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< Final Report>

Report on the AFRIMETS.M. F-S1 Supplementary force comparison for 10 kN and 100 kN

Josephat Obwoge Bangi *, Mark Seidel**, David Kimetto*, Rolf Kumme **, Henry Rotich*, Dirk Röske **.

* Kenya Bureau of Standards (KEBS).

**Physikalisch-Technische Bundesanstalt (PTB)

1.0 General information about the AFRIMETS.M. F-S1

This bilateral comparison of Force Standard Machines (FSM) named AFRIMETS.M. F-S1 was carried out in the force range from 1 kN to 100 kN between Physikalisch-Technische Bundesanstalt (PTB) of Germany as the pilot laboratory and Kenya Bureau of Standards (KEBS) of Kenya as the participant laboratory. KEBS had already participated in the APMP.M. F-K2 key comparison where measurements were made only at 50 kN and 100 kN force steps. Therefore, this bilateral comparison was planned to thoroughly compare the KEBS FSM and the PTB Deadweight Machines in wider force steps than those of the APMP.M. F-K2 key comparison and thus it had no corresponding key-comparisons values to be linked to at that time. PTB provided two force transducers for the supplementary comparison with 10 kN and 100 kN nominal capacities. The comparison method called “DKD” procedure was used. This procedure has already been used in several comparisons in Germany and other countries. The purpose to this comparison is to give support to the uncertainty claims for KEBS and will be used to determine the Calibration and Measurement Capability (CMC). In addition, this comparison will provide metrological proof of the application for a CMC entry in the BIPM Key Comparison Database (KCDB). This report describes the scheme and results of the comparison.

2.0 Description of the Force Standard Machines that participated in the comparison

2.1 KEBS Compound Lever Force Standard Machine (FSM)

The machine is divided into seven force ranges with nominal capacities of 10 kN, 20 kN, 50 kN, 100 kN, 200 kN, 500 kN and 1 MN. The relative expanded uncertainty (k = 2) of the entire range of the KEBS 1 MN compound lever Force Standard Machine (FSM) is 5.0 x 10^{-4}. Figure 1 shows the KEBS FSM.

Figure 1: KEBS 1 MN Compound Lever Force Standard Machine (FSM)

2.2 Force Standard Machines used in the comparison by PTB

2.2.1 20 kN Force Standard Machine

The short name of the machine is 20-kN-K-NME (Figure 2) is deadweight machine and was used in the 10 kN comparison. The relative expanded measurement uncertainty of the machine is 2×10^{-5} with k = 2. The measurement range of the machine is 0.25 kN to 20 kN.

Figure 2: 20-kN-K-NME Force Standard Machine (PTB)

2.2.2 100 kN Force Standard Machine

The short name of the machine is 100-kN-K-NME (Figure 3) Deadweight Machine was used in the 100 kN comparison. Its relative expanded uncertainty (k = 2) is 2.0 x 10^{-5}.

