

FINAL REPORT

GULFMET

Comparison of the Force Standard Machines

Comparison of Force Standard Machines

in the range of 100 kN and 1000 kN

GULFMET.M.F-S1

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11.11.2019

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Symbols

Symbol	Description	Unit
En	En number	
k	coverage factor	-
w_{corr}	relative standard uncertainty associated with correction value	-
$w(D)$	relative standard uncertainty due to drift	-
$w(d_{fcm})$	relative standard uncertainty associated with force generation in force calibration machine	-
w_{drift}	relative standard uncertainty due to drift of transfer standard	-
$w(F_{fism})$	relative standard uncertainty of force generated by national force standard machine	-
w_i	relative standard uncertainty associated with parameter i	-
$w(K_{TS})$	relative standard uncertainty of force value indicated by transfer standard	-
w_{ref_instab}	relative standard uncertainty of reference force transducer's long-term instability	-
w_{ref_tra}	relative standard uncertainty of calibration of reference force transducer	-
w_{rv}	relative standard uncertainty of reference value	-
w_{std}	relative standard uncertainty due to transfer standard	-
$w(X)$	relative standard uncertainty of mean deflection	-
W	relative expanded uncertainty	-
W_{CMC}	relative expanded uncertainty of force generated by force calibration machine, equivalent to CMC (calibration and measurement capability)	-
W_{fism}	relative expanded uncertainty of force generated by national force Standard machine	-
W_{rv}	relative expanded uncertainty of reference value	-
W_{ts}	relative expanded uncertainty of force value indicated by transfer standard	-
X	mean deflection	mV/V
X_{fcm}	mean deflection in force calibration machine	mV/V
X_{fcm_i}	individual deflection in force calibration machine	mV/V
X_i	individual deflection value in run i	mV/V
X_N	deflection at maximum calibration force	mV/V
Δd	absolute value of relative deviation between reference value and value obtained in force calibration machine	-
Δd_{max}	absolute value of maximum relative deviation between reference value and value obtained in force calibration machine	-

1. Introduction

It was planned to organise a comparison on force standard machines between SASO NMCC (Metrology and Quality Organization (SASO), National Measurement and Calibration Centre (NMCC) at Saudi Standards), and EMI (United Arab Emirates) and TÜBİTAK UME.

TÜBİTAK UME is acting as the pilot laboratory. The travelling standards was provided by TÜBİTAK UME. TÜBİTAK UME was responsible to monitoring standard performance during the circulation and the evaluation and reporting of the comparison results.

The comparison was carried out in accordance with the CIPM MRA-D-05 “Measurement comparisons in the CIPM MRA” [1].

The comparison was published GULFMET database on GULFMET.M.F-S1 code.

2. Travelling Standard

There are 2 force transducers as travelling standards. Their identifications are as follows:

Table 1. Details of the travelling standards

No	Description	Manufacturer	Capacity	Serial No
1	Force Transfer Standard	GTM included loading pad	100 kN	64684
2	Force Transfer Standard	HBM included loading pad	1000 kN	191430052
3	Bridge Calibration Unit	HBM BN 100 A	-	07109
4	Temperature Data Logger	-	-	-

The travelling standards were supplied by TÜBİTAK UME. These standards were chosen for its high accuracy and stability in time.

3. Participant Laboratories

The pilot institute for this comparison is TUBITAK UME (Turkey). The contact details of the coordinator are given below:

Pilot Institute:	TÜBİTAK Ulusal Metroloji Enstitüsü (TÜBİTAK UME)
Coordinator :	Dr. Bülent Aydemir Tel: +90 262 679 50 00 Fax: +90 262 679 50 01 E-mail: bulent.aydemir@tubitak.gov.tr

The participating institutes and contact persons with their addresses are given in Table 2.

