S5, participants: PTB, LNE
  2017, 5000 N·m, planned
- SIM.M.T-S1
  2016, 10 Nm, 20 Nm and 50 Nm, in progress

Main actions taken and main achievements

- Agreed Plan of CCM KCs in Force and Torque

Quantity	Key Comparison	Measurement Points	Years for repeating	Time Schedule	Covered Range
Force	CCM.F-K__	200 N, 500 N	15-20	2018	10 N – 1000 N
Force	CCM.F-K1	5 kN, 10 kN	15-20	2021	1 kN – 20 kN
Force	CCM.F-K2	50 kN, 100 kN	15-20	2027	20 kN – 200 kN
Force	CCM.F-K3	500 kN, 1000 kN	15-20	2030	200 kN – 1000 kN
Force	CCM.F-K4	2 MN, 4 MN	15-20	2024	1 MN – 20 MN
Torque	CCM.T-K1	500 N·m, 1000 N·m	15-20	2022	100 N·m, 5 kN·m
Torque	CCM.T-K2	10 kN·m, 20 kN·m	15-20	2025	5 kN·m, 100 kN·m

KCs planed: 200 N and 500 N Force Key Comparison

- Force Key Comparison CCM.F-KXX to be registered in next weeks
- Measurand: Force200 N and 500 N
- Pilot Laboratory: METAS
- Contact Person: Dr. Christian Wuethrich
- Protocol Draft Version distributed to participants for comments
- Participants from APMP, COOMET, EURAMET, SIM:
  CENAM, INRIM, KRISS, LNE, METAS, NIM, NIST, NMIJ, NPL, PTB, UMTS ?, VNIIM ?
- Measurement time schedule: July 2019 – June 2020
- **New principle: Each participants brings the own device** (2 or 4 force transducers, DMP, BN 100)
- 500 N transfer standards with 2 force steps: 200 N, 500 N
- 200 N tranfer standard with 1 force step: 200 N
- DMP 40 or DMP 41 and BN 100 to verify DMP stability
- 2 rotations of 360 degrees
- 4 min time interval
- Pilot uses same deadweight force standard machine with 200 N and 500 N steps for all measurements.

Terms of reference of CCM WG Force and Torque

- To study issues related to force and torque metrology, including dissemination, and to advise the CCM on these topics as well as on anticipated developments in this field;
- To review the results of completed key and supplementary comparisons and plan and support new comparisons;
- To facilitate the submission and review of CMCs by establishing technical review criteria and service categories and providing guidance on and coordinating the review process;
- To provide liaison at the technical level with ISO TC164/SC 1 and SC 4 and to maintain good links with IMEKO TC3.

Liaison & stakeholders of CCM WGFT

- All RMOs are involved
- ISO TC164/SC 1 and SC 4
- Industry in force and torque measurement
- IMEKO TC3

Progressing the state of the art

- Members of CCM WGFT are involved in research
- Development in large force (EMRP SIB63) https://www.ptb.de/emrp/forcemetrology.html
- Development in large torque (EMPIR 14IND14 MNm Torque) https://www.ptb.de/emrp/ind14-home.html
- Development in small force and torque (IMEKO publications)
- Consequences of SI redefinition on force and torque, in particular small force and torque (IMEKO publications)
- Multicomponent force and torque measurements
- Dynamic force measurement (new EMPIR 18SIB08 “ComTraForce” project)
- Torque measurement for Energy (new EMPIR proposal WindEfficiency)

Program of work for the next 5 years

- 200 N and 500 N Key Comparison
  measurements completed until mean of 2020
  Evaluation of 200 N and 500 N comparison in 2020/2021
- Harmonisation and review criteria for CMC in force and torque in 2020/2021
- Start of new CCM.F-K1 5 kN, 10 kN force comparison in 2021
- Start of new CCM.T-K1 500 N m, 1000 N m comparison in 2022
- Definition of other KCs in force and torque

WG Meetings planned

- NIST in Gaithersburg in autumn 2020

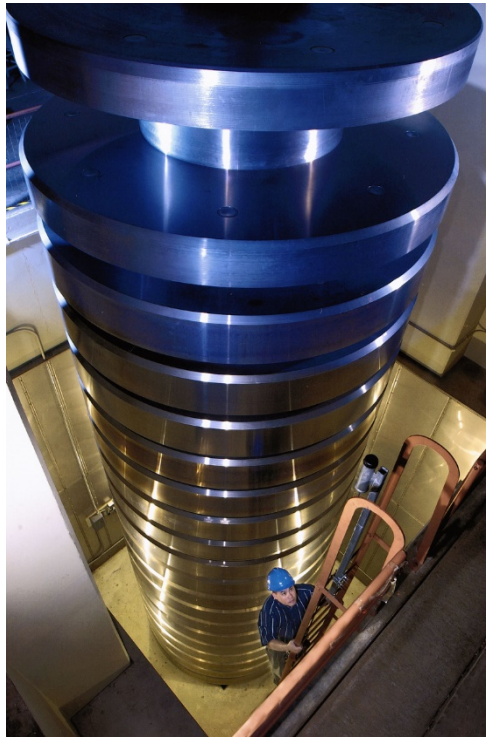
  topics:
  - new 200 N, 500 N key comparison, CCM.F__
  measurement results and evaluation of results

  - decision on new comparisons in force and torque
  pilot for CCM-F-K1 & CCM.T-K1 ?

  - CMCs in force and torque
  guideline for harmonisation and review criteria

  Future topics of CCM WGFT:
  - dynamic force and torque
  - small force and torque
  - Workshop with scientific contributions

- XXIII. IMEKO WC 2021 in Yokohama, perhaps short meeting?
- KRISS in Daejon in 2023



NIST's 4.45-million Newton deadweight force standard machine

Thank you.

Contact:
Dr. Rolf Kumme
PTB, Department 1.2 “Solid Mechanics”
E-Mail: rolf.kumme@ptb.de
Tel.: +49 531 592 1200