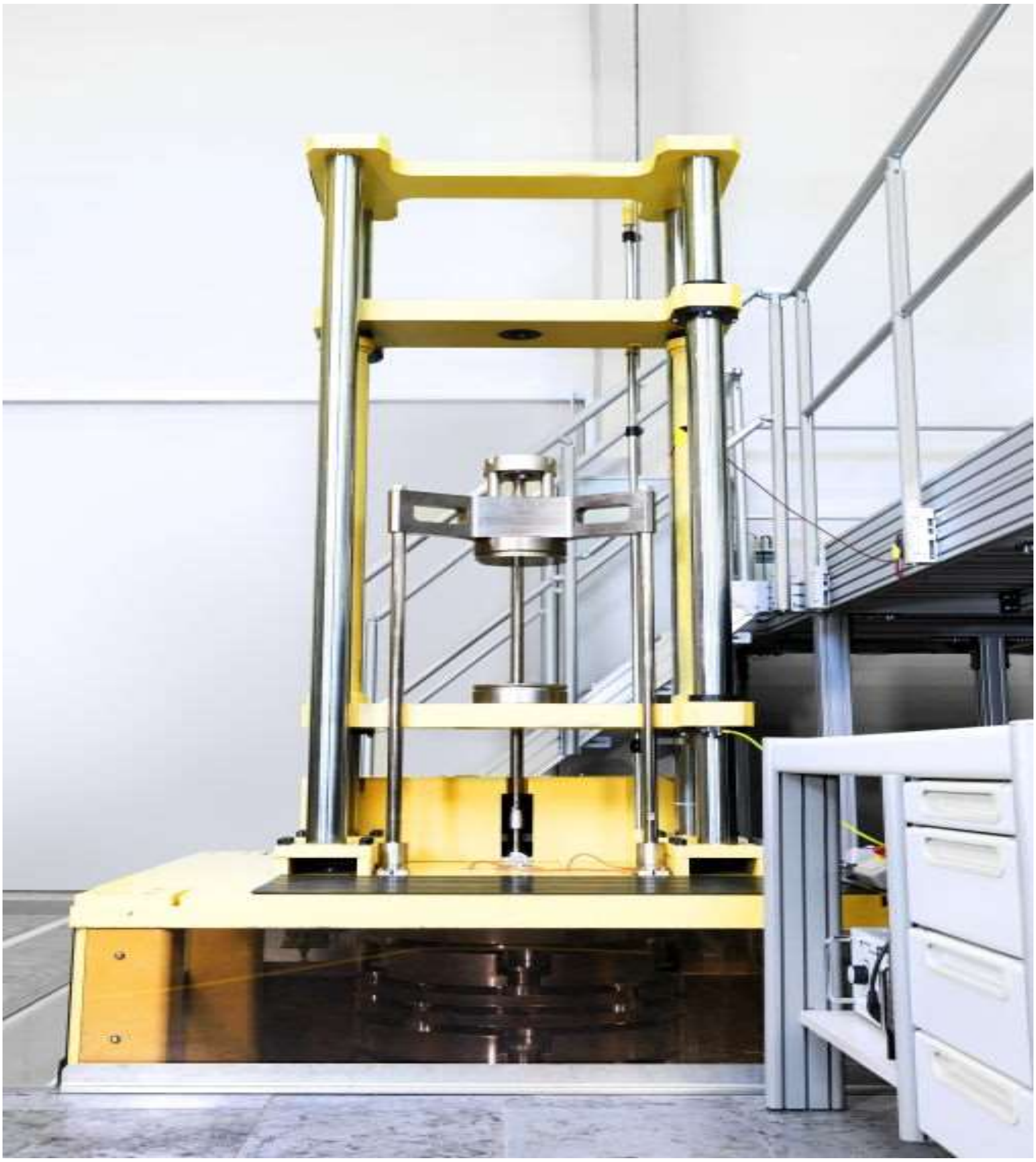

Figure 3: 100 kN Force Standard Machine (PTB)

2.3 Participants

The details of the Force Standard Machines (FSM) used for the 10 kN and 100 kN are as listed in Table 1 and Table 2 below.

Table 1: Participants and the Force Standard Machines used for the 10 kN

Country	Institute	Force Standard Machine			Remarks
		Capacity kN	Type	Relative expanded uncertainty of applied force	
Germany	PTB	20	Deadweight	2×10^{-5}	Pilot
Kenya	KEBS	1000	Lever amplification	5×10^{-4}	Participant

Table 2: Participants and the Force Standard Machines used for 100 kN

Country	Institute	Force standard machine			Remarks
		Capacity kN	Type	Relative expanded uncertainty of applied force	
Germany	PTB	100	Deadweight	2×10^{-5}	Pilot
Kenya	KEBS	1000	Lever amplification	5×10^{-4}	Participant

NOTE: Unless otherwise specified, expanded uncertainties in this report correspond to the level of confidence of approximately 95 % with a coverage factors $k = 2$.

3.0 Instrumentation used in the comparison

3.1 Force Transducers

The comparison was carried out using two force transducers. The details of the force transducers and other instruments used is as given in the Table 3 and in photographs Figures 4 and 5.