Table 2. Participants

Country	Institute	Acronym	Shipping Address	Contact Person
Turkey	TÜBİTAK Ulusal Metroloji Enstitüsü	TÜBİTAK UME	TÜBİTAK Ulusal Metroloji Enstitüsü (TÜBİTAK UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY	Dr. Bülent Aydemir
Saudi Arabia	SASO The National Measurement and Calibration Center	SASO NMCC	Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi Arabia (SASO) Riyadh 11471, P.O. Box 3437 KINGDOM of SAUDI ARABIA	A.A. Binown
UAE	EMI Emirates Metrology Institute	EMI	Emirates Metrology Institute (EMI) CERT Technology Park, Block H, Health & Environmental Building, P.O.Box 5464 Abu Dhabi, UAE	Dr. Christos Mitsas (Mr. Brian Justice)

4. Time Schedule

The time schedule for the comparison is given in the Table 3. The circulation of travelling standard is organized so that to monitor the performance of the travelling standard.

Table 3. Circulation Time Schedule

Acronym of Institute	Country	Time for measurement dates
TÜBİTAK UME	Turkey	September 2017
SASO NMCC	Saudi Arabia	December 2017
EMI	UAE	April 2018
TÜBİTAK UME	Turkey	December 2018

5. Measurement Quantities and Points

The quantities to be measured and the measurement force points are given in Table 4. All transfer force transducers used in the range 40% to 100%.

Table 4. Measurement quantity and points

Quantity	Measurement Steps (kN)
Force	40 kN, 60 kN, 80 kN, 100 kN
	400 kN, 600 kN, 800 kN, 1000 kN

6. Presentation of participation laboratories

UME Force laboratory was established the force scale in range between 0.5 N and 3 MN with five different FSMs in 1995 to 2002. All UME force standard machines were intercompared with different countries and their results were published in IMEKO TC3 conferences. UME have been participated in several intercomparison measurement with PTB as a bilaterally and also CCM key comparisons. This comparisons have been connected the UME to Europe the USA, Asia and other countries to each other. The UME FSM is lever type machine having capacity of 110 kN in dead weight side, in range between 2 kN and 110 kN, and 1.1 MN in lever side in the range between 20 kN and 1.1 MN.

SASO-NMCC Force laboratory, as a part of SASO, The National Measurement and Calibration Center (NMCC) established the force scale in range between 200 N and 110 kN with three different dead weight FSMs and between 100 kN and 5000 kN with three different hydraulic with reference transducer FSMs. 110 kN dead weight FSM and 1 MN hydraulic FSM participated in comparison measurements.

Emirates Metrology Institute (EMI) Force laboratory, it was established the force scale in range between 50 kN and 5000 kN with one FSMs. FSM is a hydraulic with built-up system having maximum force of 5000 kN, This machine participated in comparison measurements.

7. Laboratory standards and measurement methods of the participants

All laboratory standards (LS) are the computer controlled force standard machines (FSM). 100 kN dead weight and 1.1 MN lever type FSM of UME and 100 kN dead weight and 1 MN hydraulic type FSM of SASO and 5 MN hydraulic type FSM of EMI participated in this intercomparison measurement. All participants applied the international force comparison procedure (methods) given in detail below sections to compare their standards with transfer force standards (TS).

7.1. The Transfer Standards

Transfer standards or travelling standards are given in table 1. There are 2 force transducers as transfer standards. These force transducers are belonging to UME.

To minimize the uncertainty associated with the indicating instrument a high resolution, 1 ppm, indicators having good stability (HBM, type DMP 40) were used in the comparison. The indicators are self-calibrating. During an auto calibration cycle, the measuring voltage is replaced periodically by a zero signal and then by a highly-precise calibration voltage. A low frequency carrier frequency of 225 Hz is fed into the force transducers. In the DMP 40, the signal is amplified, demodulated, filtered and transformed into a digital value which is fed into a computer. For the DMP 40, the six-wire technique is used in the measuring line, i.e. the supply voltage is taken at the transducer and

returned to the amplifier. The resolution of this indicating instrument used is 1 ppm and the relative accuracy of it is estimated by PTB to be 4 ppm [8].