Table 3: Transducer details

Identification Code	Manufacturer	Type	Serial Number	Capacity	Others
Tr1	HBM	Z30	051630022	10 kN	incl. pressure pad
Tr2	GTM	KTN-D	50623	100 kN	incl. pressure pad

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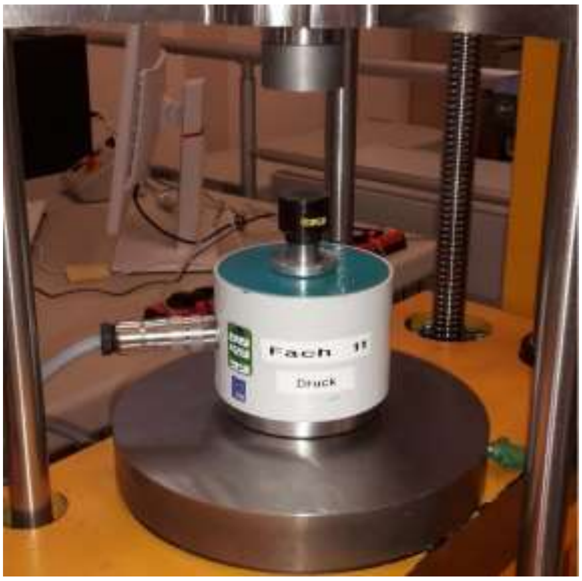

Figure 4: 10 kN HBM force transducer with pressure pad on top

Figure 5: 100 kN GTM force transducer with pressure pad on top

The force transducer and the fittings at the top (pressure pads) used in the comparison were provided by PTB. Each participant cleaned the fittings and the plates of the Force Standard Machine before the transducers were mounted to the machines and before starting the measurements. The transducers were carefully mounted in the Force Standard Machine. The force transducer with loading pad were aligned to the centre of the machine axis.

3.2 Measuring Amplifiers

For the measurements all participants used their own DMP40. The DMP40s were operated with 230 V at 50 Hz. Other important settings applied for all measurements were the bridge excitation voltage of 5 V, the measuring range of 2.5 mV/V, the resolution of 0.000001 mV/V and the cut-off frequency of low-pass filter of 0.1 Hz. During the measurements, only the measuring port was connected to the DMP40. The transducers had a 6-wire 15-pin connection to the DMP40. The details of the DMP40s used are as indicated in Table 4.

Table 4: Amplifiers details

Identification Code	Manufacturer	Type	Serial Number
PTB	HBM	DMP40	051320045
KEBS	HBM	DMP40	090220006

3.3 Environmental conditions

Actual measurement dates and ambient conditions are as shown in Table 5.

Table 5. Dates and ambient conditions of the measurements.

Capacity [kN]	Institute	Code	Date	Ambient conditions		
				Temperature °C	Humidity %	Air pressure hPa
10	PTB	R1	12/10/2017	21.4 to 21.5	37.3 to 38.4	1006 to 1009
	KEBS	K1	02/11/2017	22.0 to 22.2	50 to 52	751 to 752
	PTB	R2	09/11/2017	21.6 to 21.7	36.6 to 37.8	1014 to 1015
100	PTB	R12	12/10/2017	21.5to 21.6	38.6 to 38.8	1009 to 1011
	KEBS	K2	03/11/2017	21.8 to 21.9	52 to 53	752 to 753
	PTB	R22	10/11/2017	21.5 to 21.7	36.5 to 37.2	1005 to 1008

3.4 Principles of the comparison

The purpose of supplementary comparisons was to compare the units of the given quantities as realized throughout the world [1]. In the field of force, this is done by using force transducers of high quality, high-precision carrier frequency amplifiers and very stable bridge standards. The force transducers were subject to similar loading schemes in the Force Standard Machines of the participants following a strict measurement protocol. The loading scheme shown in Figure 6 below was agreed.

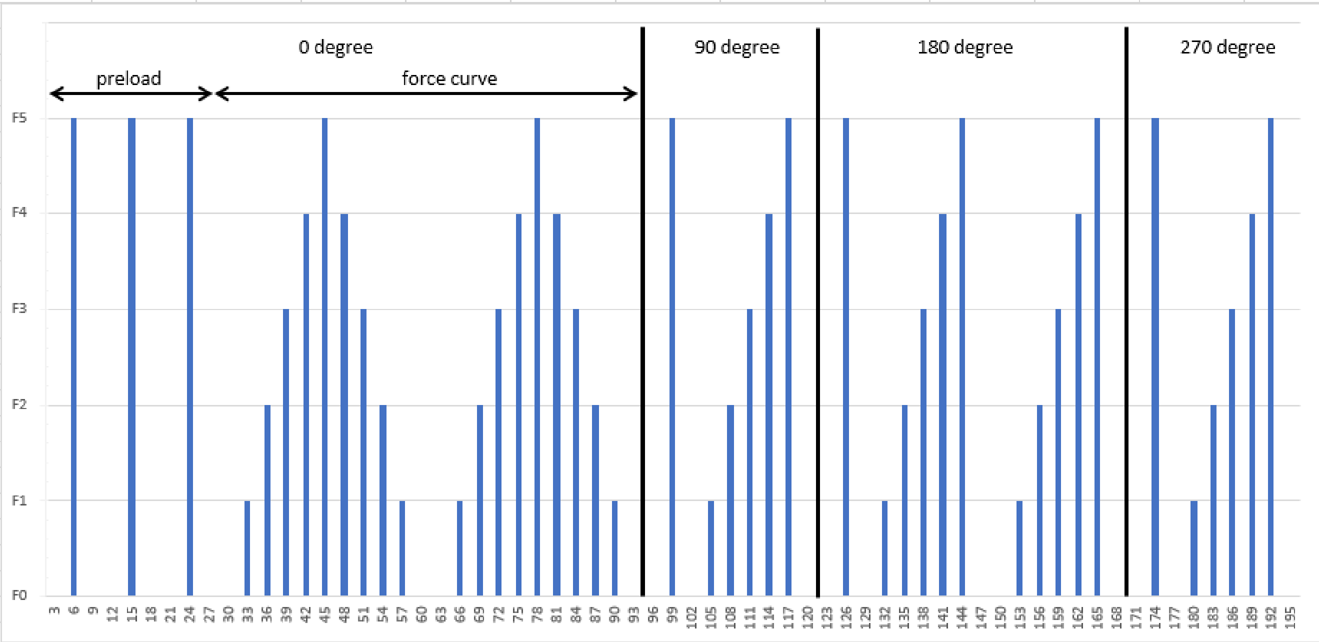

Figure 6: Diagram of the measurement sequence of the AFRIMETS.M. F-S1

3.5 Format of the comparison

This bilateral comparison the first measurements were done at pilot laboratory and then the transducers were sent to the participant laboratory and finally the transducers were sent back to the pilot laboratory after the participant laboratory's measurements. The first measurements by the Pilot laboratory was designated as the "R1" measurements and the second measurements by the Pilot after the participating laboratory was designated "R2" measurement. The change at the pilot (R2-measurement – R1-measurement) is called the drift of the comparison. The reference value for comparison is taken as the mean of the two pilot measurements.

3.6 Measurement procedure

The following measurement schedule was used:

All pre-loadings and measurement series were carried out in the same time schedule, i.e. the readings were taken three minutes after the change of the force step.

The measurements were carried out with the following force steps:
10 kN force transducer: 2 kN, 4 kN, 6 kN, 8 kN and 10 kN.
100 kN force transducer: 20 kN, 40 kN, 60 kN, 80 kN and 100 kN.

The measurement sequence for the 10 kN force transducer was as below:

0° 3 initial pre-loadings with 10 kN

0° steps (twice): 0 kN, 2 kN, 4 kN, 6 kN, 8 kN, 10 kN, 8 kN, 6 kN, 4 kN, 2 kN and 0 kN

90° 1 pre-loading with 10 kN

90° steps (once): 0 kN, 2 kN, 4 kN, 6 kN, 8 kN, 10 kN and 0 kN

180° 1 pre-loading with 10 kN

180° steps (twice): 0 kN, 2 kN, 4 kN, 6 kN, 8 kN, 10 kN and 0 kN

270° 1 pre-loading with 10 kN

270° steps (once): 0 kN, 2 kN, 4 kN, 6 kN, 8 kN, 10 kN and 0 kN

For the 100 kN force transducer. a similar procedure was also used.

PTB carried out the two comparisons using the 20 kN and 100 kN deadweight force standard machines respectively while KEBS used its 1MN force standard machine and selected the measurement range of 10 kN and the 100 kN respectively for the 10 kN and 100 kN transducer. Both participants used the same loading time.