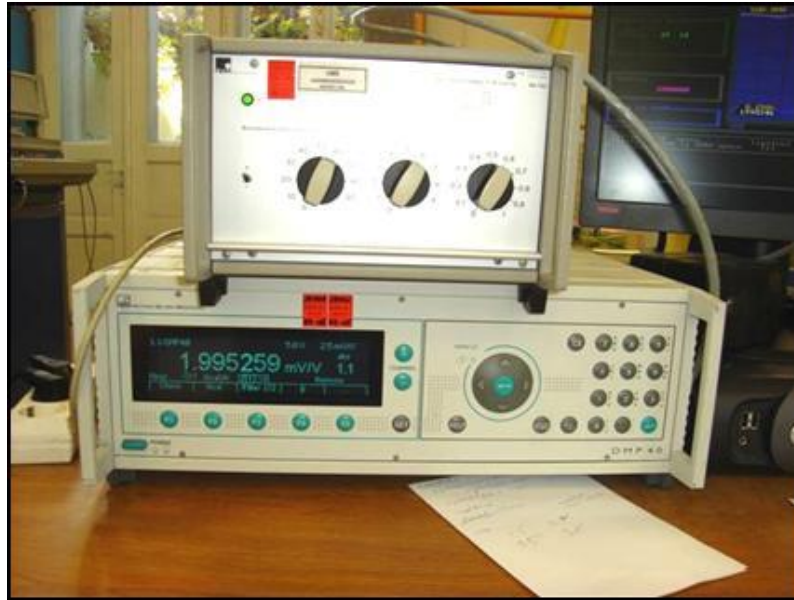


Figure 1. Precision indicating instrument (DMP 40) and BN 100 calibrator of UME

DMP 40 is adjusted as absolute value (ABS), 0.22 Hz Bessel filter, 5 V excitation voltage and ± 2.5 mV/V measuring range values during measurements.

At the same time, in order to check both DMP 40 indicating devices belonging to UME (HBM, DMP 40 S6: SN: 964720034) and SASO NMCC (HBM, DMP 40, SN: 172820006), and EMI (HBM, DMP 40, SN: 160920034), a BN 100 type HBM product calibrating device was used during comparison measurements (shown in Fig.1).

7.2. Measurement procedures

The procedure for performing the comparison measurements is described two increase series on each position. The results of all transfer force transducers evaluated in the range 40% to 100%.

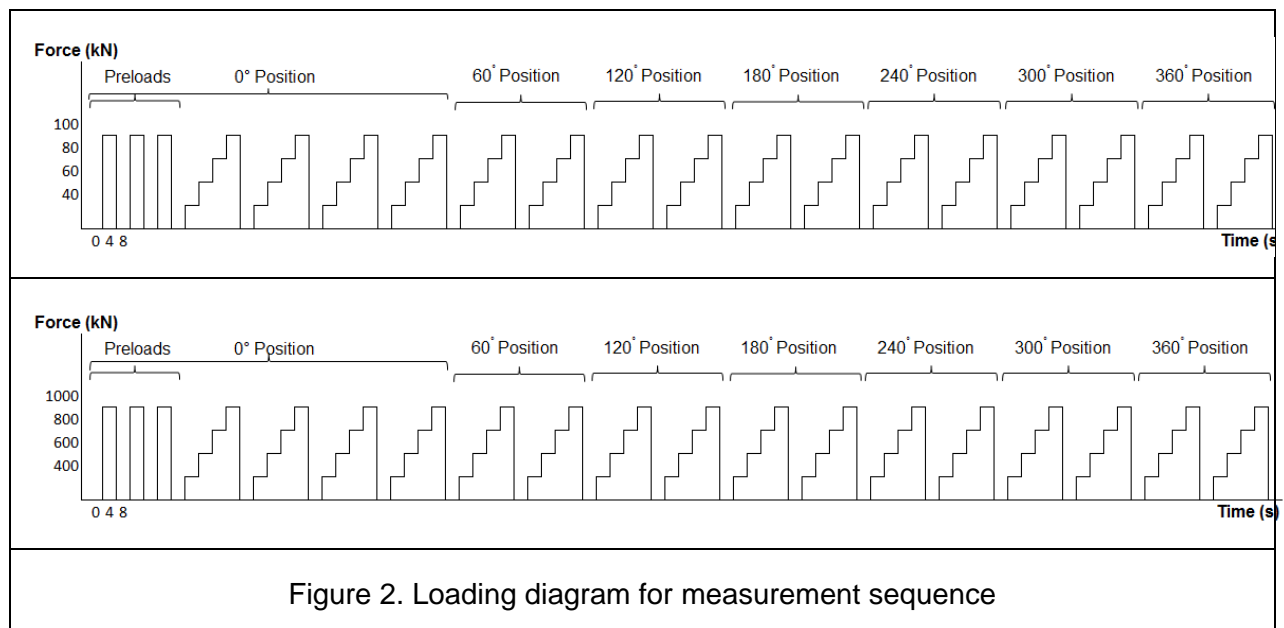
To minimize the effect of creep, for each force transducer included in the comparison, the time required achieving a stable response following loading and unloading was determined prior to start of the comparison. In most instances it was found that a 2 minutes time delay between the initiation of the loading (or unloading) and the actual reading was adequate. In addition this, after force transducer is loaded or unloaded, some drifts due to mechanical, thermal and electrical affects occur in the output of the transducer.