4.0 Results

4.1. Stability of the force transducer

Based on the fact that the quality of the comparison substantially depends on the two measurements during the loop. The stability of the transducer is extremely important. Table 6 show the stability of the two transducers used in the comparison. Which is determined as the relative deviations of the resulting deflections for all measurements made by the pilot from their arithmetical mean value [3]. The relative sensitivity drift for the 10 kN force transducer did not exceed 1.62×10^{-05}, and for the 100 kN force transducer did not exceed 7.39×10^{-06}. This drift is much smaller than the uncertainties of the proceeding and succeeding measurements by the 20 kN and 100 kN DWMs respectively at PTB.

4.2 Corrections

4.2.1 Correction for the different ambient temperature

This component is simply taken as the difference between calibration temperatures at pilot (PTB) and participant (KEBS) multiplied by the maximum estimated sensitivity value of transducers. For the 10 kN force transducer the maximum temperature effect TK_c on the characteristic value is per 1 K 0,002% (Technical data sheet HBM).

For the 100 kN force transducer the maximum temperature effect TK_c on the characteristic value is per 1 K 0,001% (Technical data sheet GTM)

The effort to determine the correct temperature coefficient for both force transducers would be simply too much in this case.

Due to the small temperature differences between PTB and KEBS the influence was neglected here.

4.2.2 Correction for the sensitivity drift

The drift uncertainty contribution is based on the difference between the two PTB measurements as per equation (1), and results are as shown in Table 6.

$$Drift = \left[\frac{\left(\frac{PTB_2 - PTB_1}{PTB_2} \right)}{2} \right] \qquad [1]$$

Where:

$\mathrm{PTB_1} - \text{first reading by the pilot aboratory, PTB}$

$\mathrm{PTB_2} - \text{second reading by the pilot laboratory , PTB}$

Table 6: Stability of the force transducer

Stability of the 10 kN force transducer				Stability of the 100 kN force transducer			
Force in	PTB_1	PTB_2	Relative drift	Force in	PTB_1	PTB_2	Relative drift
kN	mV/V	mV/V	Relative	kN	mV/V	mV/V	Relative
2	0.400072	0.400059	1.62×10^{-05}	20	0.400277	0.400283	7.39×10^{-06}
4	0.800144	0.800128	9.79×10^{-06}	40	0.800647	0.800653	3.28×10^{-06}
6	1.200233	1.200212	8.89×10^{-06}	60	1.201074	1.201063	4.82×10^{-06}
8	1.600340	1.600314	8.02×10^{-06}	80	1.601509	1.601503	1.87×10^{-06}
10	2.000462	2.000431	7.83×10^{-06}	100	2.001927	2.001921	1.46×10^{-06}

The 10 kN and 100 kN Force transducers did not exhibit noticeable sensitivity drift during the measurements.

4.3 Relative deviations from the pilot's mean for transducer 10 kN and 100 kN

Tables 7 to 8 show the details of the results and deviations obtained between PTB and KEBS in both absolute and relative terms. Deviations were calculated by subtracting the mean deflections obtained by KEBS from mean deflections obtained by PTB.

Tables 7: Results of mean deflections and deviations with 10 kN force transducer.

	Mean Deflections			Deviations (PTB-KEBS)		
Force in	PTB_1	KEBS	PTB_2	Loop value	abs. Deviations	rel. Deviations
kN	mV/V	mV/V	mV/V	mV/V	mV/V	Relative
2	0.400072	0.400207	0.400059	0.400066	0.000142	$3.54x10^{-04}$
4	0.800144	0.800213	0.800128	0.800136	0.000078	$9.69x10^{-05}$
6	1.200233	1.200209	1.200212	1.200223	-0.000013	$-1.11x10^{-05}$
8	1.600340	1.600232	1.600314	1.600327	-0.000095	$-5.94x10^{-05}$
10	2.000462	2.000227	2.000431	2.00447	-0.000220	$-1.10x10^{-04}$

Tables 8: Results of mean deflections and deviations with 100 kN force transducer

	Mean Deflections			Deviations (PTB-KEBS)		
Force in	PTB_1	KEBS	PTB_2	Loop value	absolute Deviations	relative Deviations
kN	mV/V	mV/V	mV/V	mV/V	mV/V	Relative
20	0.400277	0.400482	0.400283	0.400280	0.000203	$5.06x10^{-04}$
40	0.800647	0.800948	0.800653	0.800650	0.000298	$3.73x10^{-04}$
60	1.201074	1.201500	1.201063	1.201068	0.000432	$3.59x10^{-04}$
80	1.601509	1.601895	1.601503	1.601506	0.000389	$2.43x10^{-04}$
100	2.001927	2.002506	2.001921	2.001924	0.000582	$2.91x10^{-04}$

5.0 Uncertainty Analysis

5.1 Uncertainty of Deflection

Table 9 to12 calculates, for each mean deflection obtained in each laboratory an expanded relative uncertainty value. The relative expanded uncertainty is calculated by taking into account the contributions due to the applied force, the reproducibility of the readings and the resolution of the DMP40. From both measurements, the mean value of PTB was selected. The measurement uncertainty contribution due to use of different measuring amplifiers was very small and was neglected. The effect of drift and change in temperature are dealt as discussed in **3.2.1**. and **3.2.2.**

Table 9: Relative expanded uncertainty value for 10 kN mean deflection for KEBS

Force in kN	Institute	Relative Standard Uncertainty			Relative Expanded Uncertainty (k=2)
		Force (k=1)	Reproducibility	Resolution	
2	KEBS	2.50×10^{-4}	3.89×10^{-5}	1.02×10^{-6}	5.06×10^{-4}
4	KEBS	2.50×10^{-4}	2.38×10^{-5}	5.10×10^{-7}	5.02×10^{-4}
6	KEBS	2.50×10^{-4}	1.04×10^{-5}	3.40×10^{-7}	5.00×10^{-4}
8	KEBS	2.50×10^{-4}	1.49×10^{-5}	2.55×10^{-7}	5.01×10^{-4}
10	KEBS	2.50×10^{-4}	1.02×10^{-5}	2.04×10^{-7}	5.00×10^{-4}

Table 10: Relative expanded uncertainty value for 10 kN mean deflection for PTB

Force in kN	Institute	Relative Standard Uncertainty			Relative Expanded Uncertainty (k=2)
		Force (k=1)	Reproducibility	Resolution	
2	PTB	1.00×10^{-5}	2.04×10^{-6}	1.02×10^{-6}	2.05×10^{-5}
4	PTB	1.00×10^{-5}	1.50×10^{-6}	5.10×10^{-7}	2.03×10^{-5}
6	PTB	1.00×10^{-5}	1.51×10^{-6}	3.40×10^{-7}	2.02×10^{-5}
8	PTB	1.00×10^{-5}	1.54×10^{-6}	2.55×10^{-7}	2.02×10^{-5}
10	PTB	1.00×10^{-5}	1.86×10^{-6}	2.04×10^{-7}	2.04×10^{-5}

Table 11: Relative expanded uncertainty value for 100 kN mean deflection for KEBS

Force in kN	Institute	Relative Standard Uncertainty			Relative Expanded Uncertainty (k=2)
		Force (k=1)	Reproducibility	Resolution	
20	KEBS	2.50×10^{-4}	6.66×10^{-6}	1.02×10^{-6}	5.00×10^{-4}
40	KEBS	2.50×10^{-4}	1.51×10^{-5}	5.10×10^{-7}	5.01×10^{-4}
60	KEBS	2.50×10^{-4}	9.28×10^{-6}	3.40×10^{-7}	5.00×10^{-4}
80	KEBS	2.50×10^{-4}	8.64×10^{-6}	2.55×10^{-7}	5.00×10^{-4}
100	KEBS	2.50×10^{-4}	9.26×10^{-6}	2.04×10^{-7}	5.00×10^{-4}