Local heating due to electrical power dissipation may cause this by the strain-measuring bridge. Many measurements and experience show that this effect on force transducer output stabilizes within about 30 minutes.

Machine transducer interactions can significantly influence measurement accuracy. Normal imperfections in alignment of loading machines and force transducers can result in significant

bending, shear and twist components of deformation in the force transducers. To minimize the errors due to these non-axial components of deformation, the response of each force transducer was obtained at 7 symmetrically distributed positions relative to the axis of the machine (0°, 60°, 120°, 180°, 240°, 300°, 360°). In order to get better results, prior to start measurement cycle, the force transducer was loaded with maximum test load three times at the 0° position (Fig. 2).

The measurements were carried out at (21±1) °C and relative humidity (45±10) % rh, the usual laboratory conditions at UME and SASO NMCC. Due to equality of laboratory conditions, effect of temperature difference on uncertainty can be eliminated. Both the force transducers and indicator were kept in laboratories for at least 1 day prior to the initiation of measurements. Force steps selected for international comparison of the Force Standard Machines are shown in Table 1.



8. Measurement Uncertainty

The uncertainty of measurement must be calculated according to the JCGM 100 “Guide to the Expression of Uncertainty in Measurement” [2] for the coverage probability of approximately 95%. The uncertainties were estimated in respect of principles laid out in the Document “Expression of Uncertainty of the Measurement in Calibration”, published EA 4/02. The principal components of the uncertainty budget to be evaluated are in accordance with the document “Calibration Guide EURAMET/cg-04/v.02 (03/2011)-Uncertainty of Force Measurements” or in accordance with equivalent consensus documents.

The uncertainty budget should also be given according to the parameters listed in below according to “Calibration Guide EURAMET/cg-4/v.02 (03/2011)-Uncertainty of Force Measurements”.

$$W_{CMC} = k \times \sqrt{w_{rv}^2 + w^2(d_{fcm}) + |\Delta d|} \quad (1)$$

$$w^2(d_{fcm}) = \frac{1}{(n-1)} \sum_{i=1}^n ((X_{fcm_i} - X_{fcm}) / X_{fcm})^2 + w_{corr}^2 \quad (2)$$

$$W_{rv} = k \times \sqrt{w^2(K_{ts}) + w^2(D)} \quad (3)$$

$$w^2(X) = \frac{1}{n(n-1)} \sum_{i=1}^n ((X_i - X) / X)^2 \quad (4)$$

$$w(K_{ts}) = \sqrt{w^2(X) + w^2(F_{nfsm})} \quad (5)$$

9. Results of Participants

All measurement results are shortly presented in below tables. The calculated measurement data are below tables. On the tables, below abbreviations are used.

UME_i : UME initial measurement results

UME_f : UME final measurement results

UME_{ave} : UME average (UME initial + UME final)/2 measurement results

SASO : SASO NMCC measurement results

EMI : EMI measurement results

On the tables, below formulas are used.

$$X_{AVE} = \frac{\sum_{i=1}^7 X_i}{7} \quad (6)$$

$$b_{RP} = \frac{|X_{max} - X_{min}|}{X_{AVE}} \quad (7)$$

Table 5. 100 kN force transducer measurement results

Force	UME 1		UME 2		UME AVE	SASO		EMI	
	Mean Value	Deviation	Mean Value	Deviation	Mean Value	Mean Value	Deviation	Mean Value	Deviation
kN	X _{ave}	b _{rp}	X _{ave}	b _{rp}	X _{ave}	X _{ave}	b _{rp}	X _{ave}	b _{rp}
F	mV/V	-	mV/V	-	mV/V	mV/V	-	mV/V	-
0	0,000000	-	0,000000	-	0,000000	0,000000	-	0,000000	-
40	0,798931	3,38E-05	0,798933	4,76E-05	0,798932	0,798943	3,63E-05	-	-
60	1,198411	2,92E-05	1,198415	3,17E-05	1,198413	1,198421	3,09E-05	1,198930	2,43E-04
80	1,597909	2,63E-05	1,597916	1,75E-05	1,597912	1,597931	2,94E-05	1,598565	2,46E-04
100	1,997425	2,00E-05	1,997458	3,85E-05	1,997442	1,997475	2,25E-05	1,998179	2,14E-04

Table 6. 1000 kN force transducer measurement results

Force	UME 1		UME 2		UME AVE	SASO		EMI	
	Mean Value	Deviation	Mean Value	Deviation	Mean Value	Mean Value	Deviation	Mean Value	Deviation
kN	X _{ave}	b _{rp}	X _{ave}	b _{rp}	X _{ave}	X _{ave}	b _{rp}	X _{ave}	b _{rp}
F	mV/V	-	mV/V	-	mV/V	mV/V	-	mV/V	-
0	0,000000	-	0,000000	-	0,000000	0,000000	-	0,000000	-
400	0,800309	1,59E-04	0,800310	1,69E-04	0,800310	0,800093	2,74E-04	0,800727	2,17E-04
600	1,200574	1,29E-04	1,200572	1,65E-04	1,200573	1,200219	2,72E-04	1,200823	1,87E-04
800	1,600813	1,49E-04	1,600839	1,53E-04	1,600826	1,600216	2,97E-04	1,601247	1,87E-04
1000	2,000993	1,39E-04	2,001024	1,44E-04	2,001008	2,000110	3,18E-04	2,001905	2,01E-04

Readings Corrections due to using different indicators at UME, SASO and EMI

For these measurements, the indicators used in UME (HBM, DMP 40 S6: SN: 964720034) and SASO NMCC (HBM, DMP 40, SN: 172820006), and EMI (HBM, DMP 40, SN: 160920034). Instead of transferring the DMP 40, BN 100 calibrator belonging to UME transferred to SASO and EMI to check all DMP 40s belonging to UME, SASO and EMI. The difference of average measurement results on UME and SASO indicators are given in Table 7. In the calculations, DMP 40 indicator deviation values according to BN 100 of pilot laboratory were taken into consideration.