Table 12. Relative expanded uncertainty value for 100 kN mean deflection for PTB

Force in kN	Institute	Relative Standard Uncertainty			Relative Expanded Uncertainty (k=2)
		Force (k=1)	Reproducibility	Resolution	
20	PTB	1.00×10^{-5}	7.37×10^{-6}	1.02×10^{-6}	2.52×10^{-5}
40	PTB	1.00×10^{-5}	6.09×10^{-6}	5.10×10^{-7}	2.36×10^{-5}
60	PTB	1.00×10^{-5}	7.00×10^{-6}	3.40×10^{-7}	2.44×10^{-5}
80	PTB	1.00×10^{-5}	6.82×10^{-6}	2.55×10^{-7}	2.42×10^{-5}
100	PTB	1.00×10^{-5}	8.62×10^{-6}	2.04×10^{-7}	2.64×10^{-5}

5.2 Equivalence between the Force Standard Machines

Deviation D_i from the reference value that was chosen to be the measurement result of the 20 kN and the 100 kN DWMs of PTB was calculated at each force step of 2 kN, 4 kN, 6 kN, 8 kN, 10 kN for the 10 kN force transducer and 20 kN, 40 kN, 60 kN, 80 kN, 100 kN for the 100 kN force transducer was determined as per Equation (2).

$$D_i = PTB - KEBS \quad (2)$$

Equivalence between forces realized by the force standard machines of the participants was evaluated using the Normalized error (E_n). The relative expanded uncertainty of KEBS is more than

20 times the relative expanded uncertainty of the PTB. therefore. the comparison reference value and the comparison relative expanded uncertainty are the results of the PTB. Almost all E_n values listed in Table 13 and 14 are less than unity. Thus, it has been demonstrated that forces realized by the 1MN FSM of KEBS, 20 kN and 100 kN FSM of PTB are equivalent to each other.

Table 13. Deviations, relative expanded uncertainty of comparison and Normalized error for 10 kN

Force in	Deviation $\boldsymbol{D_i}$	Relative expanded uncertainty of KEBS $W(X)$	Relative expanded uncertainty of PTB $W(X)$	Normalized error $\boldsymbol{E_n}$
kN	mV/V	10^{-5}	10^{-5}	
2	0.000142	50	2.05	0.70
4	0.000078	50	2.03	0.19
6	-0.000013	50	2.02	-0.02
8	-0.000095	50	2.02	-0.12
10	-0.000220	50	2.04	-0.22

Table 14. Deviations, relative expanded uncertainty of comparison and Normalized error for 100 kN

Force in	Deviation $\boldsymbol{D_i}$	Relative Expanded Uncertainty- KEBS $W(X)$	Relative Expanded Uncertainty- PTB $W(X)$	Normalized error E_n
kN	mV/V	10^{-5}	10^{-5}	
20	0.000203	50	2.52	1.01
40	0.000298	50	2.36	0.74
60	0.000432	50	2.44	0.72
80	0.000389	50	2.42	0.49
100	0.000582	50	2.64	0.58

6. Summary

The AFRIMETS.M. F-S1 supplementary comparison has been conducted between KEBS (Kenya) and PTB (Germany) at the force range 10 kN and 100 kN. The comparison results revealed the equivalence of forces realized by the 1MN Force Standard Machine at KEBS and the 20 kN and 100 kN Deadweight Machine at PTB within the measurement uncertainties at 2 kN, 4 kN, 6 kN, 8 kN, 10 kN and 20 kN, 40 kN, 60 kN, 80 kN, 100 kN.

7. References

[1] Rolf Kumme, Philippe Averlant, Tom Bartel, Alessandro Germak, Andy Knott, John Man, Nieves Medina, Alexander Ostrivnoy, Yon-Kyu Park, Dirk Röske, Rick Seifarth, Mikolaj Wozniak, Kazunaga Ueda, Zhang Zhimin, Final Report on the Force Key Comparison CCM.F-K3, Measurand Force 0.5 MN, 1 MN, 2019.

[2] Kazunaga Ueda, Toshiyuki Hayashi, Hiroshi Maejima, Rolf Kumme, Dirk Röske, Mark Seidel. APMP.M. F-S1 supplementary comparison for 2 MN Force, 2016

[3] Toshiyuki Hayashi, Kazunaga Ueda, Hiroshi Maejima, Kittipong Chaemthet, Chanchai Amornsakun, Tassanai Sanponpute, APMP.M. F-S2 supplementary comparison for 100 kN force, 2019.