Table 7. The average data is taken SASO indicator by using BN 100 calibrator for 100 kN and 1000 kN force transducers measurement

BN 100 Setting mV/V	100 kN		1000 kN	
	SASO DMP40 mV/V	Correction mV/V	SASO DMP40 mV/V	Correction mV/V
+0,000 000	0,000000	0,000000	0,000000	0,000000
+0,400 000	0,400003	-0,000003	0,400003	-0,000003
+0,800 000	0,800005	-0,000005	0,800005	-0,000005
+1,200 000	1,200006	-0,000006	1,200006	-0,000006
+1,600 000	1,600009	-0,000009	1,600009	-0,000009
+2,000 000	2,000012	-0,000012	2,000012	-0,000012

Difference of indicating instruments (HBM DMP 40) can cause small deviations over the measurement results. For this reason, readings from DMP 40 indicators will be compensated as below Table 8.

Table 8. The corrected average data of SASO for 100 kN and 1000 kN force transducers

Force Steps F %	100 kN		1000 kN	
	SASO average results mV/V	SASO corrected values SASO _{cor} mV/V	SASO average results mV/V	SASO corrected values SASO _{cor} mV/V
40 %	0,798943	0,798938	0,800093	0,800088
60 %	1,198421	1,198415	1,200219	1,200213
80 %	1,597931	1,597922	1,600216	1,600207
100 %	1,997475	1,997463	2,000110	2,000098

Table 9. The average data is taken EMI indicators by using BN 100 calibrator for 100 kN and 1000 kN force transducers measurement

BN 100 Setting mV/V	100 kN		1000 kN	
	EMI DMP40 mV/V	Correction mV/V	EMI DMP40 mV/V	Correction mV/V
+0.000 000	0,000000	0,000000	0,000000	0,000000
+0,400 000	0,399997	0,000003	0,399997	0,000004
+0,800 000	0,799995	0,000005	0,799995	0,000005
+1,200 000	1,199992	0,000008	1,199994	0,000006
+1,600 000	1,599989	0,000011	1,599992	0,000009
+2,000 000	1,999988	0,000012	1,999991	0,000009

Difference of indicating instruments (HBM DMP 40) can cause small deviations over the measurement results. For this reason, readings from DMP 40 indicators will be compensated as below Table 10.

Table 10. The corrected average data of EMI for 100 kN and 1000 kN force transducers

Force Steps F %	100 kN		1000 kN	
	EMI average results mV/V	EMI corrected values EMI _{cor} mV/V	EMI average results mV/V	EMI corrected values EMI _{cor} mV/V
40 %	-	-	0,800727	0,800732
60 %	1,198930	1,198938	1,200823	1,200829
80 %	1,598565	1,598576	1,601247	1,601255
100 %	1,998179	1,998191	2,001905	2,001914

Table 11. Calculated relative uncertainty contributions of SASO of 100 kN force transducer

F	w ² (X)	w ² (F _{fsnm})	w(K _{TS})	w ² (D)	W _{rv}	w ² (d _{fcm})	\Delta d	W _{CMC}	W _{CMC}
kN	-	-	-	-	-	-	-	-	%
40	2,59E-11	1,00E-10	1,12E-05	3,85E-12	2,28E-05	1,14E-10	8,14E-06	3,93E-05	0,004
60	1,96E-11	1,00E-10	1,09E-05	4,85E-12	2,23E-05	1,15E-10	1,43E-06	3,24E-05	0,003
80	1,36E-11	1,00E-10	1,07E-05	6,14E-12	2,19E-05	1,26E-10	5,90E-06	3,72E-05	0,004
100	1,14E-11	1,00E-10	1,06E-05	8,94E-11	2,83E-05	9,73E-11	1,08E-05	4,53E-05	0,005

Table 12. Calculated relative uncertainty contributions of EMI of 100 kN force transducer

F	w ² (X)	w ² (F _{fsnm})	w(K _{TS})	w ² (D)	W _{rv}	w ² (d _{fcm})	\Delta d	W _{CMC}	W _{CMC}
kN	-	-	-	-	-	-	-	-	%
40	-	-	-	-	-	-	-	-	-
60	1,96E-11	1,00E-10	1,09E-05	4,85E-12	2,23E-05	1,12E-08	4,38E-04	6,51E-04	0,07
80	1,36E-11	1,00E-10	1,07E-05	6,14E-12	2,19E-05	1,48E-08	4,15E-04	6,59E-04	0,07
100	1,14E-11	1,00E-10	1,06E-05	8,94E-11	2,83E-05	7,86E-09	3,75E-04	5,55E-04	0,06

Table 13. Calculated relative uncertainty contributions of SASO of 1000 kN force transducer

F	w ² (X)	w ² (F _{fsnm})	w(K _{TS})	w ² (D)	W _{rv}	w ² (d _{fcm})	\Delta d	W _{CMC}	W _{CMC}
kN	-	-	-	-	-	-	-	-	%
400	3,17E-10	2,50E-09	1,06E-04	1,29E-12	1,06E-04	9,83E-09	2,77E-04	5,02E-04	0,05
600	1,84E-10	2,50E-09	1,04E-04	7,98E-13	1,04E-04	1,12E-08	3,00E-04	5,35E-04	0,05
800	3,14E-10	2,50E-09	1,06E-04	9,09E-11	1,08E-04	1,24E-08	3,87E-04	6,34E-04	0,06
1000	3,21E-10	2,50E-09	1,06E-04	7,64E-11	1,08E-04	1,90E-08	4,55E-04	7,51E-04	0,08

Table 14. Calculated relative uncertainty contributions of EMI of 1000 kN force transducer

F	w ² (X)	w ² (F _{fsnm})	w(K _{TS})	w ² (D)	W _{rv}	w ² (d _{fcm})	\Delta d	W _{CMC}	W _{CMC}
kN	-	-	-	-	-	-	-	-	%
400	3,17E-10	2,50E-09	1,06E-04	1,29E-12	1,06E-04	5,54E-09	5,28E-04	7,11E-04	0,07
600	1,84E-10	2,50E-09	1,04E-04	7,98E-13	1,04E-04	4,40E-09	2,13E-04	3,81E-04	0,04
800	3,14E-10	2,50E-09	1,06E-04	9,09E-11	1,08E-04	4,96E-09	2,68E-04	4,45E-04	0,04
1000	3,21E-10	2,50E-09	1,06E-04	7,64E-11	1,08E-04	5,65E-09	4,53E-04	6,38E-04	0,06

10. Results of E_n Numbers

Comparison results will be evaluated according to the E_n value which is calculated Equation 8 stated at ISO / IEC 17043 “Conformity assessment - General requirements for proficiency testing” Standard.

$$E_n = \frac{x_{lab} - x_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \quad (8)$$

x_{lab} : Participant laboratory measurement result

x_{ref} : Pilot laboratory measurement result

U_{lab} : Participant laboratory measurement uncertainty

U_{ref} : Pilot laboratory measurement uncertainty

The laboratory measurement results will be utilized according to the criteria of E_n value which is given below.

If $|E_n| \leq 1$ then it is successful

If $|E_n| > 1$ then it is unsuccessful

The E_n number was calculated using the equation (8) as below.

Table 15. E_n values for 100 kN force range between UME, SASO and EMI

Force	SASO	EMI
kN	E_n	E_n
40	0,18	-
60	0,04	0,67
80	0,14	0,63
100	0,22	0,68

Table 16. E_n values for 1000 kN force range between UME, SASO and EMI

Force	SASO	EMI
kN	E_n	E_n
400	0,54	0,74
600	0,55	0,54
800	0,60	0,59
1000	0,60	0,70

As it seen the E_n number for this comparison measurements given in table 15 to table 16 that this comparison is very successful due to rule given in “ISO/IEC 17043 as “ $|E_n| \leq 1 = \text{successful}$ ”.

11. Conclusions

The force realized by the UME force standard machines 2 range in 100 kN and 1000 kN was compared with SASO and EMI force standard machines.

This uncertainty value of SASO and EMI is approved by the E_n values given in Table 15 and Table 16 as $|E_n| \leq 1$ and results is called as “successful”.

12. References

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